COMPUTER SIMULATION APPLIED TO PARCEL CONVEYORS

A thesis submitted for the
Degree of Doctor of Philosophy

by

J.W.ROURKE M Sc (Eng), B Sc (Eng)(Met)

Department of Production Technology & Production Management,
BRUNEL UNIVERSITY, Uxbridge, Middlesex.

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ABSTRACT

The research reported by this thesis concerns the operation of Post Office parcel conveyors. It evaluates the behaviour of straight belt conveyors using different parcel loadings. Empirical parcel data supplied by the Post Office is used for the development of a computer-based simulation model.

An important problem in parcel conveying is the variability in size, shape and homogeneity of parcels, which may lead to conveyor jamming. Because of statutory requirements for parcel handling by the Royal Mail, it is not possible to carry out physical tests. This research demonstrated the feasibility of parcel conveyor simulation models with computing equipment current in 1970 - 1975. It established that jamming was unlikely in straight conveyors loaded with parcels conforming to Post Office recommendations. Non-conforming parcels could cause jams, particularly with humid atmospheric conditions. It was established that the continuum theory of Jenike, which assumes the conveyor to be filled with an 'Ideal' material, could not be extended to parcel conveyors. This precludes the use of finite element analysis for solution of this problem.

The model established by this research can be developed further, to deal with changes in the direction and cross-section of belt conveyors and additional parcel characteristics.

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NOTES

Locations of Figures, Tables & Diagrams

All figures, diagrams, graphs and tables are together in Appendix IX at the rear of the thesis.(See page xxxxix & 330 - 429)

Glossary of Terms

The thesis, as might be expected in the discipline of Engineering Production, is wide-ranging, and some of the words used may be unfamiliar to the reader, or may be used in an unfamiliar sense. Accordingly a Glossary of Terms is provided at the front of the document, just prior to the Index. Additionally, the terms used in the work will be explained as they appear. They appear subsequently throughout the thesis, and on these occasions the Glossary will be helpful. Some terms, which the author feels to be fundamental, are defined only in the Glossary.

Location of the Index

Owing to the positioning of the Glossary of Terms, the Index is located further inside the document, at the end of the frontispiece. (See pages xxxxii et seq.)

The index to the figures, etc. is at the rear of the index.(page xxxxix)

GLOSSARY OF TERMS

The use of capital letters for words incorporated in the definitions means that the word is defined elsewhere in the Glossary.

ABNORMAL	See CAUSATIVE.
ACCUMULATORS	The locations or words in a computer where the arithmetic operations are performed, (see ARITHMETIC UNIT, CENTRAL PROCESSOR).
ACTIVITIES	Processes which change the state of the basic components of the model, (see ENTITIES).
ALGORITHM	A computer sub-programme or procedure which will produce some particular output, usually by using computer loops or repeated operations.
ALPHA CHARACTER	The alphabet. Sometimes the punctuation characters are also included, such as full stop, comma and so forth.
ALPHA NUMERICS	The combination of ALPHA CHARACTERS and numbers 0 - 9.
ARCHES	See BRIDGE OF PARCELS.
AREA	The OCCUPIED ZONE is divided into four areas, numbered clockwise from the bottom right hand area. The four corners of the parcel are numbered in a similar fashion, called the CORNER TYPE. These two numbers for any parcel enable the decisions to be made as to placing the parcel in the PU, LU or PLU positions. (See Section 5.2.)

ARITHMETIC UNIT	A group of ACCUMULATORS, plus CORE storage, also known as the CENTRAL PROCESSOR or CPU.
ASCII CODE	A standardised input and output character format used in the U.S. and in a slightly differing form in Europe, known as ISO CODE.
ASCOP	A statistical analysis package (see Section 7.7, p. 230).
A U or A L U	See ARITHMETIC UNIT. A L U stands for Arithmetic Logic Unit, an alternative form.
BACKING STORE	Random access stores of magnetic disc or drum which provide word storage over and above the CORE capacity.
BAG CONVEYOR	This conveyor is a UNIT LOAD type, where the bags are clipped to hooks on a moving chain. A secondary function is to separate the registered parcel mail from the rest of the parcels by only using the red coloured hooks for this mail. The red hooks are routed to a distinct destination. (See PARCEL BAG)
BAG DROP	The releasing of the parcels in a bag on the BAG CONVEYOR by cutting the string ties, and allowing the parcels to drop onto a CONCENTRATOR.
BASE	The bottom of the conveyor, usually the BELT.
BATCH JOBS	Computing jobs to be RUN under the BATCH OPERATION system.

BATCH OPERATION	The input is given by cards or paper tape to the computer operators and the output is returned in due course, after the programme has been RUN.
BAUD	A transfer rate of one BIT per second.
BEATING THE SYSTEM	To overcome the various protective traps programmed into a computer operating system to prevent the use of certain facilities in certain ways by the users, rather than the operators.
BELT	The moving band which forms the base of the trough of the belt,(BELT CONVEYOR.) It consists of a textile strip, joined end to end, which is coated with a rubber-like substance. It is also referred to in this thesis as the BASE.
BELT CONVEYOR	A conveyor where the parcels etc., being conveyed, are drawn by the traction forces caused by the friction of a moving belt. This forms the base of the conveyor and the sidewalls are vertical or near-vertical plates of wood or steel. The cross section is approximately a rectangle.
BEST SOLUTION	Choosing a solution where conflicting constraints prevent all objectives being achieved completely. See OPTIMUM.
B FORTRAN	The standard FORTRAN MACRO for university use which will automatically RUN FORTRAN jobs.

BINARY	Systems which count in only two states.
BITS	BINARY digits or bits are single bistable switching devices which will store two states, off or on. They will thus represent a single binary digit.
BRANCHING	A point in a programme where two routes are possible. The route taken usually depends upon whether the CONDITIONAL or IF-statement is true or false.
BRIDGE OF PARCELS	A group of parcels which form a JAM by creating an arch shaped bridge from sidewall to sidewall in a horizontal plane, and cause the parcel flow to stop by holding the rest of the parcels back (see Fig. 3.2).
BRIDGING	See BRIDGE OF PARCELS.
BUGS	Faults in a computer programme.
BYTE	A group of BITS, usually eight bits, used to form part of a WORD or memory location (see WORD).
CAUSAL EFFECT	An effect which can be related to the presence of some factor or CAUSE (see RELATIVE FACTOR).

CAUSATIVE	The phenomenon is caused by some event or happening. For example, a jam may be caused by certain groups of abnormal parcels of particularly difficult dimensions, shape, wrapping, stringing or position of the centre of gravity.
CAUSE	See CAUSATIVE.
CDC	Control Data Corporation, a computer manufacturer of the CDC 6400, 6600 and 7600.
CENTRAL PROCESSOR	Another name for the ARITHMETIC UNIT.
CENTRE OF GRAVITY	The point at which the mass of the parcel may be considered to act.
CG	See CENTRE OF GRAVITY.
CHAIN CONVEYOR	See UNIT LOAD CONVEYOR.
CHUTES	Trough sectioned rectangular section guides which are positioned with the base at an angle to the horizontal which is sufficient to cause sliding, due to the component of the force due to gravity effects on the mass being greater than the friction drag. The sidewalls and base are usually of steel. A straight chute has some resemblance to a straight BELT CONVEYOR, apart from being tilted at an angle to the horizontal.
CODE	The actual instructions used in a computer language. Alternatively, using numbers to define a type or class, rather than a sequence.

COMMAND LANGUAGE	Commands or statements in an operating system language such as GEORGE.
COMMUNICATIONS PROCESSOR	A computer which is attached to another computer, and whose only function is to manage the input and output from peripherals. These are usually the slow peripherals such as VDU or TELETYPE.
COMPILED	The result of a computer RUN, using a COMPILER, to convert a source programme in, say, FORTRAN, into a language the computer will understand, usually BINARY.
COMPILER	A programme which converts a higher level language to a lower level, often BINARY or a machine code (see FORTRAN).
COMPLIANCE	The degree to which a parcel will deform to comply with the supports provided by the surroundings. It depends on how soft or rigid the parcel material is and the internal structure.
COMPONENTS OF THE MODEL	These are either ENTITIES, DECISIONS or INPUT PROCEDURES.
COMPUTE BOUND	When a computer cannot accept inputs from other programmes than the one it is processing, due to the proportion of calculations or, more generally, where the "bottleneck" in processing programmes is caused by the workload being greater than the capacity of the accumulators to process the calculations.

COMPUTER RUN	One operation of the computer simulation programme, which was terminated when the specified belt conveyor section was fully loaded with parcels. More generally it is the operation of any computer programme to process a programme to produce the resulting output.
CONCENTRATOR	A wide, slow moving conveyor.
CONDITIONAL	An IF-statement in a programme where BRANCHING occurs.
CONNECT TIME	The time for which an ONLINE terminal is connected up to a computer, which is always greater than the RUN time.
CONSTRAINTS	Restrictions placed upon the variation of the parameters of both REAL WORLD or the model.
CONTACT POINT	The point where parcels contact with other parcels or the conveyor.
CONTINUUM OF PARCELS	The idea that the CONVEYOR SECTION was filled with a homogeneous ideal parcel solid having voids in it.
CONTROLLERS	Independent variables (see p. 202).
CONVEYOR FULL	The arbitrary point at which the programme decides to cease loading parcels, according to a HEURISTIC ALGORITHM.

CONVEYOR SECTION	A length of the BELT CONVEYOR chosen for analysis (see Fig. 1.1, Appendix IX).
CORE	The memory locations or words of a computer, in which programmes or data are stored.
CORE SIZE	The number of WORDS or BYTES in the CORE.
CORNER POSITION	The exact location in space of the parcel corners.
CORNER POST	The concept that the parcels underneath a parcel to be positioned, which would provide the supports, may be represented as posts projecting upwards.
CORNER TYPE	The orientation of the corner, typified into the numbers from one to four. See Section 5.2 and also AREA.
COTTON	Signifying a belt consisting of a woven cotton substrate, over which is a light elastomeric coating.
COULOMB FRICTION	The laws of friction as stated by Coulomb, which suggest sliding friction as being less than static friction.
CPU	See CENTRAL PROCESSOR UNIT.
CSL	See SIMULATION LANGUAGES.
CTL	Computers made by COMPUTER TECHNOLOGY LTD., e.g. the Modula 1.

CUT-OFF	The point when the CONVEYOR FULL decision is made, and no more parcels are loaded.
DEBUG	To remove the errors in a computer programme.
DEBUGGING	See DEBUG.
DECISIONS	The term used for the decisions taken by the computer programme. These are, for example, where to position the parcel, how it will rest upon other parcels, and how the forces are transmitted.
DEGRADING	The deterioration of an ONLINE computer service to the terminals. Usually the time taken by the computer to reply to terminal (the RESPONSE TIME) becomes excessive.
DETERMINISTIC	A system where the operating and/or control parameters are based upon predetermined values.
DIAGNOSTIC	A programme or sub-programme which informs the user of the progress and actions of the computer programme during a RUN. From this the source of a fault may be detected, usually by checking the values of the variables which are given at each stage.
DIAGNOSTIC PRINTOUT	A computer output from a DIAGNOSTIC programme.
DIFFICULT	Parcels which are likely to cause jamming due to their dimensions, shape and COMPLIANCE.

DISC STAND	A magnetic disc memory which comprises the whole peripheral assembly of drive and fixed and/or exchangeable magnetic disc cartridges. A SOFTWARE driver is required to operate this HARDWARE.
DISTRIBUTION GENERATION	A method of providing INPUT PROCEDURES by an ALGORITHM, which provides a sequence of numbers distributed in a given form, such as Normal, Poisson, Exponential and so forth.
DROPPING POINT	The point over which the parcel axis of origin was located during placement. (See fig. 5.8)
DUAL PROCESSING	MULTIPROCESSING involving only two programmes at a time.
DUMP	See SECURITY DUMP.
DUMMY MAIL	A set of parcels, made mostly of wood, plywood and cardboard, wrapped in brown paper or sacking. They are used for testing by the Post Office.
EDIT	There are programmes which will alter text, usually letter by letter, using a pointer at a given letter on a given line. These programmes are used to EDIT the SOURCE text. The ICL programme is called EDITOR, the Interdata programme is called EDIT.

ENCODE	To put a programme into the CODE of the chosen computer language.
ENDOGENEOUS FACTORS	The internal constants which govern the algorithms and other procedures upon which the computer simulation is based.
ENTITIES	The objects upon which the computer simulation system is based. In this case it is the parcels which are the basic component of the model.
EVALUATORS	These are the dependent variables of the model (see p. 202).
EXECUTION ERRORS	Errors in computer programmes, which do not cause a failure in compilation, but cause a failure when the compiled programme is RUN.
EXECUTIVE	The programme below the operating system (GEORGE 3) level, which will actually operate the ICL 1900 computer. GEORGE 3 translates the GEORGE 3 language instructions into EXECUTIVE for the computer to operate.
EXOGENEOUS FACTORS	Steering information for the computer simulation, which specified conveyor sizes, the speed of loading, the sidewall and belt constructional materials, and the Parcels Office, etc.
EXTENDED	See EXTENSION STATEMENT.

EXTENSION STATEMENTS	Statements in a SOURCE language, such as FORTRAN, which make use of extra facilities for character manipulation, input and output facilities, file handling and various other features of the EXTENDED FORTRAN compiler.
FALLING AREA	See OCCUPIED SPACE.
FAST CORE	This is CORE which has a fast transfer time, usually a few hundred nano seconds.
FATHER	The current file copy in file SECURITY COPIES systems.
FEASIBILITY STUDY	An exercise carried out to see if the project is capable of being completed effectively within the existing CONSTRAINTS.
FILE	A means of holding programmes, data and other useful instructions in the peripheral memories, in such forms as magnetic disc or tape.
FILE RETRIEVAL	To obtain a FILE from the GEORGE FILE STORE by the GEORGE command RV XXX, where XXX is the file name.
FILE STORE	The storage area of GEORGE where files are kept.
FIRST TIER	See MOP.
FIT	An attempt to place a parcel in a PACKING of the conveyor.

FL	See FLAT LOAD.
FLAIR	A method of compiling FORTRAN programmes using an IN-CORE COMPILER.
FLAT LOAD	Parcels are placed into the CONVEYOR SECTION with an ORTHOGONAL LOADING. This model typifies the LOADING by hand of some containers used for parcel conveying.
FORTRAN	The "Formula Translation" language, widely used by engineers and common to many computers. It is a high-level or sophisticated language and requires a COMPILER to convert it into a language the computer (machine) will understand, known as binary or machine code.
FPMCRV	This ICL FORTRAN subroutine to generate random numbers was available from ICL COMPILER LIBRARIES (1970b) and was stored on the magnetic disc in subroutine group SRF7.
FRANUM	A subroutine written in the FORTRAN language and included in the source programme for the simulation. This subroutine was superseded by the FPMCRV subroutine. (See Fig. 4.17)
FRICTION	The effect of forces resisting sliding movements due to roughness, asperities, micro-adhesion, adsorption and other surface effects.
FRICTION ANGLE	The angle to which a plane may be tilted before gravity forces will cause sliding.

FRICTION FORCE	A perpendicular force produced when a force normal to a surface is caused to slide. It is due to FRICTION.
FTRAP ERRS	An ICL COMPILER LIBRARIES subroutine which may be called and which prevents the normal error traps causing a programme to halt in the majority of cases.
FULL	See CONVEYOR FULL.
GEORGE 3	The automatic operating system of the ICL 1900 computer used for the simulation (see EXECUTIVE). This GEORGE system is highly regarded as an operating system for user JOBS in batches, rather than from terminals.
GEORGE FILES	See FILE, FILE STORE.
GIRTH	The girth of a parcel is the length plus half the sum of the width plus the height. $\text{GIRTH} = \text{LENGTH} + \left(\frac{\text{WIDTH} + \text{HEIGHT}}{2}\right)$ Problems arise in determining the girth of parcels of irregular shape, where the definition of the length, width and height is difficult (see Section 7.13, p. 156).
GLACIS	A wide ramp, tilted at such an angle that parcels will slide down it under gravity. Often constructed of wood, the glacis otherwise resembles a very wide CHUTE.

GLIM	Generalised Linear Modelling Package (see Section 7.7, p. 230).
GPSS	General Purpose Simulation Language (see SIMULATION LANGUAGES) of the PASSIVE ENTITY type.
GRANDFATHER	See SECURITY COPIES. This copy of the file is useful in emergencies should FATHER and SON be inadvertently corrupted.
GROUP ROW	This is one row of a parcel data matrix, containing the data on the properties of one particular parcel. Thus, the matrix of data for a group of parcels in a sample has one parcel per row. Therefore, the number of GROUP ROWS in the data matrix for a group of parcels is the same as the number of parcels.
GSP	General Simulation Programme language (see SIMULATION LANGUAGES) of the ACTIVITY ENTITY type.
HARDWARE	The physical components of a system, both electrical and mechanical.
HEURISTIC	A step by step procedure, using ALGORITHMS which often involve rule-of-thumb processes.
HIGH LEVEL	A computer language where one statement will achieve many steps, such as FORTRAN.

HISTORICAL DATA	Data obtained by recording details of past operations (see, for example, SAMPLE DATA).
HUMIDITY	See RELATIVE HUMIDITY.
IDEAL FEASIBLE SYSTEM	One in which the IDEAL SYSTEM is approached and yet is feasible to construct.
IDEAL PARCELS MATERIAL	See PARCEL MATERIAL.
IDEAL SYSTEM	One where the system is chosen and constructed to operate in an ideal or perfect manner.
IDEALISED PARCEL	Parcels which are represented as an abstract concept, using simpler shapes, such as spheres, consisting of an ideal PARCEL MATERIAL.
IF STATEMENT	See BRANCHING.
ILLEGAL INSTRUCTION	An instruction, usually within the operating system, which requires the computer to perform an operation which is not permitted by the system. The computer halts and an "Illegal Instruction" message II is output on the console.
INCIPIENT JAM	This is where a JAM forms, causing a momentary check, but the changes in friction conditions caused by the jam result in the parcels re-arranging themselves and the normal flow of the conveyor resumes.

IN-CORE COMPILER	A system of operation where the COMPILER is read into the CORE locations and programmes are fed in subsequently, in a source language such as FORTRAN, one after the other. This avoids loading the COMPILER in repeatedly, once for each programme. The time to compile programmes is, therefore, greatly reduced.
IN-HOUSE COMPUTER	One which is sited on the campus and of general access.
INPUT PROCEDURES	These bring a parcel of particular dimensions from the data bank into the computer simulation model system (see SAMPLE DATA).
INTEGRATED CIRCUITS	Circuits consisting of etched patterns on silicon chips.
I/O BOUND	A situation in operating the computer, where the accumulators and core are inactive, while they are waiting for input and output operations to occur.
ISO CODE	See ASCII CODE.
JAM	A blockage of the PARCELS CONVEYOR caused by a group of parcels becoming static and forming a BRIDGE across the conveyor. This holds back the parcels upstream. It is similar to the "log jams" which form on Canadian rivers, when transporting logs from forest to pulp mills.

JCL	The JOB control language, which marshals the jobs and presents them to the GEORGE system.
JOB	A single unit of batch work from the computer user (see JCL and GEORGE).
K-	In the computer sense, 1024 or 2^{10}. It is used to measure in BITS, BYTES or WORDS.
K WORD	1024 words of memory locations (see CORE).
KEEP	A B-FORTRAN macro parameter which retains the SOURCE.
LATTICE POINT	See SPACE LATTICE.
LIMITING CONSTRAINTS	Those CONSTRAINTS which are of the most significance in the choice of the best solution.
LINE UP	Placing a parcel so that one edge is uppermost, with the aid of a PROP.
LIVE MAIL	The actual PARCELS TRAFFIC, i.e. parcels from customers to be sent to recipients.
LOADING	See PACKING.
LOCATION	See PACKING.
LOCATION POINT	See DROPPING POINT.

LOG IN	The procedure used to connect the terminal of an ON-LINE system to the computer, ready for the user to operate his programmes.
LOZENGE	A distortion of the parcel when packing so that the vertical sides remain vertical after rotation, but only in so far as the contacts with other parcels are concerned. This simplification is probably just as valid as assuming all parcels are rectangular sided blocks.
L-TURN	Two belt conveyors set at right-angles to each other.
LU	See LINE UP.
MACRO	A simple instruction, or call, which will cause the computer to follow a previously stored set of operating instructions. They are, in effect, programmes in the OPERATING SYSTEM language.
MAIL	A contraction for Royal Mail which covers all the traffic handled by the POST OFFICES throughout the country.
MAINFRAME	The larger computers using components with relatively little INTEGRATED CIRCUITS and many external wires. As the use of integration increases, the definition of a mainframe becomes more difficult (see MINICOMPUTER and MICRO-

	PROCESSOR). In general large cabinets are needed with heavy duty current supplies.
MARK	The various GEORGE programmes are divided into versions 1, 2, 3 and 4 in various marks, for example GEORGE 3 Mark 6.6 was often used. Similarly the FORTRAN COMPILER XFIV was Mark 2B.
MARKOV CHAIN	See RANDOM WALK.
MARKOV PROCESSES	These are STOCHASTIC processes which have internal transfers within the sub-systems, which result in the frequent output procedures on a PROBABILISTIC basis.
MATRIX	A method of computer storage giving the equivalent of the grid-like pattern used in algebra.
MEAN VOLUME $\overline{V}$	The mean volume of a group of parcels (see Section 3.4.1, p. 68).
MEAN WEIGHT $\overline{W}$	The mean weight of a group of parcels (see Section 3.4.1, p. 70).
MICROPROCESSOR	A computer where the use of INTEGRATED CIRCUITS has reduced the size of the computer so that 64 K WORD of CORE and all the related processing input and output circuitry may be housed on one printed circuit board of about 16 inches by 4 inches by about 1/4 inch thick. There is virtually no external wiring. (See MAINFRAME, MINICOMPUTER.)

MINICOMPUTER	A computer where the use of INTEGRATED CIRCUITS wih some external wiring has reduced the size of 64 K WORD of CORE and all related processing input and output circuitry into a 19 inch rack. This is about 19 inches square by 4 inches high. (See MICROPROCESSOR, MAINFRAME.)
MNF	A CDC FORTRAN compiler, which optimises the machine code it produces to give the lowest computer times.
MODEL WORLD	An abstract representation of the REAL WORLD. Usually created in the computer memory. The output from the model world provides a forecast of the REAL WORLD behaviour.
MODEM	Equipment used to transmit data and computer input and output along the Post Office telephone system. It comprises a modulator and demodulator at both computer and terminal.
MODULAR PROGRAMMING	Breaking a large computer programme, for example a simulation, into smaller MODULES or units which can operate as free standing sub-programmes.
MODULES	See MODULAR PROGRAMMING and Sections 1.3.2 and 4.2.2, pp. 20 and 81. See also Figs. 3.1, 3.5 and 4.7 in Appendix IX.
MONORAIL CONVEYOR	See UNIT LOAD CONVEYOR.

MONTE CARLO TECHNIQUES	A method of providing INPUT PROCEDURES by randomly selecting, in a correctly distributed manner, a sequence of input data from HISTORICAL DATA.
MOP	This is a Multiple On-line Processor terminal service, with a number of VDU or TELETYPES. It is often operated on a TWO TIER system, so that at certain times of the day only editing may be carried out. At this time (second tier operation) "zero core" is utilised so that no programmes may be run from the terminal. When first tier operation is allowed programmes can be run from the terminal.
MOVING BELT MODEL	The computer simulation which simulates the action of the BELT CONVEYOR by placing parcels along a line which moves along the conveyor section from front to back as the COMPUTER RUN proceeds. (See SHUFFLING ACTION.)
MULTI-FILING	To use many FILES for input and output to a programme.
MULTI-PROCESSING	To process more than one job at a time in the ARITHMETIC UNIT using more than one set of ACCUMULATORS. In some computers some or all of the storage locations may act as accumulators.

NAG	Programmes and sub-programmes for a wide variety of applications including statistics and engineering, produced by the Nottingham Algorithm Group.
NELAPT	An NC part programming language, based upon APT and produced by the National Engineering Laboratory at East Kilbride (NEL).
NODES	The contact points at which forces are applied and transmitted. They are not necessarily the corner points of parcels.
NODE MATRIX	A storage MATRIX for the NODES.
NON-FATAL ERRORS	Errors in computer programmes which do not stop the execution of the programme, but obviously the RUN will fail to produce effective output in some way.
NWPO	NORTH WESTERN POST OFFICE in London, which provided some of the data.
OCCUPIED SPACE	An orthogonal column of space which covered the plan area of the parcel which is being placed in the conveyor section. (See AREA & Fig. 5.8)
OFFICE	See PARCELS OFFICE.
OFF-LINE	Batch operation.
ON-LINE TERMINAL OPERATION	The computer user operates the computer from a TERMINAL, being connected continuously.

ON-SITE SATELLITE TERMINAL	A terminal service from a remote computer which gives many of the facilities and offers much the same service as an ON-SITE computer.
ON-SITE COMPUTER	See IN-HOUSE COMPUTER.
ON THE AIR	The period of time during which a computer offers a particular service to users, such as FLAIR or MOP, etc.
OPERATING SYSTEM	A programme which will obey the operating system language instructions. These cause the computer to operate the programmes and peripherals and control the computer.
OPTIMISING COMPILER	A compiler which minimises the processing time, such as the MNF CDC compiler.
OPTIMUM	The best solution viewed from the standpoint of a given evaluator.
ORDER OF MAGNITUDE	A factor of ten.
ORTHOGONAL	Oriented in the same direction as the length, width and height of the conveyor section. In other words, parallel to the sidewall, belt and end section of the conveyor. (At right-angles)
OVERHEAD	In the computer sense, the extra transfers and calculations needed to process computer jobs in a large computer, which are not directly involved in producing outputs.

OVERLAY	To run a programme in series of sections, making use of BACKING STORE to hold variables and sections of the programme not in use at the time of running the current section.
PACKAGE	A programme which merely requires the user to insert data to obtain the desired output.
PACKING	The way in which the parcels are placed in the conveyor. LOADING is another term used synonymously. Alternatively, PACKING may mean the extent to which the space in the conveyor section is occupied by parcels. (Packing Intensity)
PACKING OF SPHERES	A model which assumes the parcels are spheres and then packs them into a box. (See Section 3.5, p. 74.)
PARCEL BAG	The sacks in which some parcels arrive at the PARCELS OFFICES from the POST OFFICES.
PARCEL CONVEYOR	See BELT CONVEYOR, in the sense used in this research.
PARCEL FLOW	See PARCELS TRAFFIC.
PARCEL MATERIAL	The somewhat fallacious concept that parcels are composed of an ideal variable material, i.e. an inhomogeneous solid. There is little evidence to support this.

PARCEL OFFICES	These are centres for the collection of parcels traffic, transported from the POST OFFICES, which accept the parcels. From these Parcel Offices the parcels are sorted and conveyed for redistribution and despatched to the Post Offices which deliver the parcels.
PARCEL PLACEMENT	See PACKING.
PARCEL SORTING MACHINE	A conveyor system which sorts the parcels into their destination based upon a series of doors and GLACIS, which are set by an operator reading the parcel destination as it passes through an input gate or channel.
PARCEL STORAGE	The matrices for storing parcel data, locations and contacts in the computer simulation. (See STORAGE.)
PARCELS TRAFFIC	The general flow of parcels through the system of offices, conveyors and other transportation within the system. (See PARCEL OFFICE.)
PEAK PERIODS	There are two short periods, during week days, when the parcels arrival rates are markedly higher than the average, or indeed the rest of the day. These peak periods also arise generally in all offices throughout the day, at Christmas, or locally, for example when the Mail Order Houses issue new catalogues in Spring and Autumn.

PIER TECHNIQUE	A mnemonic for a systems method of model creation. For further detail see pp. 14/15, Sections 1.1.3 and 1.1.4.
PLACEMENT	See PACKING.
PLANE UP (PLU)	Placing the parcel so that a plane of the parcel (a side) is parallel to the base or belt of the conveyor.
PLU	See PLANE UP.
POINT	A contact point, often a corner.
POINT UP (PU)	Placing a parcel in such a way that one corner is uppermost. Usually two PROPS are required.
POST OFFICE	The normal counter service and sorting point at which parcels are accepted either over the counter or by the van delivery and collection service.
POWER	An attempt to asses the computing ability of any particular computer configuration. Often expressed as an Atlas. It involves both calculation and internal handling, plus the input/output capabilities.
PREDICTIVE MODEL	A model of a system, used to predict the operational behaviour of an actual system in the "REAL WORLD".
PROBABILISTIC	A system where the operating and/or control values are based upon a range of values which follow a probability distribution.

PROBABILITY MATRIX	A two-dimensional matrix with the input activities along one axis and the output from the same activities along the other axis. The values of the matrix elements, which are symmetrical along the diagonal, are the probabilities of transfer through that activity.
PROCESSOR	See ARITHMETIC UNIT.
PROMPT	A magnetic tape based package for production control. (ICL 1900 PACKAGE)
PROP	A parcel acting as a support for a parcel in an otherwise unstable position, such as PU or LU.
PSEUDO-RANDOM	A number sequence which, although random in characteristics, will be reproducible if started from the same point in the chain. (See RANDOM NUMBER SEED.)
PU	See POINT UP.
QUEUEING	A branch of mathematics, related to the formation of queues, where objects, etc., will wait for a service.
RANDOM NUMBER SEED	A number used as a starting point for PSEUDO-RANDOM numbers.

RANDOM PLACEMENT MODEL	A THREE-DIMENSIONAL model in which parcels are placed at points distributed at random over the plan of the conveyor section.
RANDOM WALK	A sequence of MARKOV processes linked together in a PROBABILISTIC pattern sometimes called a MARKOV CHAIN.
RANKING SUB-ROUTINE	A sub-programme which will put a list of things in order based upon a property. Ranked orders of height were the most widely used in this model and these were used to position the parcels in the CONVEYOR SECTION.
READ IN	To enter programmes or data into the computer core from an input medium.
REAL WORLD	The actual behaviour of the physical system under consideration in its own physical environment.
RELATIVE FACTOR	A factor which, if present, gives rise to a CAUSAL EFFECT.
RELATIVE HUMIDITY (RH)	The ratio of the amount of water vapour in a sample of air to the maximum amount of water vapour that the sample of air could hold at that temperature (see Appendix VIII).
REMOTE TERMINAL	A computer peripheral, which may be a teletype, a VDU or line printer, operated through MODEMS at a distance from the computer. (See RJE Terminal)
REPRODUCING	A method of duplicating computer cards.

RESPONSE TIME	The time taken by a computer to respond to the REMOTE TERMINAL.
RH	See RELATIVE HUMIDITY.
RIGID LINK MODEL	The model which assumes all the contact points or nodes are linked together by a geodetic structure of rigid linked rods.
RJE TERMINAL	The remote job entry terminal which often includes a line printer for faster output, plus a TELETYPE or VDU, & a card reader.
ROUTES	The paths through the computer programme, which are followed by the computer simulation as it carries out the processes of PARCEL PLACEMENT and calculation of the parcel loads.
RUBBER	A particular belting, known as "Grip Faced Rubber Belting".
RUN	(1) A single operation of the computer to process one job. More properly it is a computer run. (2) The call to the MACRO to run a previously compiled BINARY programme.
RUN JOB	An alternative MACRO call to the RUN MACRO, which will also run BINARY programmes, previously compiled.
RUN TIME	The time taken by the computer to complete a RUN.
S B F R	See SIDEWALL BASE FORCE RATIO

SAMPLE DATA	A sample of 2087 parcels was examined and data on size, weight, wrappings, friction characteristics and other details was recorded by the Post Office. It was made available for this research (see Castellano, Clinch and Vick 1971) and put into the form of a data bank.
SAVE	A MACRO call on the B FORTRAN MACRO which retains the BINARY file.
SCANDURA	A particular elastomeric belting with a grip face which is heavily textured.
SCOPE	The CDC computer operating system which performs similar functions to GEORGE on the ICL system.
SECOND TIER	See MOP.
SECURITY COPIES	A file system where copies are held in case files become corrupted. (See GRANDFATHER, FATHER and SON.)
SECURITY DUMP	A copy made by GEORGE of all the files in operation at a certain time, in case files become corrupted.
SHAPE FACTOR S_V	A parameter which evaluates the effects of parcel shape in a group of parcels (see Section 3.4.1, p. 68).
SHOE BOX MODEL	A model where a section of conveyor is represented by a shoe box without a lid, into which smaller closed boxes, e.g. match boxes or pill boxes, etc. are placed. (See Fig. 4.18 and Section 4.4, p. 89.)

SHOP FLOOR	The areas in Engineering Production where the operations are carried out.
SHUFFLING ACTION	The part of the programme which repositioned parcels in the MOVING BELT model to simulate the effects caused by shuffling the parcels in a belt conveyor as it transported them.
SIDEWALL	The vertical or near vertical sides of a BELT CONVEYOR.
SIDEWALL/BASE FORCE RATIO	A useful EVALUATOR, defined on p. 213.
SIMSCRIPT	A SIMULATION LANGUAGE of the PASSIVE ENTITY type.
SIMULATION LANGUAGES	These are very high level sophisticated languages which have the various computer procedures available by giving instructions consisting of a few words. GSP, GPSS, SIMSCRIPT and CSL are typical simulation languages. (See pp. 35-37 of thesis.)
SINGLE SHOT	To process one computer programme at a time, rather than DUAL PROCESSING or MULTI PROCESSING.
SLIDING	Where surfaces have lateral movement of one with respect to the other.
SLOW CORE	This is CORE which has a transfer time of micro seconds, 2-6 micro seconds.
SOFTWARE	Computer programmes to control HARDWARE.

SON	The file in a SECURITY COPIES system which is being created from the existing file, called FATHER, (see GRANDFATHER).
SOURCE	A programme which is an original creation, usually in a HIGH LEVEL language.
SPACE	The volume of the conveyor and also above it, into which parcels could be positioned.
SPACE LATTICE	The SPACE is regarded as having a network or lattice of points at geometrically regular intervals. A more complete explanation is given in Smallman (1963).
SPHERES	See PACKING OF SPHERES.
SPHERICAL MODEL	See PACKING OF SPHERES.
SPSS	Statistical Package for Social Scientists (see Section 7.7, p. 230).
STABILITY FACTOR S_{CG}	A parameter which considers the displacement of the centre of gravities from the centroid of parcels in a group (see Section 3.4.1, p. 70).
STATANAL	A statistical analysis programme.
STATIC	When two surfaces have no relative movement.
STEEL	The bright steel used for sidewalls of conveyors and chutes.
STEERING	Information which guides or directs a computer programme. (See STEERING MODULE.)

STEERING MODULE	The module of the programme which sets the EXOGENEOUS parameters of the model.
STOCHASTIC	A process which depends upon PROBABILISTIC methods (see RANDOM WALK).
STOPPAGE	See JAM.
STORAGE	The capacity a computer has to store numbers and characters in the CORE memory locations. (See also PARCELS STORAGE.)
STORE	See CORE, STORAGE.
SUBROUTINES	Computer sub-programmes which perform specific manipulations.
SYSTEM ELEMENT	The smallest sub-division of the SYSTEM into elementary units, which can be represented as ENTITIES, ACTIVITIES or INPUT PROCEDURES.
TELETYPE	The teletypewriter, similar to an ordinary electric typewriter, but connected to the computer. The speed varies, but 10 and 30 characters per second are common.
TERMINAL	A slow peripheral which will enable input/output to be sent to the computer. They usually consist of VDU and TELETYPE, but other forms such as the RJE TERMINAL exist.

TERMINAL CORE LIMIT	The maximum CORE STORAGE available to the user operating from a remote TERMINAL. In general, this was 20 K word on the ICL 1903 system.
THREE-DIMENSIONAL PARCEL MODEL	This model assumes parcels of three dimensions are packed into a three-dimensional open-topped box representing the conveyor.
TILTED	Rotation of the horizontal plane of the parcel so that it is at an angle to the base.
TL	A TILTED LOADING of parcels in the CONVEYOR SECTION.
TRACE	A feature of the GEORGE system which will trace errors in the programmes. It is a very effective method of diagnostic analysis of faulty programmes.
TRAFFIC	See PARCELS TRAFFIC, MAIL, PARCELS OFFICES.
TRAFFIC INTENSITY	The rate of flow of parcels simulated in the MOVING BELT MODEL. It is defined on p. 217.
TRANSFER	To move data from one location to another or to or from the ACCUMULATORS in the PROCESSOR.
TRANSFER CONVEYOR	A BELT CONVEYOR which transfers parcels between two other BELT CONVEYORS. It is usually slow moving and very wide.
TRANSFORM ANALYSIS	Mathematical techniques, based for example on the Laplace Transform, which simplify the solution of equations involving calculus.

TRAVERSED	The DROPPING POINT has been moved from beginning to end of the length of the conveyor section being modelled. (MOVING BELT model)
TURN AROUND	The time taken for a computer job to travel from the input hatch on receipt to the output racks on completion of the job.
TWO-DIMENSIONAL PARCEL MODEL	A model which takes a vertical cross-section at right-angles to the direction of motion.
TWO TIER	See MOP.
UNIT LOAD CONVEYORS	Conveyors which have hooks carried on an overhead railway, spaced at intervals on a traction chain. They have not been studied in this research.
UNLOADING	Calculation of the forces starting with the last parcel loaded and working progressively back to the first.
UP	The edge of a parcel being loaded, which is higher than the others, is regarded as "up".
USER	The person desiring the computer to run his programme.
USER FILES	Magnetic peripheral memory in FILE form, which is specifically allocated to a particular USER.

VALIDATION	A test to prove that a model is realistic and truly represents the REAL WORLD.
VDU	Visual Display Units with Cathode Ray Tube display and typewriter keyboard for data entry. (See TERMINAL.)
VISUAL DISPLAY UNIT	See VDU.
WDPO	Western District Post Office in London, where the validation runs were performed.
WORD	Usually one memory location, which may hold numbers of integer or real form or alpha-characters. Sometimes two or more words are needed to form the memory location.
WRAPPING	The cover of sheet material which encases many parcels.

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APPENDIX VIII

1.0 INTRODUCTION

1.0.1 Defining the Problem

The Post Office makes use of mechanised handling systems to transport the "parcels traffic".* The Post Offices are the entry points for individual parcels to the specified customers, who receive the parcels and are the exit points for parcels from the system.

Belt conveyors are an integral part of the system in the Parcel Offices, and are sometimes used to deliver parcels direct to customers with a high volume of parcel traffic, such as the mail order companies.

From time to time, these parcels on the belt conveyors formed a jam,* which was a stoppage that would either reduce the flow rate or cause the conveyor to stop, often only for a few minutes, rarely as long as half an hour. The disruption caused by these stoppages was out of all proportion to the percentage of time lost.

The disruptive effects of these jams were worrying to the Post Office management. The delay to the parcels traffic caused by these jams was displeasing to the general public and a matter of concern to the management in view of statutory requirements in handling the mail.

The parcels traffic in general is spasmodic with two large "peak periods" in the day, and the rates of parcel handling need to be designed to be much higher than the average flow to avoid queues and also to meet the statutory requirements for rapid transmission. These "peak periods" are only of short duration, usually less than two hours, except during the Christmas rush.

The excessive delay to mail was because jams occurred in the peak hours. For example, only two jams in twenty-four hours might not seem

* See Glossary of Terms

much on average, especially if they were only of a few minutes duration each. However, due to the nature of "queuing" relationships, since these occur during the worst part of the peak flow, the total amount of delay caused would be far in excess of a few minutes. The cessation of flow would cause overload at other points in the conveyor system and the resulting disruption would cause further delays.

It was therefore decided that a simulation model might give a solution to this problem. It would indicate if the jams were either probabilistic or causative in their nature. One concept was that jams were caused by some unusual arrangements of groups of acceptable parcels or traffic, which event might occur only rarely, at a frequency which could be predicted by a probability theory. Alternatively, the jams were caused by one particular parcel having certain "abnormal" characteristics, the presence of which was uncommon. Thus the occurrence of that particular type of parcel would be the sole "cause" of a jam. If this latter theory were true then these disruptions could be minimised by refusing to accept parcels having that "abnormal" characteristic at the Post Office counter. Alternatively, the former theory might be true, in which case the jams would be inevitable, and must be accepted.

There is an urgent need to increase the productivity of parcels handling, which is rapidly losing profitability. The approach of Nadler (1967, 1970 and 1976) via an "Ideal System" and an "Ideal Feasible System" is most likely to prove the best route to improvement of existing parcel handling systems, and the design of new ones.
It is possible to attribute the decline of the nationalised parcel handling undertakings, to bad operational practice. This is not the sole cause. The performance of the mechanised handling systems is

difficult to ascertain. The Royal Mail has to achieve certain statutory objectives as to throughput times and the physical nature of the mail. This means that for the majority of the time the service is lightly used, but there are certain very heavy traffic flows which must be serviced without noticeable degradation. It is difficult to measure performance under such transient conditions. To carry out such tests without giving the operatives, shop stewards and Trade Union officials,the impression that a major work measurement scheme was in progress, would be virtually impossible.

There must be areas of inefficiency, since private carriers are able to attract away portions of the parcel traffic. They then make it very profitable, in spite of problems such as the enormous increases in costs, especially diesel oil, and other inflationary effects. It is all too easy to suggest that they operate under different service conditions, and only the profitable areas are attracted away from the nationalised undertakings. It seems, according to discussions with officials of National Freight, BRS Parcels and the Post Office, that these services are all subject to a general reduction in traffic at a rate faster than the general industrial decline in 1975-77. A natural conclusion for the production engineer is that the multiplicity and generality of services offered to the public, is the cause of the trouble, since it prevents rationalisation. This is likely with the parcels traffic, where the tradition has grown up that wrappings can be what the public pleases, and that sizes can be determined by a rather quaint rule related to the girth. The majority of the British Public would associate girth with slimming rather than parcels, and even when told how to calculate the maximum parcel size, are still confused. It would seem that this definition allows awkward shapes and sizes to be accepted, which may cause problems with jamming. The costs incurred by such parcels are far in excess of the receipts for the transaction. The same applies to some very bulky, soft parcels, e.g. a continental quilt in a plastic bag.

New regulations for the parcel traffic would reduce problems in conveying and thus reduce costs and increase effectiveness. The present project looked for a solution to the problems of the conveyor belt systems, by means of a computer model. The area of research thus involved subsystems. Even if perfection were to be achieved in these subsystems, this could not optimise the whole system. A more economic approach to the problems of parcel handling would be to investigate the system, to establish where research could affect improvement with the maximum cost benefit. This is particularly true when the amount of funding available for such research is considered, since it is minute, in relation to the importance of parcel handling, from the national standpoint. Some of the studies may not please politicians, trades unionists and the Post Office management and workforce. However, the present declining situation must create a suitable background for such studies, hopefully before it is too late. The Post Office is the leading employer in Britain and any decline in demand will have eventual repercussions upon employment. The most effective research would be studies of the interactions of the real world/predictive models. Corporate planning requires a much higher level of understanding of the nature of the "real world" of parcels handling. This knowledge would make it possible to solve problems using methods which could be derived from the results of research. Surely the largest employer in the UK should have research funds allocated in keeping with the investment and importance of the operation?

1.0.2 The Research Objective

The objective was to create a simulation model which would ascertain whether jams are caused by certain groups of parcels forming by chance, or alternatively caused by an individual parcel of characteristic shape and size.

To test the hypothesis requires conveyor belt systems and the parcels they carry. To use any conveyor in the parcels service would be costly since it requires operating staff, power and there is some risk of damage, since many jams would need to be created, which overload the conveyor. This might be done in the early hours of the night in certain areas, but the range of size, shape and type of conveyor is so large that a representative sample would not be available.

To find a supply of parcels for testing presents further problems. It is not permissible to use "live" (customers') mail, since it would cause delay and would quite possibly cause damage in the jams. The Post Office have a set of "Dummy Mail" (test parcels). They are limited in size and shape and consist of about one hundred parcels. They are costly and constantly in use, and would not be suitable or available. A much larger sample would be required for this research and the cost of manufacture would be very high to be comparable to the sample data of 2087 parcels. A computer simulation was chosen because it offers the ability to model both conveyor and parcels simply and has many advantages over other model techniques, such as scale models of belt conveyors and parcels. Thus the objective was to design and programme a computer simulation which would model systematically a Post Office parcels handling belt conveyor.

Some computer simulations have been decried in the past, so it is relevant to note that Warwick quotes one manufacturer of motor cars as saying a stoppage of any conveyor costs him over £1000 per minute (Warwick 1969). What this would mean at today's values is staggering. There is no immediate loss for the parcel service, because the customer, rather than the Post Office, loses from the delay caused by jams. A reduced service may cause loss of custom and both BRS parcels and the Post Office have problems with declining returns from operating revenue, and with falling traffic levels in certain instances.

When the level of investment is measured in millions of pounds, as it is in the case of the conveyor systems under study, then research is valuable if it enables existing conveyors to offer a better service, or smaller installations to offer equal service.

Even if the degree of sophistication of the model is limited by the resources and the computing power available from 1970-75, the results of this research will lead to improved operating efficiency, and suggest further useful areas of research. The work, in 1969-71, by the Post Office (Castellano, Clinch and Vick 1971) provided the data on the parcels traffic. Their research was sufficiently comprehensive as to enable the present study to be extended to cover a secondary objective of examining the effects of friction of parcels, in addition to the main objective of studying the jamming of straight belt conveyors. The requirements of the objective resulted in three distinct design areas of research:

1. A system which would model the physical loading of a parcel conveyor.
2. A second system, which used the output of the first model as the input to calculate and resolve forces due to mass, motion and friction. The possibility of a jam could then be determined.
3. A third system to select, test and analyse the Post Office data which was the input to the model.

Accordingly, a feasibility study established that it was possible to make a computer simulation model to create a three-dimensional model on the University on-site ICL 1903 computer. The model used the concept of parcels visualised as rectangular solid shapes which were stacked into a much larger, empty, rectangular box. This box, which had no lid, represented the side walls and belt of the conveyor, with arbitrary divisions to define the beginning and end of the section being modelled. (See Fig. 1.1, Appendix IX at rear of thesis. Page 331)

Various modelling concepts were considered in the feasibility study which ranged from an abstract "packing of spheres" to a realistic "three-dimensional parcel". A two-dimensional model was favoured for the sake of simplicity, with the complication of taking a series of parallel transverse sections through the conveyor, but the model was too crude to give realistic results.

The University ICL 1903 computer arrived in 1970 when this research commenced. Some operating difficulties arose, which were associated with teething troubles in building the configuration to the size it had reached by 1977.

1.0.3 The Complexity of the Loading Model

The project began with a systems analysis of two-dimensional models, which located parcels and loaded them into a conveyor cross-section. Development of the two-dimensional model showed it was inaccurate. The work lead to programmes for three-dimensional models. A series of models for three-dimensional loading were developed, and about fifty major system changes were needed before finalising the model system.

1.0.4 The Complexity of the Force Model

The force model presented difficulties in defining a modulus for "parcel material" which had not been anticipated. The results of load-deflection experiments to give an approximate value to the parcel modulus of elasticity, even in compression, showed that relations between load and deflection were linear. Unfortunately the modulus for a given orientation was different from that of other orientations of the same parcel by up to three orders of magnitude, and this precluded the use of finite element analysis. One package had been acquired from British Rail at Derby in a two-dimensional model form called NEWPAC (Aggeman-Prempeh and Patel 1971) and set up on the 1900 system. Trials of this finite element programme showed it to be very limited for this research, since structures of only sixty nodes, equivalent to ten parcels, took about one hour of computer time and required large amounts of core for the two-dimensional package alone. Accordingly, it was decided that there was little advantage to be gained from the use of NEWPAC, and a simple "rigid-link analogy" model was used for this section. Once a system was established for this rigid-link model, there were only two further main variations written during development.

1.0.5 The Feasibility Study

As has been said this was a wide ranging study of the model systems which could be used to represent the "real world" of parcels conveying. It indicated that a probabilistic model using spheres to represent parcels would be the easiest system to create by defining a diameter based upon the three dimensions given by the distributions of actual parcel dimensions. This model was not very satisfying and was abandoned in favour of deterministic models which loaded actual parcels. The project began by creating two-dimensional models but later developments were based upon three-dimensional model systems.

The initial literature survey showed that very little computer simulation had been carried out in the field of belt conveying, although unit load (Hook type) conveyors had received much attention in the US in the last decade.

The line-of-balance analysis for mass production systems was of interest in this study. Nick Thomopoulos had written a paper (Thomopoulos 1967) which used a computer simulation which, in effect, fitted two-dimensional rectangles in a larger rectangular space. This encouraged the author to attempt to create a similar simulation for this project, but there was little available in the literature to give guidance to the model structure, or the force system. It had been hoped to use the work on hoppers and bulk powder conveying of Jenike (1954 to 1964), who had indicated that six inches was the limit of particle size for his theories. Since the mean parcel size is about six inches, the theory might be adjusted to compensate for the large average size of parcels. However, correspondence with him revealed that he felt that extrapolation of his work to the irregular shapes and greater sizes of parcels traffic would be unlikely to be satisfactory. The model is based therefore upon a simple technique, which assumes the forces caused by resting one parcel on another could be regarded as transmitted by rigid links. Although this does not take into account the compliance and deflections of the parcels, it is realistic in that it resolves the parcel weight, plus the superimposed forces, on to those parcels underneath. It first calculates the forces for the last parcel. It then adds these forces from the last parcel loaded, to the next to last, and subsequently to each preceding parcel, step by step, until the first. This method is tedious, and so the computer is used to speed the process.

1.0.6 Models Created

Two models were created, one which simulates a moving belt, and one which simulates the loading of a chute by random packing.

They use data on "live mail" i.e. actual parcels, supplied by the Post Office for six different parcel sorting offices. To enable comparison of the computer model packing to be made, some data for actual mail from the West London District Office was obtained. This had been loaded randomly into a transfer conveyor of similar section to that used in the computer model to test if packing densities were similar. This data was used for test runs on the computer model and gave packing densities close to the "real world" values. These checks were regarded as validating the method the model used to simulate the conveyor, as far as loading the parcels was concerned, and showed the packing to be representative of live parcel traffic loadings.

The project produced a computer simulation of the jamming of conveyors, which can be simply extended to chutes and glacis. It positions actual parcels according to loading rules, rather than the probabilistic model suggested by the feasibility study. The programme uses 25.6 K words of store, which is inside the normal user limit at that time of 32 K. A single fill takes a maximum of ten minutes of computer time, so that it is feasible to model the data from any of the six parcel sorting offices, which contain details of over 400 parcels in some cases. In no case was the total time on the computer in excess of 40 minutes.

The loading patterns were shown to be different in friction behaviour, but, in general, there was no jamming due to parcel configurations formed, when using the data from over 2000 typical live mail parcels, to give nearly 1500 simulations of the operation of a 40 inch wide conveyor. On the other hand the presence of "abnormal" parcels likely to induce jamming was noted.

1.1 MATHEMATICAL MODELS

1.1.1 The Reasons for Modelling

Many problems which arise in industry, commerce and research are too complex to be solved by simple techniques based upon models using formulae and algebraic symbolism. This is because either the "real world" environment changes during the period of time which is being modelled, or alternatively the system itself is changing interactively with time or in response to the environment. Sometimes situations exist where both of these changes occur. When solutions are needed to these complex situations, then computer simulations are often used to predict the behaviour. To enable computer models to be created, systems analysis provides a basis for the model. The systematic approach is to break down the total system into "activities" or processes which change the state of the basic components of the model. These components are often classified as either "entities", which are the objects or parcels upon which the system is based, or "decisions", such as the orientation of the parcel and its location, or "input procedures", which bring a parcel into the system from a data bank of parcels. The activity or process then consists of a number of operations, each of which is then broken down into a series of logical steps and simple decisions, with either binary or complex outcomes at the decision point. In this way the most complex system is often amenable to analysis, although a considerable number of man-years of effort may be required.

This process of mathematical modelling may not always be accurate, since a sequence of optimal sub-decisions do not necessarily lead to a global optimum. The large number of simplifying assumptions may result in models which do not represent accurately the "real world" system under study. However when a problem is very complex, or the system is difficult to visualise by other techniques, then a mathematical model may be the only feasible method.

The advances in electronics hardware have resulted in the cost of computing hardware being reduced steadily. The price of £24,000 in 1977 for an Interdata Minicomputer gives a very similar computing power to the University ICL 1903 as it was in 1969. Microprocessors now available will reduce this cost to around £5,000. Software costs have not shown this reduction, but modelling tends to be easier when ample storage and power is available. This has made it more feasible to model complex systems at reasonable cost.

The problem in computer mathematical models, such as this conveyor model, which is abstract, in the visual and mathematical sense, is that it may involve considerable amounts of computing power and storage. Fortunately the conveyor model avoids any great use of either distribution generation or Monte Carlo techniques, by using historical data supplied by the Post Office. The only use of random numbers was in the placing of parcels either across the conveyor in moving belt models, or anywhere on the conveyor in random packing models, and in introducing plastic wrapped parcels in varying percentages. With the situation which exists on a belt conveyor, with live parcel traffic, the visualisation of conveyor behaviour is extremely difficult. When the conveyor stops completely, the stoppage is of a duration which can be measured. The resulting losses are fairly clearly evaluated. A much more common occurrence is a jam, when parcels halt momentarily. A "bridge of parcels" is held back for a short period and then released. The surge which then occurs causes disruption and also damage to parcels traffic. In the simple case of a straight belt conveyor, stoppages are known to happen. Often the information is inadequate, and it is not possible to decide the causes from the details given by operational staff, whose main objective is to clear the stoppage and get the conveyor running again. The conveyor is only loaded heavily for short periods of the day and so any study based on observing the large number of such conveyors would be costly and somewhat inconclusive, since dimensions and operation conditions vary. Also, the parcel traffic differs from area to area, so the problem may be rather complex for any straightforward logical analysis. Observations or conclusions which are true for one office may not be true of another.

1.1.2 Types of Model

Modelling helps by producing quantitative descriptions of the system, written in mathematical language. Changes in controlling parameters, or those thought to be controlling factors, can be examined and by measuring the change on other dependent properties, the importance of each controlling factor can be established. The following types of mathematical model are commonly used:

1. Iconic This uses a scale model of the system and, in fact, the final models are scale models of the conveyor belt, although the internal storage is not in fact in a graphical form.
2. Analogue In this one property is used to represent another, as in resistance networks with current and voltage measuring devices used to measure DC effects.
3. Symbolic A mathematical relationship uses symbols to represent relations between the various factors of the system. The model suggested by the feasibility study was in fact this type, and while it lent itself to a very simple treatment of the system to reproduce the system, further study soon showed that the results it could so easily provide would only be typical of the model rather than the system it tried to depict. However, when relations

can be defined in mathematical terms, these models have many advantages.

4. Computer Simulations These models use the digital computer to create a "model world" which is an abstract representation of the "real world" in digital terms. Examples are stock control, linear programming for product mixes, or computer simulation for production control.

1.1.3 The Place of Models in Operational Research

The relative place of a mathematical model is important in relation to other components of the OR philosophy. The author uses a "PIER" technique of:

1. Plan
2. Implement
3. Evaluate
4. Revise

To apply "PIER" completely, goes beyond the scope of this present research, which provided the plan. This work provides and checks a model. The "PIER" analysis would be beyond the available resources of the University both in time and cost of computing, if carried out in the normal period of a PhD research. Hence this research establishes the model as a plan, and the only evaluation of the model is a rapid survey to suggest further work. Even the validation is a very restricted exercise since there are considerable limitations when live parcel traffic is used, and one cannot damage the mail or delay it to any extent. The simplest tests using live mail give rise to costs of interruption due to disruption of the regular service, which would not be acceptable to the Post Office. Hence the "PIER" method is applied only partially to this model, to keep within the scope of this research. The remainder must be left as suggestions for further work. The complete method was used, however, for each programme module.

1.1.4 Applying the "PIER" Method

In creating the model, the "PIER" technique could be applied as follows to the various modules:

1. Planning
    - 1.1 Identify the system and the problem, defining the objectives and working out the interactions.
    - 1.2 Design a system, write a systems description and the essential form of the model.
    - 1.3 Define the constraints, such as the computer, the language and the desirable time of the computer runs, together with those elements of the system which must be found in the computer simulation.
    - 1.4 Encode the system and debug the programme. Tune the endogeneous parameters to obtain representative performance.
    - 1.5 Simple validation of the programme is performed, together with a rapid evaluation of likely controlling parameters.
2. Implementation
    - 2.1 Develop the model by adjustment of exogeneous parameters to represent actual conveyors in the various offices.
    - 2.2 Use live parcel traffic as a data input, observing the comparative performance of the real system and the model.
3. Evaluation
    - 3.1 Examine the comparative results to confirm the model is truly representative of the real system, from the point of view of validation.
    - 3.2 Examine the results from the point of view of altering the model parameters to see if physical alteration of the conveyor, ie speed, dimensions, loading method etc, could be examined to

see if the model predicted an improvement in performance.

4. Revision

   4.1 Run the model to determine if the changes in the model showed an improvement in performance. If none is shown the process is complete and exit is made here.

   4.2 If sufficient confidence may be placed upon the predicted improvement, modify the real conveyor system to the new standard.

   4.3 Return to 2.1 for retesting, and further evaluation and revision if required.

The greatest advantage of the systems approach is the ability to programme the model in modules (modular programming) and to apply well established control principles. The advantage of simpler maintenance (adjustment of the computer programme) is probably less real.

This particular model is quite unusual in that it is not based on time, which precludes the two variations of clock-time or event triggered simulation. Most simulation languages are written with one or other of these simulations in mind. This meant that the options of SIMON (ALGOL based) (ICL, 1969 (a), HILLS, 1964) or 1900 CSL (ICL, 1966, BUXTON AND LASKI, 1962) would have been unsuitable because of the nature of the model. SIMSCRIPT (MARKOWITZ, 1963) was excluded since the 1900 configuration was too small and also unsuitable due to the 24 bit single word length and accumulator system.

1.2 COMPUTER SIMULATION

1.2.1 General Aims

There was a tendency to be too ambitious in the systems analysis and therefore to try to produce a model which was too complex and needed very long computer times. Much effort and run time could have been expended on a system which might have given results of a similar accuracy to a simple model. The system chosen was simple compared to other more complicated models, which had been considered. When development created the need for more complex routines, the programme structure was designed to enable maintenance programming, alterations and additions to be carried out easily. The model was simple in most decision-making areas to obtain results promptly.

The general aim was: "To produce estimates of loading of parcel conveyors which can be validated and the model developed to the point that it would reproduce the loading of live test parcels into conveyors of similar sizes".

1.2.2 The Selection of a Computer Simulation

A computer simulation was chosen for this research, because it tested more cheaply the effects of changes in physical dimensions of parcel conveyors upon parcel flows. The cost of computer simulation is high, even in the University environment, where the computing costs are absorbed into the service overhead cost. Computer simulation would give results at only a fraction of the cost of establishing the performance by measurement of existing conveyor systems, which is largely unrecorded. In the particular case of GPO parcel conveyors, the problem is exacerbated by the fact that even if special changes were made to the conveyor system in a particular office, and tests carried out to find the resulting change in performance, then the results would be only valid for that particular office parcel distribution at the times of day when the test was made. To be representative, tests might have to be carried out for years, even if "activity sampling" techniques were used to keep the costs within bounds.

Computer simulation of these parcel conveyor systems has the advantage that both existing and proposed conveyors can be modelled under exactly the same parcel distributions at low cost. Parcel distributions can be generated to represent parcel distributions which may occur in the future, with very high percentages of plastic-wrapped parcels, or be derived from historical data from parcel surveys to represent various parcel offices as they are known to be. The model may be adjusted to represent the variations in loading patterns due to seasonal change in parcel flow. Variations in conveyor dimensions, speed of loading, sidewall and belt materials are possible within a predetermined range. The steering information for these factors, called exogenous factors, is input from a steering data file. For a good treatment of exogenous and endogenous factors, see the excellent book by Naylor et al (1966). Endogenous factors are those built into the programme, which cannot be altered or steered from a data file, but must be changed by a change of the programme. The performance forecasts could be used to avoid basing any future investment, which will run into many millions of pounds, on pure guesswork and empiricism. Evaluation of design factors by other techniques would be more costly. The computer simulation model avoids using simplifying assumptions, provided a logic sequence can be defined and an algorithm developed.

If every system element were programmed, then the model would be a perfect replica of the physical system. These more complex models will produce very large and long running computer programmes. In the interest of simplification and also to meet the constraints of the time and size of computer available, decisions have to be made as to which system elements are important and likely to be "relative factors" giving "causal effect". These are then incorporated into the programme as a sequence of algorithms, and those of less importance are rejected. Sometimes it is necessary to reintroduce such factors or to reject factors thought to be causal during development.

1.3 A DETERMINISTIC MODEL

1.3.1 General Description

The programme which calculates the probability of jamming in chutes, glacis, and conveyors, is a model of a GPO straight conveyor system. This is loaded with a sequence of parcels which are chosen and positioned at random by the Monte Carlo method from data files of 2087 parcels from six offices.

There are six main sections. These are sub-divisions of the programme, for convenience in operating. The programme was created as a sequence of modules, which are distinct sub-programmes which can be independently tested and "debugged". One or more of these can be used to give a section. This technique gave great flexibility during programme creation. For flexibility of operation, the use of a GEORGE 3 MACRO was more useful. GEORGE is the automatic operating system of the ICL 1900 series. A MACRO is a simple line of instructions which will give the computer a pre-written programme in the operating language.

1.3.2 Division into Modules

In a similar way, the division into modules means that a whole module could be restructured without changing the rest of the programme. This aided future development of the programme to simulate any system to be considered. It also enabled an incomplete programme to be run in a skeleton form, so amendments were carried out on one or a few areas at a time by inserting untried modules into a previously well-tried skeleton programme. A further advantage is that programming of areas, which contain causal factors unlikely to have great relative effects, could be delayed, until the test runs showed whether they needed to be programmed as modules and inserted into the main programme.
W G R Stevens (1969) describes modular programming methods.

1.3.3 Systems Development

The programmes in their final forms have developed from a number of preliminary models. While this effort may seem to have been unnecessary, present models could not have been envisaged without investigating, as a preliminary, the other more primitive models and deciding that some of the present features were essential, and that some of the features of previous models were unsatisfactory and over-simplified. The design of the sub-systems required consideration of the interactions and revising of the model. This "PIER" process was an essential part in creating the final models. The technique is described in sections 1.1.3 and 1.1.4.

1.3.4 Deterministic Loading

The model was originally envisaged as being probabilistic, in the sense that a sequence of random selections from the original parcel list, could be built up into a file of parcels. The way in which the data was arranged and the ICL configuration, meant it was easier to use the COBOL language.

Two programmes were written to form the random input files. These programmes manipulated the GEORGE data files to form a new file which could be accessed by the main programme. The disadvantage of using a randomly selected input file was that the computer times were long and the values little different from those given by loading the original random sample in sequence. The technique was therefore left for future use.

1.4 THE COMPUTER, THE LANGUAGE AND THE PROGRAMME

1.4.1 Choice of Computer

An initial decision at the commencement of the project in 1969 was that the facilities of the University inhouse computer should be utilised. This ICL 1903A machine, comparatively modern, was delivered in 1970. It had a 32 K (words) store, with four magnetic tape decks. The operating system was then GEORGE 2. The advantage of having the machine on-site so that a rapid turnaround was possible, would outweigh the advantage of having larger capacity with a slower turnaround, from an outside computer such as ATLAS. The University of London Computer Centre (ULCC) computer, a CDC 7600, was not then available. An advantage of the University ICL 1903A was that the error trace facility was very good.

Considerable difficulties have arisen whenever the ICL 1903A configuration was enhanced. The major changes were to enhance the core and to add magnetic disc memory. Originally two Disc Stands were added. These were type EDS 8 with exchangeable disc facilities. Further stages were the addition of two more EDS 8 discs and then two EDS 60 stands of much larger capacity. A 7903 communications processor was added to improve the MOP (multiple on-line processing,(ICL 1970 a)) terminal service. The core was increased to 64 K in two stages and this caused the typical troubles of reduced service during commissioning, and unreliable operation and system failures in the initial stages. These hardware troubles were more easily handled, since the length of downtime was fairly predictable. New discs required a change from the magnetic tape operating system and compiler, which lost perhaps a week or two. The later software changes resulted in periods when no "Big Jobs" (over 300 seconds or 500 lines of output) or "Extra Large Jobs" (over 900 seconds or 1000 lines of output) were run. The effect of the system change from GEORGE 2 to GEORGE 3 was traumatic. The change was pressed upon the University by ICL who claimed it was essential in order to operate the terminals efficiently. An advantage of GEORGE 3 is to have user files which are called into use to run various programmes and data as required. Severe difficulties in file and programme compatibility may give an "illegal" message on the operator console. Changes in the operating software are needed to correct this problem, and the user cannot run his programme until this is done. This occurred repeatedly during the six months changeover period from GEORGE 2 to GEORGE 3 and has occurred subsequently with other work on the NELAPT part programming language and the production control package PROMPT. Often it was due to incompatibility between the EXECUTIVE and GEORGE operating systems and the user programmes.

Although the core was extended to 64 K, most of the addition was used to enable the system to handle the MOP terminals. The maximum core available for batch work and terminals together was only 20 K with the 64 K machine. For normal batch work alone the maximum core was 32 K. It was possible to call up 49 K of user core, but this reduced the throughput. At that time, programmes of between 32 and 49 K user core requirement were restricted to those cases where it is essential and unavoidable.

1.4.2 The Language

The computer also affected the choice of language. When the project commenced, three compilers were available on the 1900 ICL machine. They were the 1900 ICL magnetic tape compilers for ALGOL, FORTRAN IV (ICL 1965) and also the assembly language PLAN (ICL 1967). Investigations of the PLAN language showed it to be very limited and tedious, although for text and binary handling it had advantages over the other languages. The 1900 ALGOL seemed inferior to the Elliott 803 ALGOL used on the previous University computer and in the version on the machine at that time, was inferior in handling the tabulated output required. In some ways the selection of the output and input channels resembled FORTRAN. The 1900 had been designed for FORTRAN and it was felt that the matrix handling capability was superior in that language. The ICL FORTRAN (ICL 1968) was selected and used until extended FORTRAN (ICL 1971) became available in 1971. There was also some use of the FORTRAN Compiler Libraries (ICL 1970b) and FORTRAN 32 K Disc compilers (ICL 1969b).

1.4.3 Limitations on the Programme

The three-dimensional programmes have always been fairly large and modular programming was adopted from the beginning. The first programme series called "FL" for "Flat Loading", was based on loading the parcels on top of one another, all parallel to the belt, which was designated "Flat Load". This was only intended to act as a vehicle to lead to the more realistic "TL" series or "Tilt Load" where the parcels were at various three-dimensional angles. The final programmes were "TL 201 to 204", and these developed from the first version "TL 1" over a period of about two years. The advantage of modular programming was shown in the transition from the "FL" to "TL" series, which was achieved by changing only the module which loaded the parcels, the remainder of the programme being unchanged.

During the development of the final programme, the programme and storage requirements increased considerably, even though periodic "efficiency drives" to reduce the size of the programme were carried out. This process was essential to keep the programme inside the permissible limit on the 1900 machine. Initially the core requirement was kept under 20 K by reducing the number of parcels which could be handled, to allow a daily turnaround of the programme. For later development, it was essential to load sufficient parcels so that the conveyor was fairly full. The normal maximum programme size, which is 32 K, was used as an upper limit, and some ingenuity was necessary to maintain the programme inside that limit. The other constraint was determined by the conveyor section, and to give a representative loading about 75 parcels were necessary. To allow a reasonable margin above this, the maximum of 100 parcels was set and maintained for the ICL machine.

Other computers were used in the course of the project as they became available. The ICL 1903 on-site computer is a batch machine and, at that time, it was rather small for this type of work. The MOP on-line terminal operating system (ICL 1970a) was applied to the configuration, but it was virtually impossible for more than five or six terminals to be used together, and the degrading of the system was extreme at times. Some small jobs can be run as background, provided only one or two terminals are in use. Hence a rapid service is difficult to obtain. When small programmes are being developed and tested a slow turnaround can be most frustrating. Accordingly other computers were used. However this led to problems, since they did not offer compatibility with ICL EXTENDED FORTRAN. There were many small calculations necessary in this research and these were computed using interactive machines.

In 1970, at the beginning of the research, a terminal service was available in BASIC to an outside computer - the TELCOMP service (Time Sharing Ltd 1969). Additionally the Department had a small desk computer, the Olivetti P203, which was used for very small programmes, using Olivetti Autocode (Olivetti 1968). This machine had only five stores containing 32 decimal digits, which could be divided into ten stores of 16 decimal digits. Despite this limitation, and the slow operating speed of six to eight two-part instructions per minute, the simpler types of statistical calculation were considerably speeded by this machine. The programme storage was on magnetic card, and the data insertion on paper tape. Subsequently other time sharing systems were used, such as LEASCO using BASIC (Leasco Response 1973), and the Open University BASIC service. These two systems used the Hewlett-Packard computers, which provide a very effective terminal service.

Statistical analysis programmes or packages were also used on bigger interactive systems, such as the very effective STAN (STatistical ANalysis) package (CRC Information Systems 1972, 1973) based on CYBERNET SIGMA 9 computers. Even the simple statistical analysis took longer to programme into the CASIO AL 2000 programmable memory calculator using machine code, than desk computers took to provide completed calculations, with printed results by telex (electric teletypewriter). When the TELCOMP service was discontinued, some of the BASIC programmes were adapted and run on the ICL 1900 MOP terminal, which has rather unsatisfactory BASIC and a poor response time. Later, the Department bought a MINIC computer from Micro Computer Systems, which had a storage capacity of 16 K bytes, or 8 K words. It was equipped with both BASIC and FORTRAN compilers. Some subsidiary work was input on this machine with input by paper tape, with a different character code from both the ICL paper tape and the other on-line systems. It was not possible therefore to use the same programme tape, irrespective of whether the correct steering was added or not. This lack of compatibility was a problem, even when the paper tapes were quoted as standard ASCII code.

It was an important objective to write the programme in modules, which could be coupled on the main machine when they were operating properly, but this was difficult if more than one computer was used. The indifferent compatibility of the FORTRAN dialects and paper tape variations caused difficulties. That modular programming was used throughout, in spite of the difficulties, is positive proof of the real advantages.

For running very small modules on the ICL machine, the FLAIR in-core compiler was used. Although modules were limited to 4 K words and 15 seconds computing time, rapid turnarounds more than compensated for these restrictions. It was possible to obtain five turnarounds, on a programme under test and development, in both of the two one-hour periods that FLAIR was "on the air" each day. This was a dramatic improvement on the normal batch macro, with a turnaround in one to five days. A module could take about 15 runs to develop to the stage where the computer model simulated the real sub-system. This would take 45 days on the normal batch macro at the peak demand time, compared with five days or less at any time of the year with FLAIR. The installation of the in-core compiler had been at the insistence of the computer user panel, under the author's chairmanship. The implementation seems justified, since the computing in this project would have taken years longer, had it not been for the FLAIR compiler. A disadvantage, however, was that the EXTENDED FORTRAN (ICL 1971) of TP 4269 was not available, and the programmes had to conform with the FORTRAN of TP 1167 (ICL 1968) to use FLAIR.

The programme has also been tested on the CDC 7600 South Eastern Region Universities computer which is fed from the CTL Modula 1 on-site satellite terminal. Unfortunately, even after the various differences between EXTENDED FORTRAN IV in CDC (CONTROL DATA 1972a,b) and ICL versions had been overcome, user limitations prevented any comparative testing. The CDC 7600 machine has two core levels, the storage was 32 K fast core and 256 K of slow core. The user availability was about 19 K of fast and around 128 K of slow core. This meant that the simulation programme was too large to run in fast core. Some difficulties arose in the transfer to slow core and back to fast core again, and so delays occurred in obtaining an operational programme. The error trace facility (Control Data 1972c) was inferior to the ICL and very complex. Further problems arose in the operating system (Control Data 1972b) and the link between the satellite CTL Modula 1, and the CDC 7600. During the research the 7600 did not offer as good a user service for this computer simulation as the ICL 1903. Since this machine is so much larger and faster than the 1900, offering four times the user core space and from 10 to 100 times faster, this was a disappointment. These difficulties have now largely been overcome.

1.4.4 Relation of Programme Size to Conveyor Section

The cross section chosen for testing was 40 in. wide by 36 in. high. For the purpose of this present work the length was set at 72 in. A sketch of the conveyor section (figure 1.1) is shown with the illustrations, tables and diagrams at the rear of this thesis, Page 331. (Appendix IX) A conveyor of these dimensions would give a probable "conveyor full" loading of about 60 to 70 parcels, and so the computer matrices were dimensioned for a maximum of 100 parcels. It was decided that if the model could be tuned to represent test loadings of an existing conveyor, then at some time in the future the matrices should be increased, to permit modelling larger, more typical sections. The programme was arranged so that it could be altered simply, to achieve this. Due to the difficulties with the CDC 7600, and the limitations to the user of the 1900 ICL core store, this was not done.

The validation of the loading of the parcels was checked on both the 72 in. and 108 in. long sections, as is described fully later. It was not possible to test the "real" conveyor section absolutely, since that conveyor was one used for everyday parcel traffic. It would have been far too disruptive to interrupt the flow while tests were taken, and would defy statutory restrictions on delaying the mail. These problems were overcome by validation with live mail in a little used conveyor, more or less of the required section, at a local office. The Post Office engineers, in various discussions, had set the size of the conveyor.

With the CDC 7600 the model section could have been increased from 6 ft. to around 24 ft. long. With the 40 in. wide section, this increases the ratio of length over width, and reduces the effect due to the ends of the model area. This is shown in Table 1.2 (see the rear of the thesis, Appendix IX page 332)

$$\text{Aspect Ratio} = \frac{\text{Conveyor Length}}{\text{Conveyor Width}}$$

It can be seen that this ratio becomes undesirable with the transfer conveyor section, if the 1903 ICL computer is used. Since the width of the transfer section is 108 in. the length that can be tested is only 27 in. This is shorter than the longest parcels and so the errors due to parcels lying half-in and half-out of the section will be high. The aspect ratio will be only 0.25 for the transfer conveyor if the ICL 1900 is used normally. The ratio of 1.0 obtained with the CDC 7600 computer would probably be the limit of what is acceptable to minimise errors. The maximum permitted by the user limits with the ICL 1903 computer is somewhat restrictive.

1.5 PARCEL DATA

1.5.1 Post Office Data

The data was supplied by the Post Office and was the subject of a report by Castellano, Clinch and Vick (1971). In it the samples of actual "live mail" from six offices were treated as one large sample. (See Table 1.3 App IX,p 332) It was felt that this was incorrect and so an analysis of the data would be useful to see if there were any significant differences in the samples from each of the six offices. The means and standard deviations were obtained by creating the data checking programmes shown in Appendix VII. The results are in Table 1.4 (App IX,p 333) Initially, an analysis based upon the standard error of the mean σ_M to find the significance of the differences of the means was carried out by the method of Connolly and Sluckin (1971). (See App I,p260). Tables showing the variation in critical ratio and the significance of the differences in the means of any two samples, are Tables 1.5 and 1.6. The details of the method are given in Appendix I. (See page 260 for App I & page 334 for Tab 1.5-6)

The test statistic is:

$$z = \frac{|M_1 - M_2|}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_1}}}$$

M_i = Mean of sample i

and the Hypotheses:

$$H_o : \mu_1 - \mu_2 = 0$$

$$\text{and } H_1 : \mu_1 - \mu_2 \neq 0$$

σ_i = Standard difference of the sample i

N_i = No. of parcels in the sample i

This test showed there might be a significant difference in the parcels traffic at the different offices.

Table 1.6 shows the significance in the differences in mean values of weight for comparisons of one office against another. Four out of the six offices have one barely significant (5%) and two significant (1%) differences in the five comparisons. The method of Connolly and Sluckin (1971) relies upon the tendency of the "t-test" distribution to approach the "normal distribution" with very large samples and high degrees of freedom.

These paired comparisons are not conclusive. The significance of the differences was then tested by one-way analysis of variance. This enables the "F-test" to be made of the following hypotheses, and these tests were made on the weight, length, breadth and height of parcels in the samples:-

For samples from six offices

$H_o : \mu_1 = \mu_2 = \ldots\ldots\ldots = \mu_6$ μ_i = Sample mean of ith office

H_1 : not all μ_i are equal

This more sensitive test shows that there is significance in differences of the means for certain of the properties. The results are tabulated in Table 1.7 and the programme in BASIC to calculate the F-ratio and the results are given Fig. 1.8 and 1.9. It will be seen that there are highly significant (0.1%) differences in the weight and the width of parcels from different offices. The height shows a significant difference (1%). The length shows no significant difference between the parcel samples from the six offices. (See pages 335 to 338)

Thus the one-way analysis of variance test confirms the suggestion that the parcels traffic from the various offices are from independent populations, and we should reject the null hypothesis H_o.

1.5.2 Parcel Variation with Office Area

The samples from each office in turn were compared individually to the remainder from all offices by the one-way analysis of variance. Table 1.10 is derived from the BASIC computer programme and gives the significance of differences in the means, of the variables obtained from samples of each of the offices. (See page 342)

The sample of parcels from Croydon Office (3) showed highly significant differences for weight and breadth and it confirms that we should reject the null hypothesis. Brighton is significantly different in three properties out of four. Liverpool and Manchester differ significantly in one property out of four. North West London Post Office differs barely significantly in one property out of four. It seems likely that parcels traffic from each office has a characteristic set of properties. Some offices, of which Croydon and Brighton are examples, have properties which have significant differences from parcels traffic at other offices.

1.5.3 Effects of Variation

It is evident that considerable variations in parcel sizes, shapes and weights occur, and that this makes for difficulties in a deterministic model. On the other hand, if these variations were expressed as mean values and standard deviations, as in some models considered in the feasibility study, then any results would not cover individual interactions of parcels, which might be the main causes of stoppages. For this reason a deterministic model was used, rather than a probabilistic model, such as is used in component handling or powder and mineral conveying. The unit load* types of analysis were rejected, since the unit loads are taken as being identical. The only use of this type of conveyor in parcel handling, was the bag conveyor, which transfers the parcel bags from the motor vans to the belt conveyors.

* See Glossary of Terms

To create a model to test the performance of these conveyors, was of no great significance. Their purpose was simply to load very wide, slow moving belt conveyors or chutes, which then loaded the normal belt conveyor. They did not jam or cause jams.

2.0 LITERATURE SURVEY

2.1 COMPUTER SIMULATION MODELS

This thesis used the definition of Naylor, Balintfy, Burdick and Chu (1966): "Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a business or economic system (or some component thereof) over extended periods of real time". In these models of a GPO parcel conveyor, the stochastic positioning of parcels and their initial orientation, is coupled to a deterministic system which arranges the parcels in the conveyor and subsequently calculates the forces upon each parcel and the base and sidewalls. The time function is not present in the first model which locates parcels at random in the conveyor. The second model considers the flow of the belt conveyor, with time represented as a linear function of parcel number. There is no time clock, or use of time as the independent variable in the sense of Maisel and Gnugoli (1973). In their terms the second model is a "critical-event discrete stochastic system" rather than a "time-slice system". The status variable is the arrival of a parcel. If subsequent research should show that the assumption of a linear time function is not valid, then a revised model could be created by the addition of a module, in which the elapsed time interval between parcels can be given by a Monte Carlo distribution generator. This would then be used to calculate the distance travelled by the conveyor during the interval to give the next location point. Most stochastic or Monte Carlo models are based on time or money as the status variable. This engineering model differs in that numbers of parcels and forces in pounds are the basis for the model. Quite apart from the limitations of the computing facilities available, the nature of the problem meant that computer simulation languages, available on University computers, were unsuitable, since they were biased towards simplifying the programming of models widely different from that of this project. The symposium at Duke University on "The Design of Computer Simulation Experiments" (Naylor 1969) contains much excellent material on simulation generally, but has nothing which is relevant directly to this research. A. Brown's review (1971) of the methods for the trim-loss problem, was helpful in formulating the approach to parcel location, but most of the text was more applicable to production planning. Similarly, Kilbridge and Wester (1961) draw an analogy between the balance delay problem and the packing of boxes into a number of equal sized larger boxes. This idea was applied to this model of the belt conveyor. The approach of Thomopoulos (1967) was helpful. Thomopoulos refers to the "belt", but it is fairly obvious that a unit-load system is intended. It was therefore decided that the literature gave only useful guidelines as to how to make a new model and so new systems were created, starting with two dimensions and progressing to the final three-dimensional model.

Parslow (1967) of this University, has developed the AS language, (Parslow 1968), based upon the General Simulation Programme language (GSP MKII) of Tocher and Hopkins (1964). This uses ALGOL and was developed for the KDF 9 computer at the National Physical Laboratory. It was altered so the programme was coded in Elliot ALGOL and could be run on ATLAS computers. Tocher (1965) in his excellent analysis of simulation languages, classifies GSP as an "activity entity" type of language, as are SIMON (ALGOL based) (Hills 1964) and CSL (FORTRAN based) (ICL 1966; Buxton and Laski 1962) both potentially available on-site at Brunel, at the time the research began. There would have been difficulties if simulation languages were used, since the user core size of the ICL 1903 was limited. This would make it necessary to overlay the programme, (i.e. run it in sections) which would prolong the running time. The need for sole occupation (complete dedication) of the computer, by this programme, would reduce the turnaround and service to other users. In any case, the systems analysis and the model developed in this thesis would lend itself more to other "passive entity" types of languages such as GPSS III (GORDON 1961, 1962; Herscovitch and Schneider 1966) or SIMSCRIPT (Markowitz, Hausner and Karr 1963), which are not available at present. Developments at the University, of both the SERU CDC 7600 at the London University Computer Centre, which offers GPSS and SIMSCRIPT, and the ICL 1903, will enable future researches to use the appropriate simulation language. Krasnow and Merikallio (1964) suggest in their article, that the need to spend a considerable time in becoming proficient in a computer language, will be obviated by future developments in simulation languages. Tuan and Nee (1969) in the U.S.A. have produced a GPSS simulation called MASS - a mail service simulation. This models the collection, the distribution offices and transport of mail. Future developments in the U.K. Universities will make similar work possible.

The on-site ICL 1900 configuration could accommodate the 1900 CSL computer simulation language during the latter stages of the project only. However, the CSL documentation (ICL 1966) reveals that the method of operation is to translate the CSL into FORTRAN and then compile the FORTRAN code produced by the CSL translator. This would require the programme to carry a core image of the FORTRAN compiler, or bring in a file copy, after removing the CSL translator, and three passes through the computer instead of two would be required. 1900 CSL required much computer time and core space, needing complex overlays and many file operations. It was therefore decided that the GEORGE operating system (ICL 1972) plus the 1900 EXTENDED FORTRAN (ICL 1971) would be the most feasible method of writing a computer simulation, which would run satisfactorily on the system at that time. The South Eastern Regional Universities' computer, a 256 k CDC 7600, available in 1973-4 on a trial and commissioning basis, offered the possibility of using the GPSS and SIMSCRIPT languages.

The experimental work of this project could have been transferred to the CDC 7600 computer, which the Computer Board provided for work requiring large core store or long running times. Difficulties with the system, which provides two types of core store, restricted any changeover. SIMSCRIPT was available on London University's own CDC 6600 computer and test runs could have been arranged. However, the time available was limited, and all work had to be carried out personally at the ULCC London Centre. It was decided that to remain within the scope and time-scale of this project, the ICL 1900 on-site computer would have to be used for the experimental work. As more and more experience was obtained with the GEORGE 3 and the 1900 EXTENDED FORTRAN, it was realised that much of the overlaying and data storage of simulation languages could be duplicated easily by means of the GEORGE 3 file structure. It was felt that many of the so-called disadvantages of using a language such as FORTRAN did not exist on the ICL 1903 configuration using GEORGE 3. However, the initial research was to acquire expertise in modular programming in FORTRAN and the use of GEORGE operating system commands, which could be a disadvantage.

2.2 RUSSIAN WORK ON CONVEYORS

Vladziyevskii (1967) in his analysis first published in 1958, refers to the case of continuous flow transfer between machines in automatic production lines. His method of probabilistic analysis results in a stochastic process of the Markov type, since the effort is concentrated on triggered feeders, and whether they fail to pick up one or a batch of components or not. While this approach could be used to model the conveyor, and was considered in the feasibility study, it was felt that this was only an extension of the unit-load, Markov (Bharucha-Reid 1960) approach, which considers the continuous flow case in an approximate manner, rather than to consider the problem afresh. This is borne out by consideration of the comment by Vul'fson and Dymshits (1967) who extend the work of Vladziyevskii. They comment that "in non-cyclical pick-up mechanisms .... the elementary probabilities .... are determined in a considerably more complicated manner .... At the present time the only reliable method is the experimental determination of these values corresponding to real conditions. A large amount of systematic experimental work is being done at the Tula Mechanical Institute (V. F. Preis). In recent years similar work has been done at the L'vov Industrial Institute (A. N. Rabinovich) and at many mass production plants". It is interesting that the authors do not consider the use of simulation, probably because of the reluctance of the Russians to accept OR as a subject. Vul'fson and Dymshits (1967) express this as follows:- .... "According to our experience however, the automatic feeders with non-cyclical operation may, in the majority of cases, be considered with sufficient accuracy as feeders with full release".

2.3 AMERICAN WORK ON CONVEYORS

T. T. Kwo (1959) analysed the behaviour of the loop overhead monorail chain conveyor with suspended hooks. He studied this as a mechanism for transforming the input flow of the conveyor, which he considered as the output flow of some other process, into the output flow of the conveyor, again considered as the input flow of yet another process. This is the characteristic operational research approach, and Kwo argues that this is an essential part of any analysis. He then proceeds to a very useful method of classifying conveyors into discrete or continuous, equal or unequal rate types. He chooses for study, the monorail type conveyor, slinging unit loads on hooks. This is shown schematically in Fig. 2.1. Among his basic assumptions, he includes:- (See page 343)

".... (b) 2. That there are no random fluctuations in either the loading rate or the unloading rate ...."

This makes his detailed study of little application in this project but his general method of approach is of value. He postulates three fundamental operating parameters governing the operation of the conveyor, namely:-

1. The speed rule: This sets upper and lower limits on the permissible speed.
2. The capacity constraint: This gives, in effect, a limit to the input and output flow rates. This he regards from the point of view of increasing the capacity of the system so that it will accommodate "excess rates". This constraint is a function of conveyor speed of travel.
3. The uniformity principle: In essence, this is a form of resource smoothing. Kwo makes the point that if the conveyor is loaded uniformly, then the random excess rates will be reduced and the effective capacity increased.

Kwo then determines the operational speed for his conveying system, using the above principles. He does not, however, use his analysis to produce a mathematical model to test his three operational rules, but rather prefers simulation, giving two different methods. Both are numerical tables of the distribution of the items on the conveyor, as time proceeds, but the first method only could be applied to belt conveyors, whereas the second is suitable only for unit loads. Kwo goes on to discuss the methods of analysis available and suggests that there are two possible methods of approach. They are:-

1. The "complete simulation" approach. This is a computer assisted, Monte Carlo random generation of disturbances, which can then be used to optimise the process.
2. The "semi-simulation" approach. This uses the sum of the peak accumulation given by his second method of simulation (specific to unit loads) and the "permanent storage".

He discusses the viability of these models and states that both of them are conservative in their estimations in that ".... they tend to give answers that are very safe". He examines the reasons for this and concludes that at the moment the empirical method seems to be the most promising. While that was possibly true in 1959, it can be seen that later papers tend to use standard forms of queueing theory as a basis for modelling, with recent papers bringing in Transform and Markovian analysis. Kwo did adjust his second model, however, and the modification produces results which are practical.

W. T. Morris (1962) produced a book - "Analysis for Materials Handling Management". This includes a chapter 7 on "Conveyors", which is a practical attempt to classify conveying systems, and to apply probability theory and queueing theory to conveying systems. This is a great advance on the approach of Kwo, but is mainly concerned with the unit-load hook type conveyor, so far as the examples go. Morris does consider the analysis of random flow, continuous belt systems, and would make a good basis for the preparation of mathematical models of the type under consideration in this report. The book is general in the coverage it gives, and to discuss it in this report in detail would be too time consuming. The techniques he outlines, however, formed a basis and are referred to in many subsequent papers by others.

R. L. Disney (1962) published a note on "Some multichannel queueing problems with ordered entry". This was directly applying queueing theory for truncated queues, multichannel service, and ordered (rather than random) entry to the problems associated with conveying. He followed this with a paper (Disney 1963) on "Some results of multichannel queueing problems with ordered entry - an application to conveyor theory". This is a highly specialised paper, studying power and free (gravity fall) unit load conveying systems. He was concerned with the situation where a pendant on arrival finds all stations full and is lost to the system. This introduces the Erlangian distribution, and the Erlang "lost call" formula of Palm, reported in Tele, (1957) for the overflow problem of telephone calls. This was shown by Khintchine (1960) to be lacking somewhat in academic rigour, and further he showed the assumption of a Poisson distribution of a discharge of one conveyor (which is then taken as the input of the next conveyor) is invalid. This was unfortunate since the adoption of this assumption vastly simplifies the modelling. Disney comments on this and other problems of the study of conveying systems and then gives some likely areas for future research. He comments upon the interaction of the various parts of the system in a similar manner to Kwo.

Reis, Dunlap and Schneider (1963) published "Conveyor theory - the individual station" which is a useful and fundamental paper. They suggest seven factors which are relevant to the formation of an analytical model of a conveyor. They then proceed to give a number of models in mathematical terms for loading and unloading, according to the levels at which their factors are held. They point out that the development of models for unit load (hook-type) conveyors is usually carried out, since it is simpler than other forms, but do state that development of the theory to other forms should not be difficult. A further paper by Reis and Hatcher (1963) on "Probabilistic conveyor analysis" applies a similar approach and analyses the method of derivation of a probabilistic model, using a schematic representation of the physical nature of a conveying system and similar parameters to the previous paper. In their conclusion the authors state that work is proceeding at the University of Arkansas, so that these techniques of analysis may be applied in a straightforward manner. This eventually may provide a way of optimising the many economic factors involved.

A. A. B. Pritsker of the Arizona State University spent some time at the Rand Corporation. While he was there, he produced (Pritsker 1964) "An analysis of conveyor systems" Rand Collection No. p 3016. This 74 page report is a comprehensive treatise based upon queueing theory, for multichannel problems with ordered entry and no feedback. Using fairly widely accepted formulae for different types of input and output distributions, which involve the parameters of traffic intensity and input and service rates, he derives some general parameters for conveying. The alternative would be the deterministic procedure of obtaining a specific probability associated with the number of units in each channel. He then develops the model and gives computer programmes for the analysis and also for the model, written in Simscript.

This is a sophisticated language developed by H. Markowitz et al (1963), and which has a FORTRAN based compiler for the IBM 709/7090 systems. The method given by the article would provide a good basis for the modelling of conveying systems considered by this report, although consideration of whether the SIMSCRIPT language would be the best for the UK situation would be necessary. The system considered by Pritsker is shown in Fig. 2.2. (See page 344)

A further paper by Pritsker (1966) "Application of multichannel queueing results to the analysis of conveyor systems", develops the application of standard queueing theory further, and states ".... The promising aspect of this application of queueing theory is that no major effort was required to develop new and novel equations for the performance measures of a conveyor system. The development presented, relies heavily on knowledge of existing results, and a logical transformation of these results to the conveyor situation. A major conclusion of this study is that there are many parameters, associated with the types of conveyor systems studied, that do not significantly affect the steady-state probabilistic performance of the system". It would appear that this again makes a useful contribution to the preparation of models for general solution. He lists some parameters which can be ignored, an example being: "The form of the service distribution, if the interarrival distribution is exponential".

Reis, Brennan and Crisp (1967) published the paper "A Markovian analysis for delay at conveyor-serviced production stations". This is a useful paper which gives an alternative method of approach for modelling. They use a matrix method, with a vector notation for the Markov process, which they introduce for situations where the worker loads and unloads the conveyor system. This is often the case in systems under consideration.

Beightler and Crisp (1968) wrote a paper - " A discrete-time queueing analysis of conveyor-serviced production stations" - which uses a similar analysis to the Reis, Brennan and Crisp paper for unit load conveying. They develop a "Sequential Range Policy" which they claim to be superior to the policies proposed by Morris (1962), Reis and Hatcher (1963), and Reis, Brennan and Crisp (1967). They analyse, in addition, economic factors, examining optimising procedures and discussing various objective functions. Their theories were tested in a subsequent paper by Crisp, Skeith and Barnes (1969) in 1969. Their paper "A simulated study of conveyor-serviced production stations" gives a simulating procedure using GPSS III and FORTRAN IV languages to test the "Sequential Range Policy" of Beightler and Crisp (1968). They report that the fundamental assumption made by them, that the distribution of units on the conveyor system studies was a stationary Bernoulli distribution, cannot be supported.

Pritsker (1970) was more interested in scheduling than in conveying in recent years. Skeith and Phillips extended the work of Pritsker to cover even further examples of unit load conveyors for assembly lines, with multiple servers and multiple queues and storages. They published a paper on this in 1969 (Phillips and Skeith 1969b) and in spite of the considerable work done by this group, a research report published by Phillips and Skeith (1969a) was saying ".... The problem of defining closed form solutions for the general queueing service system appears to be formidable, if not impossible, using mathematical research alone. The choice of a simulation analysis in this study as a supplement to mathematical analysis is primarily due to the belief that the basic scientific problem appears to be to first obtain a better understanding of the interrelationships which exist, before developing a foundation of general predictive theory for the statistical properties of the system as a function of the state variables". To make the task of achieving this objective easier, and yet to avoid the rejection of work carried out by the group in FORTRAN IV, the programmes were written in GPSS III, a general purpose simulation language. This is described by Herscovitch and Schneider (1966) and is developed from the original version of GPSS by Gordon (1961, 1962). This particular research is very specific to the unit load production line and concentrates upon the development of a predictive theory for the operating characteristics. As such it is no more relevant than the early work, but it does suggest a method of attack for the problem of the belt conveyor which is engaged upon the transmission of irregular shapes such as GPO parcel traffic.

The behaviour of a system may be classified into three forms:-

1. Deterministic, and easily calculated.
2. Probabilistic, but where the distribution is well-known and the effects of interrelations are sufficiently small for the performance to be predictably calculated.
3. Probabilistic, where the interrelations are such as to make simulation the only likely method of finding predictive methods.

The adequacy of the method of using computer simulation to establish predictive methods has been established for machine tools and even machine shops at the University by Rourke and Liu (Rourke 1973, Rourke, Boyd and Liu 1975) who have extended computer queueing simulation to apply it to Network Planning (Rourke and Liu 1974). In general it would seem that the correlation between queueing analysis and computer simulation is very good. However, the predicted values are accurate only where steady state values for variables such as throughput time or average queue length are needed. If the behaviour of one specific object in the process must be predicted then computer simulation would seem to offer the best way to study the outcome, as Phillips and Skeith (1969b) have said.

2.4 CALCULATION OF FORCES

2.4.1 Continuum Methods

Much research has been carried out in the flow of bulk solids using continuum techniques to find the effects of arching and bridging in hoppers, chutes and channels. At first sight it would appear that this could be of relevance to the jamming of parcel conveyors. There are a number of theories, but probably the most prolific writers in this area are Jenike and his co-workers, and the most comprehensive treatises are the Utah Engineering Experiment Station Bulletins published by the University of Utah (Jenike 1954d, 1958, 1961, 1964). Other relevant publications are quoted in the bibliography (Jenike 1954a to 1955d). Jenike, in his earlier works, bases his theories on the soil mechanics approach, using a rigid plastic solid using quasi-static equilibrium equations in conjunction with Mohr-Coulomb yield criteria. His later work uses the plasticity approach of obtaining the stress field independently, by neglecting the convective and time dependent terms. Thus the velocity and stress fields are uncoupled and the velocity field may be calculated by the continuity equation, assuming that the principal stress and the strain-rate coincide. The extension of these theories by Savage (1965), using a coupled velocity stress field, and the alternative minimum energy rate theories of Brown (1961) and co-worker Richards (Brown and Richards 1960) give an alternative approach. Wilson (1957) gives useful operating data for belt feeders or hoppers, which are similar to belt conveyors. To use these methods, one would have to assume that the group of parcels on the conveyor would be a continuum, that is a rigid plastic solid on the belt. This is a much safer assumption for powder materials, than parcels, but Jenike had suggested in his papers that the theories would apply to particulate mineral materials up to six inches in diameter.

When this was discussed with Jenike (1970) he did not feel that the extension of his and similar theories to parcels flowing on conveyor belts was possible. The essence of his assumptions was that a continuum existed on the conveyor and he felt that the parcels would always be too few in number to achieve this condition. Since most of the theories of this type follow the reasoning of Kvapil (1959) that there is an ellipsoid of motion, which becomes eccentric, it follows that if there is no continuum,no theory of this type will be valid. Accordingly this line of research was not pursued any further.

2.4.2 Finite Element Techniques

A second line of approach would be to use the finite element approach of Zienkiewicz (1971) and others. In the Brunel University Mechanical Engineering Department, work on this and similar methods is being carried out by Yettram (1971) for various stress analysis problems and by Wright (1974), and programmes written and developed by them could have been made available. However, in the application being considered, the use of these programmes would have required the complete core store of the Brunel ICL 1903 configuration for excessively long run times. Even then only a very modest number of parcels (elements) could have been evaluated. This applied also to other finite element packages such as the NEWPAC (Aggeman Prempeh and Patel 1971) and the PAFEC 70 (Henshall 1971, 1973) both of which have been fully assessed by the Mechanical Engineering Department, and the former bought by them and set up for use on the Brunel ICL 1903. A further problem to be met in using finite element methods to represent parcels and calculate forces is that if, for example, three-dimensional orthotropic elements are being considered, then values of Young's modulus and Poisson's ratio are required for three principal orthotropic directions. Some tests were put in hand to obtain values for these, and it was found that a constant load-deflection relation was obtained with the majority of parcels. This was not the whole answer, since the values obtained for the Modulus of Elasticity varied with the orientation by two or three orders, (i.e. up to a 1000:1 ratio). It became obvious that the structure of the parcel might be nearer to a thin walled box than a solid cube, and due to this, very wide variations occurred. However, it was felt that this line of research, while interesting, might prove to be very intractable, and was not in the nature of being a small part of a larger project. Accordingly it was put to one side as a topic for further work.

Finally a system was devised for considering the model as a rigid linked structure of three-point contacts, and the forces were resolved through the resulting three-dimensional structure to the base and sidewalls as explained in Chapter 5, Section 5.4. (See page 127)

3.0 THEORETICAL CONSIDERATIONS

3.1 DEVELOPMENT OF THE MODEL

The project began with the systems analysis of various simple two-dimensional models which located parcels, loading them in a systematic packing. As the system became more fully defined, it became apparent that two-dimensional models would be so inaccurate as to be unattractive. On the other hand, through studying the simple models in depth, it became obvious that the difficulties in creating a simulation model in three-dimensions that would run on the Brunel 1900 configuration, were less than had been supposed. A number of systems were considered, and the best of these chosen for programme development. The two models were the "Flat-Load" (FL) and the "Tilt-Load" (TL) series. The FL series loaded the parcels parallel to the belt or base (orthogonal), which although not a realistic model of a belt conveyor, could well simulate the container system proposed by the Post Office as a possible new parcel traffic system (General Post Office 1969). The TL series loaded parcels in tilted attitudes, and around 200 systems were tried and developed before achieving the final model. The TL series was helped considerably by using modules from the FL programme and this enabled development to be concentrated on creating a model which closely simulated the packing of parcels in a conveyor.

An assessment was made to analyse the problem. The following sections describe how this was done. A modular structure was created, with three major divisions, as shown in Figure 3.1. They were (a) loading the parcels, (b) resolving and calculating the forces on base and sidewalls, and finally (c) evaluating the friction forces to see if jamming would occur. (See page 345)

3.2 BASIC SPECIFICATION

This section examines the development of a family of mathematical models, to enable predictions to be made of the behaviour of the various conveying methods for parcels in the Post Office establishments, both existing and projected. It is important to appreciate that a method of examining the problem in modules, step by step, produces difficulties in modelling. This is due to the interaction, resulting from the output distribution of one unit, being the input distribution of the next. This either complicates the mathematics of the theory, or falsifies the assumption that the input distribution is a form which makes the equations simple. This difficulty has resulted in the use of Monte Carlo simulation techniques by some of the workers in the field. Whichever approach is used, either that of an analytical queueing model or Monte Carlo simulation, it is apparent that thorough testing of the model is essential, to see if simplifying assumptions are justified.

These problems are an important part of any academic consideration of conveyor belt modelling, yet it is essential to keep firmly in mind that the real purpose of a model is to derive information which predicts the effect of changes of operating condition on the behaviour of the system. It also follows that the criteria for choosing the optimum model, will be those which produce the "best solution" from the practical point of view. This would suggest that a set of simple assumptions, producing a simple model, would be the best starting point. Such a model could then be tested for validity and a heuristic procedure adopted, which seeks improved solutions, until the optimum was achieved. This would give acceptable results more rapidly. This could be said to be an "engineering approach". The alternative would be protracted analysis to derive a more acceptable model until a complex model was finally arrived at - an "academic approach". Since the "engineering approach" will always be directed to the computational facilities available, it will not be so likely to run into problems of finding a computer large enough to handle the problem.

The need to establish the degree of accuracy of the prediction is important, since the object of this study is to produce a computer model, which predicts jamming. The model need only represent the real world well enough to produce accurate predictions, without wasting money and resources in unnecessary detail. The basic assumptions presume a stable state in the system, i.e. that conditions remain the same over long periods of time. This is not exactly true. The errors caused by this assumption may be more than variations between a simple and a complex model, since the conditions for a jam forming,are of low probability. A simple model could give results which vary by a factor of two compared with a complex model. This would mean that one might predict a jam once in three months, and the other once in six months. These predictions are probably acceptable from the practical point of view and regarded as being of the same order of magnitude.

The choice must be made between models of varying complexity. The production of a complex general model, after lengthy analysis, is one approach. It involves considerable analytical computation and verification, and needs very large computational facilities. The alternative is to produce a series of models, starting from the simplest, using a common computer language, a modular structure and common subroutines. This would be developed into a general model.

A logical method of approach is to synthesise the model and define the input data. This would suggest limiting constraints for each of the parameters, and indicate where measurements to provide data are required. There is still the question to be established of whether the jams are caused by "bridging of parcels" as shown in Figure 3.2, or alternatively by occasional juxtapositions of the mass of parcels loaded into the conveyor section. (See page 345)

3.3 MODEL SYNTHESIS

3.3.1 Conditions for Jamming

The basis for the model is the assumption that a jam will occur when the forces on a parcel or a group of parcels which tend to move the parcel along (belt-parcel frictional forces) become less than the forces which tend to make the parcel or group of parcels static (forces due to friction of the parcels to the walls, together with the reaction components when parcels change direction, and the inertia force component at a change of direction). (See Fig 3.3, p 346) Some probabilistic estimation of the nature of the parcels present at that point will also be necessary, since the parcel distribution will vary from time to time on the belt.

Mathematically we may say, summing forces along an axis:-

1. For a jam to occur:

$$\overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{BP} N_i < \overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{WP} B_i + \overset{n}{\underset{i=1}{\Sigma_x}} \frac{W_i}{G} A_i + \overset{n}{\underset{i=1}{\Sigma_x}} R_i$$

2. For a jam to be incipient, that is for momentary stoppages to occur, which are then immediately cleared by following parcels:

$$\overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{BP} N_i = \overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{WP} B_i + \overset{n}{\underset{i=1}{\Sigma_x}} \frac{W_i}{G} A_i + \overset{n}{\underset{i=1}{\Sigma_x}} R_i$$

3. For normal traction to occur:

$$\overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{BP} N_i > \overset{n}{\underset{i=1}{\Sigma_x}} \mu_i^{WP} B_i + \overset{n}{\underset{i=1}{\Sigma_x}} \frac{W_i}{G} A_i + \overset{n}{\underset{i=1}{\Sigma_x}} R_i$$

Where:

μ_i^{BP} = the coefficient of friction of the ith parcel to the belt.

N_i = the normal force of the ith parcel to the belt.

$\sum_{i=1}^{n}{}_{x}$ = the sum of the given force for parcels 1 to n, at point X. i = the species of the parcel.

n = the total number of parcels in the distribution at point X.

μ_i^{WP} = the frictional coefficient of the ith parcel to the wall at X.

B_i = the sidewall force exerted due to bridging at X.

W_i = the weight of the ith parcel.

G = the acceleration due to gravity.

A_i = the acceleration of the ith parcel due to directional change.

R_i = the force due to the deflecting surface when changing direction.

The problem resolves into the solution of the conditions at a number of points on the belt and determining the number of cases in the total number of solutions where a jam has been predicted. This is then the probability that the model has a jam in the projected time period. How true this is, when related to the actual system, is open to testing. The main areas of test will be the basic assumptions; the bias of the data fed in to represent service and input, and the rate at which the solutions converge (how rapidly the computer arrives at a solution).

The actual data required to be specified for the model would fall into four main categories:

1. A classification of the parcel population into groups.
2. Deterministic data on the frictional coefficients of the above groups on both belt and wall materials; probably obtained from tests of samples from the group.
3. Data from the "real world" for the probabilistic analysis of the distribution of parcels on the belt. This would be for both the arrival (or input) and also the service (or output) rates from the various systems to be considered. Timing of "shop floor" operations is always regarded with suspicion by the operatives and Trade Union officials, and this would need to be done with consultation and a clear understanding of the purpose of any measurements.
4. Data which defines how parcels will move, subsequent to the initial positioning in the conveyor. They are not likely to adopt random positions (a simplifying assumption) but rather to have a probability of migrating in a series of random or stochastic movements upward or downward according to their parcel densities. This can be handled mathematically by random walk or Markov Chain analysis and the use of probability matrices, but it requires large computational facilities and leads to complex models. It is probable that this effect is too serious to be neglected, since these movements bias the frictional coefficients of certain dense parcels. Owing to the difficulty in modelling these movements, a heuristic method was used in the model, rather than the Markov approach.

Each of these four groups of data is considered in greater detail in the next few pages. The consideration of each part of the information supplied to the model, must be carried out on a basis of whether the contribution it makes, will give a significant change in the accuracy of prediction of the model, for the author found that some changes in input condition made no change to the model. Similarly, with the assumptions made, if these are so general that the model becomes too unrepresentative to be of value, then there is no gain.

Obtaining the information, to only the degree of accuracy required for modelling, is vital, as is minimising the cost of computing time by more efficient programming. Once again, since less data is required, a simple model is recommended.

3.3.2 The Conveyor as a Queueing Model

Considerable research into the use of computer simulations based upon queueing models has been carried out at the University in the Department of Production Technology and Production Management. This work provided a methodology for postgraduate studies under the author's supervision. A variable discrete time interval simulation model was used for the "Cabtrack" urban transportation system by Haddon (1971), where a number of different input distributions were generated by probabilistic techniques. The fixed time clock model of the jobbing shop produced by Wan (1971) was developed by him into a variable time system, and then extended by Lopez (1972). A most comprehensive model comparing NC and jobbing shops was produced by Liu (1974). In spite of the studies on queueing techniques, it was decided not to use a computer simulation model having a queueing representation and a variable input flow pattern. A queueing model was unnecessary since the occurrence of jams was one of the main concerns. The simulation would model a condition where the arrivals would always fill the conveyor section and the maximum probability of demand would then result. To make this simulation a queueing model would increase the size and complexity considerably. The computing times would be extended, since the jamming condition for a straight conveyor is rare, even when all simulated tests are of congested systems. The research on variable flow input was applied to the simulation of various methods of manufacture, and has been and will be published elsewhere. (See, for example, Rourke and Liu 1974). The analysis has some merit, and is a basis for further work in other areas. A conventional classification considers three main areas for this data:-

1. The Input Process.
2. Queue Discipline.
3. The Service Mechanism.

Each of these areas will further subdivide into sub-areas. For a large number of systems, queueing theory has been developed. Sometimes the parameters are not capable of changes without making the model very complex, and so-called simplifying assumptions must be made. Testing of the model will establish whether making these assumptions can be supported or not.

The question of whether a simplifying assumption may be made or not, should be decided in this case on the degree of error it introduces into the assessment, not whether this method or that is more theoretically correct. Palm's problem, which was noted at the beginning of this century (reviewed in Palm 1957) was not capable of being supported mathematically, as was pointed out by Khintchine (1960). This did not invalidate Palm's approach nor the solutions it gave. On the other hand, Beightler and Crisp (1968) derived a policy of operation which they claimed superior to any previously published, using as a basic assumption that a Bernoulli distribution controlled the input. In other simulation tests, Crisp, Skeith and Barnes (1969) found that this basic assumption of a Bernoulli distribution was insupportable. If the model is derived analytically any hypotheses made must be tested as soon as possible, to validate the assumptions.

The Input Process

This again subdivides into a number of parameters, most of these being determined by the particular conveyor system. Once defined they will remain unchanged, providing the system itself only changes in terms of rate of arrival of parcels or rate of service, i.e. transmission or output of parcels. The parcel populations, from the various offices, are so large that they can be regarded as infinite. Removing a test sample to provide a model input would not change the population to any significant extent.

The main parameters, which would be changed for each conveying system when required, are four in total:

1. Number of Parcels Arriving at a Time

   Parcels may arrive singly or in batches of variable number. Sometimes a batch arrives as a single unit, such as bagged parcels.

2. Interval Between Arrivals

   The inter-arrival time may be constant, as in the unit load, hook-type conveyor. Alternatively it may vary at random, as on a belt. There are also many other distributions. The type of distribution is important, subject only to the more important consideration that a given conveyor situation is analogous to queueing. The parcels are assumed to arrive at random, unless the parcel input differs widely. This occurs if parcels arrive on a belt conveyor, on which they have been redistributed by a density effect. The simplifying assumption is usually that the Poisson distribution represents the arrivals. This means that well known, fairly simple formulae, may be used to produce symbolic models. These could be applied to predict those jams which are associated with excessive parcel flows. The probability of a critical number of parcels flowing through the system could be calculated, since a well established body of records is readily available. However, when systems comprise a collection of sub-systems, such that the output of one part is the input of the next, then the input distribution is no longer Poisson, and other distributions should be assumed. The mathematical analysis is then more complex.

3. Average Rate of Arrival

   The rate of arrival may be constant or it could vary with time. If the system is completely jammed, then it could be influenced by the state of the queue.

4. Outside Influence

   This is whether the input is, or is not, the output of another queue.

The Queue

The number of input channels or feeder conveyors, or whether any of the queue of parcels have priority, are both significant factors. The queue may even re-arrange itself. The model includes also the migration of dense parcels considered under 3.4, and other characteristics of the queue.

Examples of the normal parameters are:

1. Number of Queues (conveyor section changes or turns)

   There may be one, but much more likely to be a large number, each requiring a variation of the model. Any accumulation of parcels is a queue, whether moving along the belt, or on a glacis. Sometimes the service and the exit points are difficult to define.

2. Queue Handling

Parcels may be serviced strictly in order of arrival (FIFO or first in, first out). The random placement model does this and models a concentrator. The moving belt model has a queue discipline based upon the number of parcels in the conveyor. Other models would be required for systems for the handling of registered mail. It is not likely that either the completely random queue, or last in, first out, (LIFO) will need models, but such patterns occur in parcels handling.

3. The Service Mechanism

Here, the use of the term "service" is very wide. It may be applied to specific and easily defined cases, such as the removal of bags at a chute exit, or the passage of parcels through the parcel sorting machine (PSM) gate. "Service" could be also the degree of restriction of parcel flow due to friction at points where jamming may occur. When the number of contact points causing friction is the service, as in the model, it is a function of the height of the distribution on the belt, and the lengths and shape factor of the parcels to be found in the distribution. This effect increases with the intensity of parcel flow, so the service rate or output is reduced. The number of parcels on the conveyor increases, and so friction forces on the sidewall increase. This makes a jam more likely.

Thus, the input rate reaches the point where retarding forces increase significantly. This is because the effect of an additional parcel is relative to the volume of the parcel, compared to the volume of the conveyor which is not filled with parcels. The more parcels a conveyor contains, the more significant an additional parcel, since it is more likely to increase contact with the sidewalls and form "bridges". The probability of certain groups of parcels coming into contact is also increased. Thus the probability of a jam due to this cause also increases. The model operates at flow rates above this level, at which jamming is more likely. The physical characteristics of the system provides the data from which the service rate is obtained, as well as the service time distribution. A model type code, and simple data on sizes, rate of travel and similar parameters which define the service, will select the appropriate computer model, through the steering module of the programme.

The actual subdivision of the service parameters is:

1. Number of Service Outlets (especially "L-turns" and section changes)

   The number of conveyors in use may change according to a time pattern or the numbers of parcels flowing.

2. Number Served

   These may be one parcel at a time; or batches of constant number; or variable numbers. For example, the handling of mailbags at the bottom of a chute serves batches of parcels in one or two "parcel bags" at a time. The Parcels Sorting Machine (PSM) handles only single items.

3. Service Availability

   This may be permanent or intermittent, as for example in the dual PSM lines. In these machines only one service is used for normal conditions.

4. Duration of Time of Service

   This can be constant, as for example, the discharge of a unit-load conveyor into a chute; or exponentially distributed as in handling of mail bags from a chute or mail van. The time of service will depend on the physical position of the bag, which will vary from the shortest times for the nearest bags to the longest times for the bags which are most remote. Although the time is likely to be normally distributed, it will change cyclically during the unloading of each van load of parcels or batch on the floor at the chute exit. There are also other related but even more complex distributions. Those which depend upon the time the parcel (customer) has been on the storage glacis (in the queue), will affect the speed at which the postal operative will handle the parcel.

5. Average Rate of Service

   This is considered to be constant, which is a simplifying assumption which is often made. Other possibilities are that the rate varies with time; or the rate may vary with the number of parcels in the system.

It is important to establish these parameters in an analytical model, since they establish which equations must be used for the model. Queueing theory, as was mentioned in the review of the paper by Pritsker (1966), is quite capable of giving the necessary equations for the models required. Simplifying assumptions may have to be made, to reduce the costs of obtaining data, for example. These service parameters would be defined for the type of conveyor selected for initial study, noting any assumptions made.

3.3.3 Stochastic Movement on the Belt

As mentioned previously, consideration must be given to the choice of a model which is either static or dynamic, as far as parcel movements are concerned. The dynamic model would assume the relative position of the parcels on the belt, one to another, would be subject to stochastic movement, and would make a "random walk" according to the probability of motion along one route or another. The "random walk" or Markov Chain analysis, would make the model more complicated, and would not be justified initially. Adjustment to the queue would provide a compromise method, and was used in one model, the "moving belt" version. Tests of this model showed this was sufficient to achieve a simulation of the belt conveyor. For hook type conveyors and chutes this problem does not arise since FIFO operation will occur.

3.3.4 Project Development

The articles reviewed showed that two main approaches have been made to the solution of conveying problems, namely simulation or analytical. Both of these involve considerable computation, and thorough testing of the models is suggested by the authors. Both methods have their protagonists, and either would seem to be suitable at first sight. A simulation is a complicated operation, whereas an analytical approach could be made more simply on a chosen handling problem, such as elements of a system, such as a transfer belt or a chute. Since the problem of jamming requires a simulation approach to give satisfactory predictions, a simple area of "real world" to study is best. Accordingly a simple straight conveyor section was chosen for this study.

It is doubtful whether a general approach, (that is, in the mathematical sense, one which handles any type of problem) could be considered as the optimum from the cost effectiveness point of view. Much time would be wasted in a general model on areas where no practical system existed.

The following order was a practical one, based on the PIER technique previously mentioned:

1. Plan a simple model system of a conveyor which lends itself to easy analysis, and yet typifies a "real world" situation. The model is to be prepared in a modular form, which would enable it to form part of a general system, by all computer programmes and data being prepared for a medium or large size computer in segments.
2. Implement, i.e. create model, module by module, evaluating and revising each module in turn.
3. Evaluate this model for validity of assumptions and solutions.
4. Revise this model as required to achieve better representation. Consider the specific application with a view to making the model more general and of wider application.
5. Revise the original plan to achieve a more sophisticated model system. Produce a detailed plan which shows the revisions required to each module and what additional modules are required.
6. Implement the changes to the modules. The advantage of modular construction is that the more rigid definition of conventions in programming make it easy to change the module or to write a new module. Ideally only small changes will be required (usually called maintenance programming), and this is much easier and less prone to error. Modular programming reduces the time spent in checking the revised programmes, since only the modules involved in the change need to be tested.
7. Evaluate the new model on the same basis as before, making comparative assessments.
8. Revise the model until it is fully representative, and as general as is required for all typical conveyor and handling "real world" situations.
9. Repeat process of steps 5 to 8 as required.

The flowchart shown in Fig. 3.4 shows the application of this method. An extension of the technique to producing an outline for the computer simulation model of a straight conveyor, on which the present project was based, is shown in Fig. 3.5. (See pages 347 & 348)

3.4 THE DATA INPUT FOR THE MODEL

3.4.1 Classification into Groups

The parcels should be classified into groups of offices of related characteristics to reduce the computation required. The work of Castellano, Clinch and Vick (1971) is useful here, and further data may be obtained. Economic considerations will determine how many groups are allowed.

One of the problems in entering the data, is that the information consists of a number of groups, which can be thought of as the number of rows in a matrix. (See Fig. 3.6.) (page 349) For each of the groups there will be a number of elements and factors of related information, such as friction coefficients, the probability of finding a parcel from the group in the input sample selected, the mean weight of parcels in the group, size factors, factors for the percentage of parcels in a group likely to be tied with string, factors on the probability that the sample will be subjected to movement in the distribution, and other factors. This results in a matrix of more than thirty columns by the number of group rows. If the number of groups was arbitrarily restricted to 250 then a 5 k store is required for the holding of the general input data alone, without even entering any information on the conveyor system.

As an initial estimation, the following statistical information would be necessary, but obviously the accuracy of the data would depend upon model needs and economic factors.

Volume of the Group $\bar{V}$

An arithmetic mean and standard deviation for the group would be an initial choice.

Mean = $\bar{V}$ Standard Deviation = V_{SD}

$$\bar{V} = \sum_{i=1}^{n} \frac{V_i}{n} \qquad \& \qquad V_{SD} = \sqrt{\sum_{i=1}^{n} \frac{(V_i - \bar{V})^2}{n}}$$

where V_i = volume of the ith parcel = $L_i \times B_i \times H_i$

and i = 1, ..., n and $n > 30$

L_i = maximum length of the ith parcel

B_i = maximum breadth of the ith parcel

H_i = maximum height of the ith parcel

The Shape Factor S_V

The calculation of a deviation in parcel shape would offer a useful contribution, in some non-dimensional form, as a measure of the deviation of the shape from a cube. It was felt that a measure of the length of the linear dimensions compared to the length of a cube would give a representative factor. The mathematical form chosen was one which would be non-dimensional and similar to those used in materials testing.

This expression was derived from the extent to which the linear dimensions of a parcel differ from a cube:

$$S_V = \frac{\displaystyle\sum_{i=1}^{n} \frac{L_i + B_i + H_i}{3n} - \sqrt[3]{\bar{V}}}{\sqrt[3]{\bar{V}}}$$

A high value of S_V would indicate longer, thinner parcels, and one which tended to zero would indicate the parcels were virtually cubes.

Let us consider an example. For simplicity let it be a cube of 4 units dimensions and of volume 4 x 4 x 4 = 64 units^3. For the cube itself, S_V may be calculated thus:

$$\underset{(4 \times 4 \times 4)}{S_V} = \frac{\dfrac{4 + 4 + 4}{3} - 4}{4} = 0$$

and the surface area A = 96 units^2.

If the shape changes such that the shape is 8 x 8 x 1, i.e. still 64 volume units, then

$$\underset{(8 \times 8 \times 1)}{S_V} = \frac{\dfrac{8 + 8 + 1}{3} - 4}{4} = 0.416$$

This form is a plate. The surface area is A = 160 units^2.

If we rearrange this volume to an 8 unit long rod i.e. maintaining the maximum dimension, we get

$$\underset{(8 \times 2.828 \times 2.828)}{S_V} = \frac{\dfrac{8 + 2.828 + 2.828}{3} - 4}{4} = 0.138$$

A = 106 area units, which shows how S_V changes with shape.

A more complete demonstration of the effects of change in shape on S_V is shown in the table 3.7. (See page 350)

It will be noted how the rod-like shapes with high values of length give the higher values of S_V. The S_V is a very useful measure, since it shows up those parcels likely to cause jams by wedging across the conveyor section.

The Mean Weight of the Parcels in the Group

$$\overline{W} = \sum_{i=1}^{n} \frac{W_i}{n} \qquad W_{SD} = \sqrt{\sum_{i=1}^{n} \frac{(W_i - \overline{W})^2}{n}}$$

W_{SD} = Standard Deviation in weight of parcels in group

$\overline{W}$ = mean weight of parcels in that group

W_i = weight of the individual parcels in the group

n = the number of parcels in the group

It would become necessary to use sampling techniques for this information if the parcels in the group became large. The information on volume and weight enables other derived information to be calculated, for example mean density.

The Stability Factor S_{CG}

This compares the position of the centre of gravity to the centre of volume, on the same sort of non-dimensional basis as the Shape Factor. This tends to one as the centre of gravity approaches the centroid of the enclosing shape. To calculate this factor, a number of determinations for a sample of parcels from the group is taken, to find the centre of gravity as the distance along three mutually perpendicular axes, which are the orthogonal axes of the enclosing shape, from an origin in one corner. The dimensions of the parcel must also be known, in terms of the same three axes. The expression below will produce the stability factor, as a mean of the deviation of the centres of gravity for the sample, which can then be taken as being the same as the total population.

$$S_{CG} = \sqrt{\frac{\left(\frac{\sum_{i=1}^{n} I_{CGL_i}}{n}\right)^2 + \left(\frac{\sum_{i=1}^{n} J_{CGB_i}}{n}\right)^2 + \left(\frac{\sum_{i=1}^{n} K_{CGH_i}}{n}\right)^2}{\left(\frac{\sum_{i=1}^{n} I_{L_i}}{2n}\right)^2 + \left(\frac{\sum_{i=1}^{n} J_{B_i}}{2n}\right)^2 + \left(\frac{\sum_{i=1}^{n} K_{H_i}}{2n}\right)^2}}$$

$$\left.\begin{array}{l} I_{CGL_i} \\ J_{CGB_i} \\ K_{CGH_i} \end{array}\right\}$$ = the orthogonal co-ordinates of the centre of gravity for the ith parcel along the I, J, K, axes.

$$\left.\begin{array}{l} I_{L_i} \\ J_{B_i} \\ K_{H_i} \end{array}\right\}$$ = the dimensions of the ith parcel, measured along the I, J, K, axes.

i = 1, ..., n

The shape factor S_V detects variations in section, especially when the parcel is long and thin. The stability factor S_{CG} detects displacement of the centre of the mass of the parcel away from the centroid or geometrical centre. Together, the two factors will take into account variations in shape, and variations in homogeneity, that is variations in the density of a parcel. This enables distinctions to be made between long thin parcels of uniform density, and long thin parcels where it is concentrated at one end.

Such classifications and groupings should enable the computer to generate a representative model of the parcels in the system. The accuracy will be limited by the correctness of the assumption that like members of a group are really similar. Overall, the more groups one may consider, the more representative the model. Since the larger the number of groups, the more complex the computation, the point is eventually reached where the cost of modelling to evaluate jamming could be more costly than the loss of time due to jamming, and possibly more costly than direct measurement over a long period of time.

At this point, it should be borne in mind that the point made previously, that it will be much more economic to model a simple system and develop this to a more general system, than to produce a very complex model, which would require many years to evaluate and rectify.

3.4.2 Frictional Coefficients

Once the parcel groupings have been determined, the coefficient of friction of each group could be based on test values of various wall and belt surfaces. The work of Eden (1971) based on sliding small samples on a rotating disc, gives values of most parcel/conveyor frictional coefficients. Webber (1972) outlines a method for relating the frictional coefficient of belt materials to values found by experiments with a simple slider, and also a belt and pulley. He shows a graph which indicates that SBR synthetic rubber gives a friction coefficient which depends on area and not pressure. The value of μ ranges from under 0.5 with contact areas around 250 mm^2, to above 1.4 with 2000 mm^2, and levels falling gently to around 1.2 with as much as 12000 mm^2 contact area.

An important related factor is whether there is a high proportion of strung parcels in the groups. While a simple proportionate factor could be introduced, it is probable that the effects of stringing on the sample parcels on the group would affect the apparent coefficient of friction. Obviously, if most were strung or alternatively, unstrung, the effect of the smaller proportion of the group could be easily adjusted by a factor. If tests showed that string presented a major change in frictional characteristics, especially if the wall or belt surface included slight changes such as are encountered at joints in walls and belts, then this must be catered for by making two sub-groups of the parcels group, with different data for friction on the sub-groups.

3.5 IDEALISED SPHERICAL PARCELS

One approach which would enable the theories of R. L. Brown (1961), Jenike (1954) or Savage (1965) to be utilised would be to make the simplifying assumption that all parcels were hard spheres, and use the methods of the materials scientists such as Denton (1953). This is the concept of the idealised spherical parcel. While the statistical analysis would be relatively easy, and the data is available (Castellano, Clinch and Vick 1971), it is unlikely that the results would apply in the "real world" to anything other than the flow of spheres of varying size. Accordingly, although this theoretical approach was considered as a system, from which originated the final method of placement of parcels on three points based on the ideas used in the spherical model system, the sphere model was never taken as far as coding a programme to run on the computer. It served to focus attention on whether a generalised approach to the various parameters was possible, or whether each parcel should carry its own record of friction coefficients, size, weight, shape and compliance. It was decided that generalised data would invalidate the model to a large extent, and vastly reduce confidence in the model predictions. Accordingly, the final decision on whether to continue with a spherical model,was left until the first stage of completion was reached with the model which used actual parcel data, and packings of parcels could then be compared with the values given by Denton (1953),which were that approximately 40% of the volume of the container consisted of spheres. These values were extremely consistent. The computer model based on individual real parcels never showed a consistent packing density and neither did the validation trial. The values varied over a wide range. The results are discussed in Chapter 7. (See pages 152 and following)

4.0 THE PRINCIPLES OF THE CONVEYOR MODEL

4.1 THE "REAL WORLD" SYSTEM SURVEY

An initial survey was carried out of a PO parcels office, with the co-operation of the PO Engineering Department. They were kind enough to provide assistance in obtaining photographs of the conveyor system, which were taken by available light, using a Polaroid camera. The quality of these has suffered somewhat in reproduction but they serve to illustrate the points of the system where conditions change. (See pages 351 to 353)

The first illustrates the unit conveyor which is used to transport the mail bags from the van to the belt conveyor system, (Fig. 4.1). The bag strings are cut, the openings being downwards, and the load disgorges onto the eight foot wide conveyor, moving very slowly, (Fig. 4.2). This then transfers the parcels to a faster moving belt conveyor about three feet wide, (Fig. 4.3). Owing to the confined nature of this particular office, there is immediately an "L-turn" and the parcels transfer to another, slightly faster moving conveyor at 90^{o} to the first. This is almost visible in the foreground of the picture, the end of the first belt being clearly visible, with parcels dropping onto the second belt. The end of this is also visible, with part of the drop to the third belt, but the third belt itself is obscured by the sidewall. This third belt lifts the parcels to two glacis above parcel sorting machines (PSM), the parcels being deflected by boards which are visible in Fig. 4.4, one partially, and one completely, closing the forward path. Fig. 4.5 shows the congestion which can occur on the glacis, with the parcels still widely spaced on the belt above. Fig. 4.6, taken a little while later, shows how a jam on the belt forms with very little piling up, the parcels merely being shunted together.

Accordingly, the model represents the belt conveyors found in fig 4.3. (Page 352) While the model loading would be a module which would be preserved in both models, two forms of parcel positioning would be required. One would typify the parcels dropping at random over an area onto the first conveyor, while the second would represent the conveyor moving rapidly under parcels dropping at a fixed point.

The physical size, modelled by the conveyor, should cover a range of widths from around two to six feet, and heights of up to six feet, with a length sufficient to minimise the effects of the ends. The abnormal height was necessary to enable modelling of containers, in future extensions of the model, at the request of PO engineers. Since the computer available at that time was small, it was hoped that it would model a section that was sufficiently long to give a fair representation, which would allow parcels some overlap at the ends of the system under consideration. The original 32 k 1903A ICL machine, with only two systems discs and four tape decks, which was used for the initial model, proved very limiting. Fortunately the ICL 1903A was enhanced about half way through the project, which improved the model considerably.

The initial systems study for a simple model was carried out. It was intended only as a test to enable systems to be developed, with the use of modular programming techniques. The model was a stochastic simulation of parcel placement in the conveyor, using deterministic parcel data. Standardised queueing forms were not considered at this time, although it would be easy to add a simple module to test varying rates of flow of parcels. It was felt that jamming was much more likely to occur under heavily congested conditions. The model was therefore tested under conditions of high flow rate, which are found only briefly during the week, and more commonly at seasons of heavy postal traffic such as Christmas.

The mathematical model was to be a combined mixture of deterministic theory for the forces and stresses generated by bridges and arches, and also a probabilistic model of contacts in the parcel distributions likely to be present in the section. The model would simplify the establishment of algorithms to calculate the stresses and forces. Two alternatives were envisaged, the first based on the idea of a continuum of parcels, with a complex shape to be handled by finite element techniques, which overcame the problems due to the voids between parcels. The second was to use the idea that forces would be transmitted through the parcels in the manner of a series of rigid links.

4.2 MODEL CHOICE

4.2.1 The Fundamentals of the System

Initially it was felt that only a simple model should be built. Even so, many of the decisions made were virtually irrevocable once the model was created. Therefore, in spite of careful systems evaluation, many revisions had to be made, mostly of a minor nature, with the exception of the major change from a two-dimensional model to a three-dimensional model. The two models differ widely, since the two-dimensional model was far less abstract and easy to create than the three-dimensional version and the two models did not have the same "image" in the computer memory of a parcel. The two-dimensional model portrayed the conveyor cross-section as a two-dimensional matrix. Each matrix location represented the point in space equivalent to its co-ordinates. If a parcel occupied an area of the conveyor cross-section, the matrix was set to "1" wherever the parcel existed. Empty space was represented by "0" (zero).

It was intended to use the assembly language "PLAN" and set the matrix representation in binary locations (bit-patterns) rather than the word locations used in FORTRAN. The computer storage needed to model a 36 x 40 in conveyor cross-section was 1440 words at one inch resolution, or 60 words if the "bit-pattern" technique was used. In two-dimensional models this is very effective. In extending the technique to three-dimensional models, two problems emerge. The first is that the programmes to handle the three-dimensional matrices are very tedious in assembly level languages, and are very lengthy. Secondly, the storage requirement rose dramatically. For a 36 x 40 in cross-section, 72in long, the storage at a one inch resolution is 103,680 words using FORTRAN. To this must be added storage of the programme. The alternative use of bit-pattern storage in binary form is more attractive at 4320 words, but means that the programming is tedious and complicated.

Accordingly, better methods were required for storage of the data on parcel geometry and location, using a high-level language to make the programming more simple. It was found that as research proceeded improved methods were devised for the storage of data giving parcel positions. One of these methods was that of the final three-dimensional model, where the co-ordinates of the parcel corners are stored in computer memory. Despite the major differences in model, there were areas where the original modules were used, such as the steering module.

4.2.2 Model Development

The method of creating the model was somewhat involved, and was an evolutionary process. An abstract model was conceived, with only the minimum written notation and recording in the first stage, any committal to paper as notes and drawings only being made as and when the whole concept had been thought out. Sometimes small areas which were familiar were left as vague, ill-defined concepts, since they could easily be defined in the later stages but, in general, the whole system was visualised in concept.

The next stage was to write down and sketch the conceptual system, in both "real world" implications and computer model implication. The concept was taken and as far as possible programmed without any alteration. At this stage much detail was filled in, and providing the systems concept could be preserved, the most efficient techniques for programming were applied. Sometimes there were considerable difficulties in maintaining the original system concept and a period of development would be spent on that particular module, until the computer programme scheme was as close to the abstract system concept as possible. This work was not as abstract as the first stage, since more documentation was involved. Certain areas of the systems specification had now to be defined or were perforce already defined at the interfaces between this and the preceding and successive modules.

The third stage was to complete a systems specification, which was fairly rigid, with a strong family resemblance in each module. Thus variable names were carried through from module to module, as were the more obvious elements such as exogeneous parameters, such as the switch for suppression of diagnostic information in the output. Once the systems specification was complete, as far as could be foreseen, then the programme was coded. At this stage there was as little reference as possible to the original abstract system, only the programme scheme being used as a basis. Sometimes it was not possible to avoid such consideration, especially if one lost sight of the exact objective of the portion of programme being coded, in relation to other parts of the system.

It is possible that a more expert programmer might have coded the abstract model directly, but the number of variables and parameters to be carried through the system was very high and it seems unlikely that the technique would have been successful without a systematic approach. The programme might well have been written in one large complex. The task of then debugging the coding errors would have been formidable, let alone tracing that the system was operating correctly and all errors found.

The use of a sophisticated language like FORTRAN IV might conceal the actual efficiency of operation of the programme. To test the efficiency of programme sub-routines, timings were taken of various programme techniques. Simple programme routines repeated many times were the basis of the mathematical model.

A ranking sub-routine was chosen for the initial trials. A number of versions of this developed. Tests proceeded as to the most rapid techniques. Since they were carried out on a small ICL 1900 series machine the FORTRAN IV language was translated into the machine language in the XFAT and subsequently the XFIV compilers. These trials were therefore dependent on the ICL configuration in use at the time. Any future extension to the finalised programme should involve testing the modules to validate that they are equally effective on other larger machines such as ATLAS or CDC 7600.

Six months was taken up in becoming familiar with FORTRAN programming. Previously the author had been programming in autocodes and ALGOL. On balance there was no particular advantage to either language, since both had their own special features.

The importance in this area of programming of using labels as a code rather than a sequence of numbers cannot be over-emphasised. FORTRAN, with five digits for the label, enabled label numbers to be allocated in blocks of 1000 to each module, 100 to each sub-module, and blocks of 10 to each programme piece. Using this method, it was easy to trace errors to the particular module which was giving trouble. Another advantage was that return labels (GO TO xxx) were easy to identify, since the return module, sub-module and programme piece were all encoded. The modular programming technique rarely involved constructing modules of over 300 statements, and sometimes only 25 or so statements would be involved. The need for rigidly enforced discipline was not apparent over label sequences at the time of coding a programme module. Once the module was assembled into the main programme, it was a very different story and after one or two early sequences had overlapped, or return label errors had been found which proved extremely tedious to correct, the practice of coding label sequences to a rigid system became a matter of habit.

Similarly, the simulation itself began to be created in a more and more systematic way as the project proceeded. The technique for this is shown in the flowchart in Fig. 4.7. (page 354) The method had advantages in introducing simulation to postgraduate students, who learnt the system as part of learning to programme in FORTRAN, and it has been shown on a number of occasions that it only takes about two months to reach a reasonable level of competence in the FORTRAN language for research project work for students, who had previously had typical undergraduate courses, either in FORTRAN or ALGOL. The method of project teaching using this systematic approach does not work with all students and it is probable that some minimum critical thinking level and high creative disposition is required from the student. The creative thought required to trace the errors in computer simulations, is minimised by modular programming and systematic building up from sub-systems into a large complex model. This is particularly true of non-fatal errors and to a lesser extent execution errors. In a small sub-system it is fairly easy to define what is required of the sub-system, and verify that it does that, by inserting test data and carrying out a comparison based upon manual calculation or simple computation. In the same way execution errors from small sub-systems are easier to analyse and rectify than for a complete system.

The model was a combination of a deterministic model of the forces on the parcel and conveyor and a stochastic placement of the parcels in the conveyor, using a random generator. The initial series of models used the sub-routine FRANUM (Fig. 4.17) (page 361) which was written for the programmes. There was a random number generator FPMCRV available on the 1900 system, but it was only rarely available, and to use it delayed the turnaround. After about two years of work the 1900 configuration was enhanced by the addition of extra disc stands, which meant the random number generator FPMCRV was always available if the scientific sub-routine group SRF7 was called. For details of this random number generator see ICL FORTRAN Compiler Libraries (ICL 1970b). A check was then carried out to find the quality of the two random generators. Since the numbers are pseudo-random, they will cycle (that is, to repeat the sequence) and this is undesirable until the string of numbers is at least a million numbers long. The seed itself is of importance since it must have enough digits, for example, to prevent the last few digits of the number beginning to cycle. This happens with certain combinations in the case of the FRANUM sub-routine, which although it is a modulo method (Meyer 1954) is not a good generator, since it also cycles every few hundred thousand numbers, has a poor poker test, and a slightly biased mean towards the low numbers. For a condensed introduction to this subject area see the Appendix 7 in Liu (1974). The ICL system generator FPMCRV is certainly superior, and had the CDC system been available, the longer computer word length of 60 bits for CDC against 24 for ICL, would have given even better random number generation.

The use of modular programming meant the specification of variable names had to be a meticulous operation, since they would be used in system models unforeseen at the time of specification. This was also true of the methods of matrix storage used in the model. In general very few subsequent changes of system were made. The only exception was in the method of storage of parcel contacts, which were called nodes. For ease of operation of the DO-loops, these had all been two-dimensional. As the final force calculation was programmed, it became obvious that for ease of coding, and to accurately reproduce the system, certain node storage matrices must be three-dimensional instead of two-dimensional. Accordingly, the change was made, and about fifty statements had to be rewritten to the new form.

The formalised method of using a system specification and programming in modules, typical of commercial programming, saved much time in the writing of the system. The use of FORTRAN IV, rather than a simulation language, was justified by the earlier completion of the project. If this project were being commenced now, with a much larger and faster memory available on the ICL 1903, it might be preferable to write the system in a simulation language, either CSL for 1900 (Buxton and Laski 1962) or GPSS for CDC (Gordon 1961, 1962). This was not possible during this project due to the need to have as much memory available for the programme. The use of the suitable simulation languages used up a large part of the memory available at that time.

Another difficulty is that this project system has the space, included in conveyor and parcel volumes, as the main variable, rather than time. It would therefore present many problems in the use of a simulation language, but might well avoid the need to make use of and understand the GEORGE 3 operating system, and so become machine independent.

The initial systems study and modular programme was written as a feasibility study. It established the input parameters, and was then used for checking the input data supplied by the Post Office. As the project progressed from the early runs on the computer, an understanding emerged of what was practicable for the final model. In the feasibility studies, it became apparent that some method of removing the probabilistic approach would be essential to avoid long computer runs. The "random placement" model was then proposed which filled the conveyor completely, since the jamming of parcel conveyors rather than their flow characteristics was under consideration. The feasibility studies indicated that jamming was not likely to occur very often, if at all, in the type of straight conveyor under consideration, except when caused by a configuration of unusual parcels, such as a parcel like a long cylinder propped into place by other irregular shaped parcels.

4.3 THE TWO-DIMENSIONAL MODEL

The first programming concepts had visualised the use of a "space lattice" of co-ordinates to define conveyor space, with some sort of binary switching based on PLAN programming. Tests of PLAN showed it to be tedious and time consuming for use in this manner, and the gain in the number of co-ordinate stores was still not enough to make this method attractive. However the method is feasible, since even if the addresses of the memory locations are deducted, there would be about 400,000 binary bits available to record the lattice points. The bit could be switched on for occupied lattice point, and off for unoccupied lattice point. The method was rejected due to the disadvantages of the unwieldy method of programming to record the parcel location, and the difficulties which would arise from having to write the programme in PLAN. This would be very tedious for the calculations of the location system, or require a mixture of segments, some in a sophisticated language and some in PLAN.

However, as a preliminary trial of the method, the system was taken to the programming level, i.e. from an abstract concept through to a programme specified but not coded in FORTRAN. This also was abandoned, since during the systems and programming work for this model, the idea was conceived of using an approach of just storing the corners and calculating the occupied space within bounds. This new approach did away completely with the lattice point model.

The rules for placement are relevant however, since they were the basis for the placement rules of the later models. They were based on the principle that a parcel could be either flat, that is orthogonally placed with respect to both base and sidewall; or tilted, which would rotate the parcel in the vertical plane; or diagonally rotated, which would turn the parcel in the horizontal plane, parallel to the belt of the conveyor.

4.3.1 Right Rectangular Placement

The base is regarded as the x-axis at y = 0, the sidewalls are the y-axis at x = 0 and x = max. Parcels are placed close to the origin, then to touch the x-axis until a layer is completed along the x-axis. Further layers are added, starting at the y-axis. This is shown in Fig. 4.8. Any gaps in the packing were assumed to be (See p.355) equivalent to the irregular gaps which would arise in a real conveyor, which was not likely to be very accurate. Packing of parcels would be terminated by a procedure which would reject a parcel after ten trial fits, the orientation of length, width and height being selected by Monte Carlo techniques before each placement. After rejecting twenty parcels in succession, the programme would cease and declare the conveyor full. Rejection would be based upon any parcel not fitting inside the conveyor section.

4.3.2 Tilted Placement

The parcel was placed as though it dropped through space into the conveyor. If it would rest stably it was placed parallel to the x-axis position as in 4.3.1. It was tilted to rest on other parcels when it was unstable or placed parallel to the x-axis if it was stable. No sliding or bounce was allowed. The rotation was in the vertical plane only, and a rectangular or square plane side was placed in the conveyor section. The corner of the parcel nearest the origin was positioned on a dropping point on the conveyor base. The dropping point was traversed in fixed intervals, from the origin across the conveyor, until the far sidewall was reached. The dropping point was then returned across the conveyor, starting again at the sidewall. This carried on, layer by layer, until the conveyor was full. Fig. 4.9 shows this arrangement. (See page 355)

4.3.3 Diagonally Rotated Placement

Parcels were rotated from the orthogonal position about a vertical axis at a random angle and then were "allowed to fall" by randomly selecting a point for the location of the parcel, which has been previously oriented about one corner. The parcel is parallel to the base. This greatly simplifies the computing, but the model is not very realistic. (See Fig. 4.10, page 356)

While the models were not coded, the lessons learnt in producing the concept of a system and a programme specification for the computer, were of considerable value in the first three-dimensional models. The breaking down of the random orientation of parcels in space, into orthogonal, tilted, or rotated positions was of value. It formed the basis of the final placement system, which used these subsystems to position the parcels in space. This lead to a new positioning system (see Section 4.7 and Fig. 5.9) which gave a flat parcel a
(Page 96 & page 370)
"plane up" (PLU) placement and a parcel with an edge upwards attitude a "line up" (LU) placement & developed by logical progression to a definition of a randomly oriented parcel as "point up" (PU). This considerably eased the geometry of the system.

4.4 THE THREE-DIMENSIONAL MODEL

Essentially there were five basic models. These were based on placing the cubes or rectangles which were taken as being typical of all parcels. To allow for compliance with soft and irregular parcels, the parcel data defined each parcel as being "soft", "regular", "irregular" or "cylindrical". This could have been a basis for the adjustment of the positioning and definition of the corner points. However, this was not used in the final models, although provision for this had been made. Tests showed this complication had little effect and increased computer times. Much larger variations in model performance, in terms of representing "real world" packing of parcels, was obtained by changing the representation of the attitude or position of the parcel in the packing.

The differences lay in the degree of complexity, firstly in positioning the parcel in the conveyor section, and secondly in the way that one parcel was positioned on one or more other parcels.

A useful analogy to understand the placement of parcels it to use a "shoe box" model. The axes of the three dimensions may be taken as j = length, i = width and k = height. Most interest is in the width and height plane in i and k, and if the axes are orthogonal the origin is now on the right-hand side. If the conveyor is regarded as a "shoe box" (Fig. 4.18) with the label facing you, then parcels could be
(Page 362)
regarded as a number of different "match boxes" to be placed within the shoe box. A point (dropping point) is chosen at random in the "shoe box" (conveyor), and the "match box" will then be held above the box so the "front right-hand corner", as it faces you, will lie over the dropping point. The "match box" (parcel) is held so that either length, breadth, or width, chosen randomly, will be facing you. The "match box" is now rotated clockwise by a random angle, and lowered

into the box. If it falls upon other "match boxes" it is tilted so that it will rest in a stable position on three points. This is an analogy of the model of parcel placement.

The five models were, respectively:

4.4.1 Close Packed Model

This was typical of hand packed containers and it was possible to obtain a fairly close correlation with data which was provided by the Post Office for hand packing such containers. Using the "shoe box" analogy, the parcels were packed in the conveyor section by locating the parcel "right-hand front corner" as close to the front of the section length and as close as possible to the "right-hand" sidewall, or previous parcel. This is shown in Figs. 4.11 and 4.12.(P.356&7) Packing proceeds row by row until the bottom layer is complete. The next layer is added, using the basis that the new parcel will rest horizontally, parallel to the base on the tallest parcel underneath it. Further layers were then added until the required cut-off height was reached in a similar way to the two-dimensional models. The values of packing density given by this model corresponded reasonably well with the figures obtained from the Post Office, so little adjustment of endogeneous parameters was made. The parcels always fitted inside the section and sidewalls. The major advantage given by the technique of storing only the cartesian co-ordinates of the parcels, on which this programme was based, was that there was no need to overlay the programme or to make use of backing store. This had been tried as a technique, but at that time the data and programme backing store was on magnetic tape, due to the limited disc capacity with only two disc stands, and transfer times were excessive. The model closely resembled the two-dimensional model, 4.3.1, and was developed from it. Obviously, in some cases such as the placement of parcel 11 in Fig. 4.12, (Page 357) the position of a parcel could not be stable, so the assumption was not particularly valid. However, it was a major step since it enabled a three-dimensional model to be programmed within the limits of the 1900 ICL configuration then available.

4.4.2 Close Packed Tilted Model

This model was based on the first three-dimensional model 4.4.1 and extended the model to represent the transfer conveyor, rather than a simple conveyor. This development assumed that parcels would rest parallel to the sidewall, as it would be much easier to add diagonal rotation in a further stage of development.

Hence, the parcels were loaded as in model 4.4.1 in plan, (see Fig. 4.11), (Page 356) but in side elevation some of the parcels were tilted, (see Fig. 4.13). (Page 357) If on locating a new parcel, it was found to be unstable when placing it on top of any underparcel so that it rested parallel to the base, then it was relocated in a stable, tilted position. This model was somewhat more complex to programme, but it managed to avoid any storage of space lattice points other than the cartesian co-ordinates of the corner points as in model 4.4.1. The arithmetic was much more involved and the time for a single fill of the section was around four minutes.

4.4.3 Diagonally Oriented Tilted Model

A point inside the conveyor section was chosen at random and the parcel corner was placed over it, as before. The parcel was rotated about the centre in the horizontal plane at a random angle. It now dropped until contact was achieved on the base (the conveyor belt) or on other parcels. If it had parcels underneath it tilted to rest. If it was stable then the process was repeated with another parcel, but if the parcel was unstable then this position was rejected and another attempt at loading was made with a new random position. This model is complicated, but rather less realistic than model 4.4.4, which is even more complex. (See Fig. 4.14. Page 358)

4.4.4 Diagonally Oriented Tilted with Sliding Model

In this model the procedure of 4.4.3 was followed, except that with tilted parcels a further test was made. If the angle of tilt was greater than 45° then the parcel slid across the lower parcels until it found a stable position on the lower parcels, or alternatively slid beyond them to fall again to a further position. This model was more realistic, in that it more closely represented the real world situation. In practice there was little difference between the two programmes, as far as packing density and loading parcels was concerned, except that the computer times for loading the conveyor section with the model, which included sliding, could be very much longer when the conveyor was tall.

The model which included sliding was regarded as being excessively complex, to apply to all parcels, and was applied only when the moving belt was to be modelled.

4.4.5 Diagonally Oriented Tilted Moving Belt Model

This model resembled the model 4.4.3 in that the parcel dropped randomly across the conveyor and randomly rotated. It differed in that the position along the belt progressed from the start of the conveyor section, at a rate determined exogeneously, until it reached the end of the section. The cut-off no longer operated on a basis of the parcels reaching the top of the sidewalls, but when the length of the conveyor section was traversed. Any parcels which were too high were "rolled" or slid along the section, in an upstream direction, until they were positioned in a stable manner. This gave an effective model of the action of a moving belt parcel conveyor.

4.5 FURTHER DEVELOPMENT OF THE TILTED MODELS

The development of the models was now concentrated upon the models 4.4.3 and 4.4.5 of the previous section. There were two main areas of development. The first area contained the modules which loaded the parcels into the conveyor section. The second contained the modules which calculated the forces in the parcels and also the base and sidewalls. This resulted in four models as there was a choice of two options in each of the two groups of modules. This is shown graphically in Fig. 4.15. (Page 359) The choice of A or B coupled with C or D gives the four alternative routes AC, AD, BC and BD. These are the four versions PMS 1 to 4. For ease of programme control the programmes were numbered TL 1 upwards, a new number being used whenever a major structural change was made, for example a new module which had a different system.

4.6 STORAGE METHODS

It became obvious at an early stage, that since the two-dimensional model was unsatisfactory, some special technique was required for three dimensions to store the model "space". If a "space lattice" was represented, then two states could exist as "occupied" or "empty". A binary bit could represent this "lattice point", by being set to 1 for "occupied" and 0 for "empty". The number of "lattice points" for even a small conveyor based upon, say, a 5 cm lattice unit, would greatly exceed the storage capacity of even the largest available computer, when the need for compilers, operating systems and programme was allowed for. The model could be programmed in PLAN and individual bits of the word set in a binary manner to represent a lattice point. This was discussed in section 4.3 but this was outside the scope of this research. (Page 86)

An early model had been tested with a system which was based upon the idea of storing the cartesian co-ordinates of the corners of the parcel. The matrix handling of FORTRAN was useful here. The programme had been developed as a two-dimensional model, and the extension into three dimensions merely required the change of the matrix variable suffixes from (i,j) to (i,j,k) and the altering of the loops to work through i, j and k dimensions by nesting. This was easier to do than it might appear. The penalty was that the storage was increased by nearly 50% and the computer run time greatly increased. This increase in time was due to the i,j loops of the original programme being run through once for every step in the k loop, rather than the increased complexity of the arithmetic. Using the FORTRAN language, the ease of programming was noteworthy, using cartesian co-ordinates for definition of parcels, base and sidewalls. The method was therefore chosen as the basis of the storage technique.

As it developed, it became obvious that there would be considerable gains to be made in the force calculation stages of the simulation, if use were made of the stored co-ordinates which were inherent in the programme. Two suitable techniques were eventually developed at a later stage. Initially, the finite element technique was tried, but this proved far too costly in computer storage and time. The simpler technique of the final programme was based on the author's simple rigid link model, which met the most important constraint. This was to create a simulation model acceptable to the Brunel ICL 1903A computer system. (See Fig. 4.16. Page 360)

To try to produce a programme to fit within the limits of the CDC 7600 SERU system would be a project in its own right, since the availability allowed for the larger type jobs (J 12) would prolong the research considerably. This programme was rated as J 12, or the largest size, because of the printout, which would be difficult to compress into a size small enough to obtain a rapid turn around. It would be possible to disc file the output and then produce programmes to interrogate the files, but this was considered to be more suited to future research using an on-line terminal.

4.7 POINT UP, LINE UP, PLANE UP PRINCIPLE (PU, LU, PLU)

It was also necessary to devise some system that would position parcels one upon another. Early models were very restrictive in their geometrical orientation in an attempt to simplify the computing requirements. These were dismissed as unrealistic. Finally a system was evolved which defined parcels as being in one of three mutually exclusive states of positioning. It was named the "point up, line up, plane up system". (PU, LU, PLU, see Fig. 5.9, Page 370)

The "point up" (PU) state places the parcel so that a single corner is the uppermost point, with the parcel supported stably by the corners of the three other parcels. The "line up" (LU) state puts an edge of the parcel uppermost and so needs to have a "prop" for the parcel of an edge or corner of another parcel, or the sidewall. The "plane up" (PLU) state puts the parcel down, parallel to the base, on the belt or another parcel already on the belt. This was a simplification, but it gave an enormous range of possible positioning of the parcels, due to the infinite variations of orientation available for each case.

While many methods of positioning were tried in the initial period of the research, all were abandoned, after about the first year, in favour of the "Flat Load" or FL and the "Tilt" or TL series which were both in the sixteenth or "P" group of programmes. The FL series were abandoned and finally attention concentrated on the two best TL programmes in the P series. These were PD 1 and PF and these programmes were those which were used for the validation tests at the Western District Office of the Post Office. Two models PG and PM were then built, which were versions of PD 1 and PF which used the full core storage and also calculated the forces. Development was much slower because these larger programmes were "turned around" very slowly by the computer. This series of models depended on the principle of a parcel being allocated a vertical column of "occupied space" and then being placed in a stable position, at the lowest feasible arrangement in that column. If the parcel could not be positioned stably a new "occupied space" was allocated.

The basis of the programmes was the following:

1. The cases of point up PU, line up LU or plane up PLU, were mutually exclusive.
2. The parcel rests on three points or nodes and is stable.
3. Parcels are formed into lozenges so that the upright sides are always vertical. This simplification was necessary to limit the size of the simulation and reduce the run time. Although it introduced a great change in the assumed shape of the parcels, it must be remembered that the basic assumption that parcels are all rectangular is as great a simplification as that they are lozenge sided.

These simplifications were not found to cause any great variation in the accuracy of the modelling. The errors caused by the main assumptions and simplifications, particularly in the force calculations area, were considered as a much higher source of error. A particular weakness is the fact that it is possible for small parcels to be loaded into the interior of larger parcels, but this has not been observed to occur in the trials which have been checked either manually or by the graph plotter. A system was designed to avoid the error occurring, but was not used, since trials showed markedly increased computer run times for little change in model parameters. In any case it was felt that the model need not slavishly represent the real world, since the order of accuracy resulting from the simplifying assumptions was enough for the present purpose.

4.8 STABILITY OF PARCELS

The parcels were placed into the system with the three axes of the length, width and height, oriented randomly on the orthogonal axes of the conveyor. The length, width and height were determined by placing into decreasing order of dimension the lengths of the sides parallel to three main orthogonal axes of the rectangular shape which enclosed the parcel. In the tests of the system, it was found that the model placed parcels with the length upwards much more frequently than was representative of actual loadings, as observed in the parcel conveyors. Accordingly some arbitrary limiters were programmed in the random generation of orientation, so that if the height was less than one third of the length, then the parcel was placed with the height upwards. If the height was more than one third of the length, an additional test was made to see if the sum of width and height was less than the 1½ times the length, and if so, once again the parcel was placed with height upwards. In these cases the change to give certain parcels another orientation with the height upwards avoided excessive bias. The unrealistic upwards projection of certain parcels, which had been apparent in the original model, was no longer present. The new model thus represented the "real world" condition, including the intervention of the Post Office operative, who would turn a parcel down if it projected. It also simulated the effects of gravity and the "rolling effect" of a parcel settling down, which had been observed in conveyors at the Western District Office, even without any manual intervention.

4.9 LOADING ARRANGEMENT

The distribution of parcels across the conveyor was at random in this initial model. The simulation of conveyor movement was given by moving the "dropping point" along the length (the J-axis) of the conveyor every time a new parcel is selected to be placed in the conveyor. A range of 1.25 to 40 parcels per foot of conveyor length was used in the simulation. The distribution of parcels along the conveyor was uniform. This represented the loading during the period of time that it would take for a range of between two and eight feet of conveyor to pass a fixed point. In this indirect modelling of time intervals, the model differed from other simulations by the author or done under his supervision (Haddon 1971, Wan 1971, Lopez 1972, Liu 1974, Rourke and Liu 1974). Simple additions to this original model could enable the "L-turn", the concentrator loading, and the bag drop from a unit load (hook type) conveyor, to be simulated by a choice of I-axis and J-axis generators, which would give the location of the reference point. The model used the bottom right-hand front corner of the parcel, in the sense of the "shoe box" analogy, which was numbered 1 for the bottom corner and 5 for the upper, and this position was always used as the origin of the three orthogonal axes for both conveyor and parcels.

A problem arose from the overlap, which then occurred because the "dropping point" was distributed up to the outer wall of the conveyor. This allowed virtually all the parcels to overlap, so a decision had to be made as to what to do to accurately represent overlapping parcels. The movement to the right, in the sense of the "shoe box" analogy, of the overlapping parcel, so that the left-hand outer edge or corner just contacts the sidewall, was rejected. A number of tests showed this technique as not being typical of the "real world", due to biased loading along one side. Any overlapping parcel was then programmed by another method so that it was relocated, as if it was a fresh parcel. If it could not be relocated after five tries, the girth was considered, to see if it had already been noted as being oversize. If it was, then the oversize girth parcel was located with its bottom right-hand corner touching the right-hand side of the conveyor, with its height across and its length along the conveyor length. This was tried once more. The oversize girth parcel was completely rejected if it would not then fit. Normal girth parcels were orientated with the length along the conveyor length for ten tries. If any still did not fit, the parcels were aligned with their lengths along and heights across the conveyor. If any of these then would not fit, they would be rejected in a similar way to the oversize parcels. This never occurred with the sample of parcels tested. This simulation would represent the real life situation more accurately in the modelling of "difficult" parcels.

4.10 THE PRINCIPLE OF LOADING AND UNLOADING

In the programme one area of considerable difficulty had been the force calculation module. It was obvious that a simple and rapid method was essential. The first step to a solution was to use the simple "rigid link" model to transmit the forces, a diagram of which is shown in Fig. 4.16. (Page 360) The weight of the uppermost parcel acts at the centre of gravity. Three rigid links couple this weight onto parcels underneath. Rigid links in the under parcel connect to the upper parcel links and transmit components of the weight of the uppermost parcel. These components are added to the under parcel weight and transmitted via the three lower rigid links to further parcels underneath the two uppermost parcels.

The lower right-hand parcel of Fig. 4.16 (Page 360) shows a sidewall correction. The computer selects a point on the sidewall, indicated by the short vertical line at the end of the rear-most lower rigid link. A component of the sum of the resolved weights is transmitted to the sidewall at that one link. The other two lower links on the same parcel transmit the other components to the base or belt.

A second step in solving the problem is needed, for even if the "rigid link" analogy was used for the parcel, by either method of moments or trigonometry, the problem was statically indeterminate. It became necessary, if this problem was to be solved within the constraints of the University computer, that some heuristic rules were required so that an approximate solution could be found. Once a heuristic method was created, it was presumed that further research by other workers would improve the method and techniques until a satisfactory and accurate technique evolved for more involved and complex conveying configurations not covered in this initial work. In this project, the heuristic rules developed give adequate results for the straight conveyor, and would be a basis for work on other systems. The heuristic rules allocate the parcel weight to a set of three contact nodes, which is relatively easy and logical. The key rule for the method however, depends upon the fact that when any parcel is loaded, it must rest only upon parcels which have been loaded before it, or the belt or sidewall. Since the only parcels which can rest upon other parcels will be those loaded subsequently, the last parcel to be loaded cannot have parcels resting upon it. Therefore, the forces for this parcel can be resolved, since the case of this parcel element is not statically indeterminate. As soon as this parcel has the forces resolved, those parcels which support the last parcel have their upper forces resolved, since they are equal to the forces on the three nodes of the last parcel. Now the "last-but-one" parcel forces can be resolved since the upper forces can only come from the last parcel, if they exist, and so whether the last parcel rests on it or not, the nodes of the last but one parcel can be resolved also. These then provide the upper forces for the parcels which support the last but one parcel. By progressing through the parcels from the last to the first, the forces can be resolved for all parcels. Any of these which contact the base and sidewall will give perpendicular or normal friction forces respectively. If the individual coefficient of friction, for the parcel and the base or sidewall material, is known and the product summed, then friction forces for base and sidewall are found. If a parcel has contact with base or sidewall at the time it is loaded, then the programme records this in matrix registers. Subsequently this avoids searching the co-ordinate matrices to establish which parcels are in contact with the conveyor. This method is also very helpful in simulating the settling of the parcels in close proximity to the sidewall, as would occur in the "real world", since closeness of the parcel to the sidewall can be tested at the time of loading.

The heuristic rules are:

1. Assume parcels only rest on three points of contact.
2. Divide the parcel weight amongst the three points of contact.
3. Starting from the last parcel calculate and store the three orthogonal force components for each of the three base contact nodes.
4. Sum these three orthogonal force components on each of the three nodes to give forces on the parcel for the lower three points of the upper parcel. This is held in a matrix for subsequent use.
5. Sum the three orthogonal force components for each of the three nodes to give the force on the respective upper points of the under parcels. Up to ten parcels may give rise to upper forces.
6. Repeat the steps 3, 4 and 5 until all parcels have had their forces calculated.

While this technique obviously involves repeated calculation and summation, this is the type of work at which the digital computer excels. As an initial method which provides a solution of this simulation problem, it has the outstanding merit of simplicity. Certain refinements have been programmed to improve the accuracy of the calculation, but in essence this module of the programme has worked reasonably well from the first trials.

5.0 PROGRAMME DESCRIPTION

5.0.1 General Introduction

The programme consists of five modules, shown in Figs. 5.1 to (P.363-6) 5.4. The module 1, the steering module, shown in Fig. 5.1, is linked to module 2, the parcel placement module, shown in Fig. 5.2. The connection is shown at point number 2 at the bottom of Fig. 5.1, which is connected to point number 1 on Fig. 5.2. This is read as "going to" at the bottom of the flowchart and "coming from" at the top, generally speaking. Thus the 5 at the top of Fig. 5.1 means an input "coming from" module 5, and the 3 on the right-hand side of Fig. 5.1 indicates "going to" module 3. Hence the 2 in Fig. 5.1 at the bottom of the page indicates "going to" module 2 and the 1 at the top of Fig. 5.2 indicates "coming from" module 1. Each of the modules was programmed as a separate unit for ease and speed of development. The technique enables initial testing of modules to be carried out at the same time as others were undergoing development. Some modules had a continuous development throughout the project, for example, the parcel placement module, while others, such as the steering module, changed only occasionally. Considerable development of the location and placement model was carried out with only skeleton modules, which jumped the particular process, or established values in a rapid and simple way. As an example, the force calculator skeleton module did not carry out any calculation. It merely checked that the geometry of the parcel was placed correctly in the matrix, so that the interface was as it should be. Similarly, to obtain a rapid turnaround, the skeleton steering module created only small matrices to hold twenty parcels, so that the whole test programme required only 7K to 11K of store and five minutes of computer time. This was essential since the programme had to be recompiled every time it was altered during testing.

5.0.2 Steering Module

The first module is as simple as possible within the constraint of including all the necessary steering information. It allows for random placement over the conveyor section, or alternatively a moving dropping point which simulates parcels flowing along a moving belt conveyor. Fig. 5.1 shows the flowchart for this module. (Page 363)

The limit on the number of parcels is one hundred, so that the core store in the computer is less than 32K words. This is set endogeneously by the matrix dimensions of the module. The conveyor section is set exogeneously by values, read in as data, to examine the effect of change of cross section. Other exogeneous factors are the office, and whether the printout is to be a full diagnostic printout or a reduced normal version. To avoid a premature failure, the maximum number of parcels in the data must be entered and finally the friction data, such as the percentage of plastic parcels to be put in by Monte Carlo techniques, if any, and whether humidity is to be considered at 40% only or at four points from 40 to 70% relative humidity. In addition to this for friction purposes the belt and sidewall material must be specified. The programme then reads for each parcel the respective friction coefficients, along with the other data unique to that parcel.

5.0.3 Parcel Placement Module

This module loads parcels as "point up", PU, "line up", LU or "plane up", PLU. (See 5.6 and Fig. 5.9). The systems design made
(page 368 and 370)
provision for some very sophisticated features in loading, which considered the respective rotation of upper and lower parcels in the horizontal plane and a large number of potential points for loading the parcel. Some of these were incorporated initially and some had provision made, so they could be added, if that had been found necessary.

When the loading system was developed sufficiently to validate well, the surplus features were removed to reduce the computer time. This did not seem to affect the accuracy.

5.0.4 Data Recording Module

The parcels are loaded and the parcel corners are recorded as three-dimensional cartesian co-ordinates. The contact points are also recorded in a similar way. Additionally, registers are kept of parcel details, weight, friction coefficients and so forth, and also of contact with belt and/or sidewall and whether the parcel is PU, LU or PLU. In this module, the check is made as to whether the conveyor is either "full" or "traversed" according to the particular model.

5.0.5 Force Calculation Module

This module assumes parcels are rigid and behave as rigid bars between the contact point, three on the underside and up to ten above. No deflection, which would change the force, is assumed to occur. The load of the parcel at the centre of gravity is predivided onto the three under points. The three axis components at each contact point are found by taking moments, or trigonometrically, according to the particular programme. Starting at the top with the last parcel which was loaded, the forces are calculated and the three components of the weight resolved to the contact points. These are then used to calculate the upper forces on the parcels lying under the last parcel. The parcels are tackled in sequence from the last to the first, and since there are then never any unknown upper forces on a parcel under consideration, it then follows that there are never more than three unknown forces, which are the three lower forces.

5.0.6 Friction Force and Jamming Determination

The programme now proceeds to calculate the friction force at each contact on the belt and sidewall. The friction forces which have been calculated are summed and compared for the belt and sidewall contacts respectively. If the sum of the friction forces resulting from the parcels being static on the belt exceeds the sum of the friction forces from parcels sliding on the sidewall, then no jam can occur. Every run showed this condition, but in the event that any loading had shown the reverse case, when sliding friction forces on the sidewall might have been the greater, then the forces would have been further evaluated. The sum of the friction forces for the parcels, sliding on the belt and static on the sidewall, would have been examined. If the sidewall force exceeds the belt force, then a permanent jam would have been declared for that drop. If the belt force exceeds the sidewall force, then an incipient jam would have been declared, that is, one where a jam caused a momentary check, but the altered friction condition caused the jam to break up. Neither of these cases have been shown to occur as yet. A straight conveyor is unlikely to jam from these causes unless some change occurs in conveyor configuration or radically in parcel composition and structure. Both events are highly unlikely in a straight parcel conveyor.

During the evaluation of the results from this section some doubt was thrown on the friction coefficient values in the data of the original parcel survey (Castellano et al. 1971). This was especially true of the plastic covered parcels. The friction effects are not as is shown in many classical texts, for example, Shames (1959) Chapter 7 on "Frictional Forces" shows the dynamic force as being constant and less than the static. This is discussed more fully in Section 5.5.

(See page 129)

Some work at the University by Eden (1971) used a test rig which resembled a gramophone, where the needle was the wrapping material and the record was the belt or sidewall material. The samples of wrapping materials covered a block of wood. A weight, which gave loads typical of parcels on conveyor belts, pressed the block onto a disc covered with belt or sidewall material, rotating at preset controlled speeds. This rig was in a controlled atmosphere inside a chamber. Friction effects are discussed later, together with the effects of humidity. This work gave some values which were regarded as more representative. When Monte Carlo techniques are used in the model to provide friction data, the values used in the generator are those of Eden. Comparisons were mainly carried out at a relative humidity of 40%. This relative humidity (r.h.) was quoted as a typical figure for the parcel offices, but this is doubtful, as discussed in Section 5.5. The effects of increasing r.h. are shown in the model over the range of 40% to 70% r.h. This is achieved very simply since it was obvious that the friction coefficient varied exponentially with r.h. from an analysis of the curves given by Eden (1971). The exponent was simple to derive and the programme calculated the friction coefficients at increasing humidity rapidly as follows:

$(\text{Friction Force})_{n+1} = (\text{Friction Force}_n)*\text{PEXP}$

where the step from n to n+1 represents a uniform increase of humidity (actually 10%) and PEXP = the exponent for the parcel wrapping. This generator obviates the need for storing the coefficients at humidities other than 40% r.h., providing the curves for sliding and static friction against r.h. are available.

5.1 DETAILED DESCRIPTION - STEERING MODULE 1

This is shown as a flowchart in Fig. 5.1. (Page 363) It is designed as the simplest possible module which would control the programme and it includes all the steering information at present required. This section is the one which would incorporate the random or other flow patterns if the programme were extended to cover probabilistic flow.

Since the conveyor is only likely to jam when fully loaded, this initial programme always allows the section to fill completely and to give the worst conditions for test. The generators to give simple flow distributions such as rectangular, normal, log-normal, etc., are already available in the Department as standardised sub-routines (Wan 1971, Rourke and Liu 1974, Rourke, Liu and Boyd 1975), and very little extension is required to give a flow pattern.

5.1.1 First Segment of Module 1

The first part declares to the computer how many parcels can be loaded, which controls the amount of computer store needed. The limit of 32 K of user programme sets that number of parcels at 100, which was adequate for this initial research giving up to four fillings of the conveyor section.

The second part reads on the conveyor dimensions, the materials of the sidewalls and base, and as a check, the office from which the data should come, so that misplaced or mispunched cards are detected.

5.1.2 Second Segment of Module 1 - Input and Checking

This segment takes in data for a parcel and checks it against standards set endogeneously and from exogeneous factors set in the first segment. This is the main entry point to the appropriate data bank file where the card image on the disc file gives the data for a parcel. Each card image carries office, parcel number, shape, wrap, weight in lb. and oz., length and position of the centre of gravity (C.G.) and similarly, width and height with respective C.G. positions, and the friction angles for steel, cotton, scandura and rubber in both static and sliding cases, provided from a Post Office parcel survey (Castellano et al. 1971). The parcel data also includes data on whether the parcel is tied with string, how regular the shape is, and whether the parcel is hard or soft, i.e. the compliance. The degree of compliance varies widely in the "real world" parcels. These can be as hard as a pack of steel plates held together by a steel band, or as soft as an eiderdown packed in a plastic bag.

The parcel data is input to the programme starting with the first parcel and following in sequence until the conveyor is full, when it then gives an intermediate output and commences a new filling until 100 parcels have been loaded. Because pseudo-random numbers are used, the parcels will load in exactly the same positions if the same sequence of parcels is fed as data. If desired, this can be avoided. The programme will ignore some predetermined number of parcels before starting to fill the conveyor by adjustment of the data files. If this is used, care must be taken to ensure that sufficient parcels are available from the starting point to fill the conveyor to avoid the risk of premature failure. An alternative method would be to write the programme to obtain parcel data at random by a Monte Carlo technique by interrogation of the GEORGE files in the data bank. Such a practice would extend the run times even further, but it was felt that to do so would cause excessive computer time usage which would extend the time of this research beyond the scope of a Ph.D. The computer turnaround for large programmes was one to three days in the good part of the year (April to July and September to November), one week or over in the bad parts (late November to March) even with the CDC 7600.

The dimensions were used to calculate the volume, and then rounded to the nearest inch, except that any dimensions less than one inch are taken as one inch. The girth is checked and a warning is printed if it is illegal, that is, greater than Post Office regulations allow. The parcel volume is calculated and added to the sub-total. The weight is calculated as a decimal pound system and stored as tenths of a pound. One hundredth units caused overflow in the computer registers on some calculations and one pound units were inaccurate.

The programme checks the office of each card image against the office given in the steering information. Should the office shown on the steering data disagree with the office given by the data on the file, a warning is printed. However, the programme is not failed, since the data files had been well checked previously. This eventuality was more likely to be due to an error in the steering information than to calling in the wrong data from the data bank.

The programme resets the steering so that the office of the first card is then assumed to be the one selected. A warning will then only be given should any subsequent cards not have the same office as the first card. This was unlikely since cards were only used to enter data in the initial stages of GEORGE 3 data file creation, and checked and corrected at that time.

5.1.3 Substitution of Plastic Wrapping

The proportion of parcels traffic wrapped in plastic seems likely to increase, in spite of the oil shortage, since there is also a paper shortage. The higher costs of plastic materials are often offset by the reduction in labour costs using modern plastic wrapping equipment. To attempt to predict the effects of an increase in parcels wrapped in such organic polymers, a segment was included in the programme (see the fourth process block of Fig. 5.1 (Page 363) on left-hand side of page), so that the wrappings of any given proportion of parcels, up to 100%, could be changed by Monte Carlo techniques and given the appropriate data for plastic outer wrapping. This segment was switched in or out by the steering information. Instead of using values from plastic covered parcels in the original data, values taken from research into the coefficients of friction of parcel wrapping materials by Eden (1971) were used as values which were more likely to be correct than the parcel data from the survey, which is discussed in the results chapter. This was because the plastic wrapped parcels were such a small proportion in the original survey that their characteristics were masked by the large proportions of paper and cardboard parcels, and the values for coefficients of friction given at that time were not typical of those given by traffic at parcel offices such as Peterborough, which has a high proportion of plastic wrappings.

5.1.4 Location of the Parcel

This segment of the model now selects the "dropping point" using Monte Carlo techniques. (See Fig. 5.1) (Page 363) This locates the "front right-hand" lower corner position, in the terminology of the "shoe box" analogy. (See Figs. 4.14 and 4.18.) (Page 358 & 362) This is followed by selection of the attitude of the parcel, which is the way in which the longest, mid and shortest dimensions are aligned in the conveyor as length, width and height. Lastly a random angle of rotation of the parcel in a horizontal plane is chosen from 0° to 45° to reduce bias.

Since the location point is allowed to range over the conveyor, and since the longest diagonal of some of the parcels is sufficient to cover the conveyor width, the parcel will often overlap the wall. When this occurs, adjustment is made (see Fig. 5.5). (Page 367) In the first version the parcel was simply moved inwards, so that the outermost corner of the parcel rested on the outer wall. Should it also be found to overlap the inner wall due to this move, the parcel was relocated. This caused bias, and for this and other reasons, the Post Office engineers requested that the parcel should always be relocated if it overlapped the sidewall. This is now incorporated in the programme, with the additional refinement of limiting the relocations to five. If the relevant dimension of the parcel exceeds the conveyor width a warning is printed out. If the parcel will not fit after five relocations, a final attempt is made to place the parcel with its length along the conveyor section, in contact with the inner wall and the smallest dimension across the conveyor. If the parcel is of illegal girth, it brings the leading edge of the parcel up to the front of the conveyor section. If it still will not load inside the section in this position, the parcel is rejected and a fresh one taken. The programme outputs a warning that his has occurred.

It now looks in the area under the parcel to be dropped, to find the corner position of any parcels which lie underneath the parcel to be located. It searches the last 25 parcels to be placed (100 corners) and makes a list of corners which it finds under the parcel. From these it selects the highest three which are suitable, in readiness for placing the parcel in the next module. It keeps the list of other corners in reserve, in case the parcel needs relocation due to slipping, etc. For the highest three corners of the under parcels, it notes the quadrant, that is, "left-hand front" etc. and the type, which is "PU, LU, PLU" etc. (see Section 4.7). (Page 96) It then moves on to the next module.

5.1.5 Reasons for Checking Data in the Simulation

The data was analysed by the data checking programmes before the files were created, but in spite of this, the data from certain offices still contains parcel sizes which give rise to difficulties, where the traffic includes some parcels which are oversize on the girth. Where an obvious inaccuracy has arisen, for example in punching the data card, it was corrected. Some dimensions were correctly punched from the data in the survey, but were still oversize in the girth, and it seemed possible that, since the measurement of girth is a little tedious, parcels were accepted by a post office if they seemed to be inside the length requirement. Hence, while oversize girth on the parcel was adjusted when it was due to punching errors, in general the small oversizes in dimensions of length and width were often accepted. The difficulty is that the oversize girth was found in parcels where the longest diagonal was long compared to the conveyor width. It became difficult to fit such parcels into the model conveyor section, needing repeated relocation. In the "real world" situation manual intervention by the use of a long stick, to put the parcel into place, can occur, or the parcel is removed and manually sorted. The simulation could reproduce the difficulties in loading, but could not show that the presence of such parcels was a possible cause of jamming.

It seems that post offices accept a proportion of "difficult parcels", (not obviously so) which are sometimes, but not always, outside the limits of the Post Office Guide regulations. The term "difficult parcels" in this context refers to the number of attempts necessary to fit the parcel into the conveyor, and the loss of packing efficiency they cause. When combined with other causes, it is also likely that they could be a cause of unexpected jamming.

5.2 DETAILED DESCRIPTION OF THE PARCEL PLACEMENT - MODULE 2

The flowchart for this module is shown in Fig. 5.2. (Page 364) The loading arrangement is based upon the "point up, line up, plane up" principle (PU, LU, PLU - see Section 4.7). (Page 96) It has a structure which incorporates some sophisticated features in the packing system, which were allowed for in programming and coding, and partially programmed. In the models used for this thesis, the routes taken, during a run through the programme, have been kept simple, to render inoperative much of the sophistication, which was not shown to give any major advantage over the current models. At the loss of some programme efficiency, the features, or the allowance for sophisticated features, have not all been removed. They could be incorporated with the more complex conveying models, should the need arise in the future.

5.2.1 Parcel Location - Position and Rotation

The "dropping point" (see Fig. 4.18) (Page 362) was chosen (see Page 112, Section 5.1.4) and the attitude and rotation of the parcel was fixed, but the parcel was not yet positioned. If the parcel overlapped the sidewall then the corrective technique described previously (see Page 112, Section 5.1.4) was employed. If the parcel overlapped the end of the section, then no action was taken. This was found to give the best correlation with actual parcel packings found in the validation. Presumably the error caused by having no overlap at the beginning of the section, and therefore having excessive voids, was cancelled out by the additional volume of parcel outside the section, which was considered as being inside the end of the section. The parcel is checked for contact with inner or outer sidewalls and this is recorded. The search technique could be adjusted simply, had the model not put sufficient parcels into contact with the sidewalls. It could examine parcels and move into contact with the sidewall those that were positioned "close" to the sidewall. This was not done, but it was felt this technique would aid future work, where simulation of jamming due to "causative" events was modelled.

5.2.2 Finding the Best Nodes for Loading

One of the main features of the method of defining a parcel in these various models is the corner post principle. The corners of the parcels are used as definitive points. In loading a parcel, the upper corners of any underparcels are regarded as posts which project upwards towards the overparcel. The parcel must fill the space between the corner posts and it is fairly easy for the system to define whether a space between corner posts is filled with parcel or empty space. To aid in this, there is a major simplifying assumption which considerably reduces the amount of calculation and storage of the programme. This is achieved by distorting the parcel geometry in the case of the "line up" loading and "point up" loading, so that the upper and lower parcel corners on the same post have the same co-ordinates in the horizontal plane. This is shown in Fig. 5.6.(Page 368) Using the "shoe box" analogy, the "match boxes" (i.e. parcels) which have already been placed can be regarded as four "matchsticks", or corner posts, pointing upwards, with their tops at the positions as the upper four corners of the "match boxes" which they are representing. The "match box" to be placed is lowered onto the "matchsticks" and a position of rest chosen in the state of PU, LU or PLU (see Section 4.7,p.96) This principle has no effect on the volume of the parcel, since the rectangular or square parcel sides become parallelograms or lozenges, with the area unchanged. If the height of the parcel is known, then the positions of the upper corner points are very easily found from the lower four, by adding the height to the "k" co-ordinate, the "i" and "j" co-ordinates remaining unchanged. The same technique is even more useful for the "point up" placement. In this case the four lower corners all have differing heights, but the upper point is found quite simply by increasing the "k" co-ordinate as before. The conveyor is regarded as always fixed in orthogonal space. The "i" co-ordinate lies across the conveyor, the "j" co-ordinate lies along the conveyor length, or axis, and the "k" direction is the height of the conveyor. The point up (PU) parcel loading in the orthogonally oriented conveyor space is shown in Fig. 5.7. (Page 368) (See flowchart Fig. 5.2.) (Page 364)

While this approximation may seem crude, simple trials have shown that the errors arising are small compared with those due to premature termination of loading by deficiencies due to difficulties in devising efficient heuristics for detecting the "conveyor full" condition.

Position of Underparcels

If we define the "occupied space" to mean a rectangular volume, standing on the orthogonal area enclosing the parcel being loaded (see Fig. 5.8), (Page 369) the corners of the most recently loaded parcels are scanned up to a maximum of 100 to see if any lie inside the "occupied space". The highest 40 corners are noted, together with the parcel number, corner type (numbered 1 to 4 in Fig. 5.8), (Page 369) and type of loading of the under parcel, whether it is plane up (PLU), line up (LU) or point up (PU). A definition of this loading is given (P.96) in Section 4.7 and examples of these three loadings are shown in Fig. 5.9. (Page 370)

In early programmes the highest six points were taken and from these the three nodes for loading were selected. In the final versions the highest three points are taken, since this made very little difference and simplifies the model without significant loss of accuracy of loadings. If there are no points present, then the parcel is sent for PLU loading onto the base. If there are less than three points available this is noted and the programme is speeded up by jumping some areas in these cases. The position of these nodes, and the nature of the underparcel, belt or sidewall, is then examined and on this basis a loading case for the underparcel is chosen, either PLU, LU or PU. (Fig. 5.9 shows these three cases). (Page 370)

5.2.3 The Position of the Three Nodes in Occupied Space

The normal selection process is based on whether the underparcel corner is of type 1 to 4 (see Fig. 5.8 for details of the (Page 369) corner numbering) and also in which quarter of the occupied space the underparcel corner lies. (See Fig. 5.10) (Page 371) The corner type and position in occupied space is therefore found for the six highest corners, which provides more than sufficient to give three contacts. The relative angle of twist of upper and lower parcels is also noted, to check that under parcel corners lie inside the overparcel area. For this thesis the three nodes are chosen by taking the three highest points in the occupied area, except in cases where the upper point masks the lower points, when the loading case becomes LU if one point is masked, or PLU if two points are masked. A more complex analysis was designed, which found if any planes or edges of underparcels could provide support inside the "occupied space". From six of such potential supporting points, the best three were chosen, and the parcel placed on these. This model was programmed and tested, but was expensive in computer time and gave an output which differed lit little from the simpler models. It was therefore abandoned.

5.2.4 Selection of Loading Type - PU, LU or PLU

It was found that the sophisticated simulation, mentioned in Section 5.2.3, which considered the angle of twist and the exact position of the underparcel planes and edges, to establish whether they would support the parcel, did not affect the loading pattern greatly. Accordingly, the analysis of the six points is not used in the final version of the programme since there are no great advantages. However, a very simple change is all that is required to restore the programme so that it will select the "best" three points from six or even more selected as probably suitable from up to 40 under points. The selection of PLU, LU or PU is now carried out. The programming of the decision process is based on a simple decision tree, with binary outcomes. However, the COMPUTED GO TO in the FORTRAN language enables the programme coding to be even simpler than the logic tabulation or the flowchart. This means that this powerful section was capable of rapid adaptation for adjustment as validation was carried out. Thus, many options for positioning have been programmed, but the outcomes have been controlled by a very simple system in the final programme, since the more complex systems did not give any obvious gain in the straight conveyor model.

If reference to Fig. 5.11 (Page 372) is made, and also the flowchart of Fig. 5.2,p.364, is followed through, then the decision process for a given parcel may be followed. The underparcel is of type "PLU" (plane up) and there are only two corner posts. The first corner post is corner 1 of the underparcel and the second corner post is corner 4 of the underparcel. The "occupied space" divides into four areas. The lower left-hand area is numbered 1, and the areas are numbered clockwise in sequence. The areas in which the corner posts lie are noted. There are four possibilities for any corner in area 1. If a corner of type 1 lies in area 1, as it does, then the underparcel lies under the parcel being placed. If the corner of type 3 does not lie below and to the left of the centre of gravity of the upper parcel, then the upper parcel can be placed flat or PLU on the underparcel. The first corner post is shown in Fig. 5.11 (Page 372) and is in area 1, it is also of type 1 and the loading would therefore be PLU. If the first corner post had been of type 2, then the underparcel would have been lower in the figure, mostly in area 4 as shown in Fig. 5.11. The parcel would then have rested on the edge between corners 2 and 3 of the underparcel and would have been loaded LU (line up). Had the underparcel corners been of type 3 or 4, and in area 1, then the parcel would have been positioned LU also, but with different edges upward. Adjustments are made by the programme if the corner lies in or out of the overparcel area.

In the next example (see Fig. 5.12) (Page 373) two underparcels giving three corner posts are found. The first corner post belongs to parcel A, type 2, in area 4, which is the higher. The second corner post belongs to parcel B, corner type 1, in area 2, and so does corner post 3, which is of corner type 4, in area 2. These latter two corner posts are the same height, which is noted by the programme. It therefore starts to load the parcel as PU, since the upper corner post of parcel A has a corner type 2 in area 4, plus two lower corner posts. However, the PU system investigates the two lower corner posts to see if they are level and from the same parcel. If they are, the loading then changes to LU, since only two parcels are involved. Hence this two underparcel case is an exception, but an example of how the parcel is placed by a logical system in a relatively complex manner. Line up (LU) loadings will also occur when only one corner post exists and no support exists for the plane up case. For example, if the first corner post of parcel A (type 2, area 4), existed, but parcel B did not exist to provide the lower support, then the parcel would be loaded as LU on the belt and first corner post. To refer to which side is upwards with LU loadings, they are referred to as North, East, South or West. North is the edge towards the top of the overparcel in fig. 5.12.(Page 373)

In the third example, Fig. 5.13, (Page 374) there are three underparcels, with one corner point from each parcel. Parcel A gives the first corner post, which is the highest with corner type 1 in area 3. Parcel B gives the second corner post, which is next highest with corner type 2 in area 4. Finally parcel C gives the lowest corner post with corner type 4 in area 2. In this example, the model will find three corner posts from different parcels, at different heights, and so it loads the parcel as point up (PU).

In each case the parcels are placed in the conveyor by calculating the corner positions by geometrical logic, based on joining corner posts and defining lines and then skew lines in the plane as necessary. The lowest point is often in contact with a flat surface, but the position of lowest corner may also be calculated as above if necessary, as was the case in the third example.

Summarising, the placement system operates on the basis of searching the corner post stores to find the last 40 corner posts to be loaded, which are inside the "occupied space" using one set of heuristic rules. This reduced matrix is then searched for the optimum loading points, according to another set of heuristic rules which selects three corner posts, on which the parcel may stably rest in one of three ways, either PU, LU or PLU. Exceptions are made when the corner posts are less than three, that is 0, one or two, and the programme then diverts to other loadings. This is the case in example 2 of Fig. 5.12, (Page 373) in which the placement of the parcel is in a line up (LU) position. This is because the programme finds only two parcels in the occupied zone, and the lower of these can provide two supporting corner posts of equal height. The programme would inspect the geometry of the two lower points and this would result in rejection of the "point up" (PU) loading in favour of the "line up" (LU). Similarly, if one, two or three points rest on the belt, then other exceptions are made to the nominal choice of loading.

5.2.5 Weakness and Accuracy of Module 2 (Parcel Placement)

It is possible to load a small parcel right through a very large parcel, although some random sampling of the computer runs has failed to find such a case, and it seems to have a low probability of occurrence. The variation of the size of parcels post is not great, and the majority of small parcels are sent by letter packet post, which minimises the number of small parcels present. Even if a small parcel or two were loaded into space occupied by another parcel, the error in the total volume of parcels loaded would be small, because the small parcels represent a very small fraction of the total volume. A number of parcel loadings were checked for this error by the rather tedious manual plotting of the points. The use of the existing CALCOMP graph plotter on the 1900 system was restricted by hardware and software limitations at that time, so computer plotting was abandoned. The weakness of placing a parcel inside could be overcome by a system which carries out a subsidiary search after placement. This would increase the computing time, which is undesirable. Roughly the same number of calculations are required as in the original search for suitable underparcels. The decision was made to structure this segment so that the change could be made in the future if it was shown to be necessary.

The final validation showed a satisfactory agreement on the packing density, which is the volume of parcels loaded compared with the conveyor volume, for both the computer simulation and the "real world" conveyor system, as discussed later.

5.3 DETAILED DESCRIPTION OF THE DATA RECORDING MODULE 3

Thus it is seen that the programme decides from the nature of the underparcels the position of the contact points or nodes. It then places the falling parcel as "PLU", "LU" or "PU". It stores these three points or nodes in registers for over and underparcels. The corner posts are put into another store and also the parcel data read in from the original data. The loading type and the amount of parcel rotation are also held on record. (See flowchart Fig. 5.3. Page 365)

Nodes are selected and put in a 3 x 3 temporary matrix from a 3 x 1 node matrix. From these the three lower points to the parcel are recorded. Contact points or nodes are recorded also for upper parcels.

5.3.1 Three Lower Contact Points

The method of solving the forces requires that the parcel sits stably on three points, or nodes, irrespective of whether the loading is PLU, LU or PU. The position of these three points is recorded at the time of loading each parcel. This matrix is thus partially filled and, as the upper parcels are loaded, the matrix will be filled subsequently. Additionally, since the lower three points of any parcel being fitted also form up to three upper points for any underparcel, the co-ordinates of the same points will also be recorded as upper points on the underparcel node matrices, together with a register of the underparcel numbers to enable the computer to remember which parcels are in contact. Should a parcel be in contact with either wall or the base, this will be recorded on other registers at this time also.

5.3.2 Total Number of Contacts

The number of lower contacts is three. The number of upper parcels in which contact is allowed is ten. This gives the total number of parcels linked in any one contact as eleven. There are often large numbers of contacts and, to enable the information to be stored, an average point of contact with resolved forces had to be used for each upper parcel. If every individual contact had been recorded, the storage capacity of the machine would have been exceeded. Any parcel having two contacts from an upper parcel combines the two vectors, to record one point, which increases the effective storage capacity of the model.

5.3.3 Optimum Storage of Nodes

The number of nodes available is based on estimated contacts. Since in FORTRAN programming the store size is declared at the beginning of the programme, there is redundant storage caused by the need to make available a sufficient number of parcel contacts. If there were never as much as eleven parcels in contact, there is an opportunity to reduce the length and storage size of the compiled programme. In practice, with the loadings of parcels in this work, the figure of eleven contacts was reached but not exceeded.

5.3.4 Capacity of Matrices

A check is now made to ensure that the capacity of the matrices to hold more parcels exists, since any attempt to overload matrix stores would result in a premature failure.

5.3.5 Conveyor Full

A check is made to see if the conveyor is full. This is a sensitive decision making area, and it was apparent from the early stages of loading systems, that the first appearance of a parcel over the top of the sidewall was not a good guide as to whether the conveyor was full or not. This was due to the fact that with even (random) distribution of the parcels, the parcels were large compared with the total area of the conveyor, so a mound or pile of parcels would soon arise which soon showed above the sidewall and stopped any further loading if a simple rule was used. The Post Office engineers suggested a loading rule which overcame this drawback. This it does by giving a warning when any parcel shows above the sidewall. When a parcel shows the bottom edge above the sidewall it is relocated. If the below? same parcel cannot load below the sidewall after three such relocations, ? the conveyor is now declared full. This needs adjustment to give a more realistic load. The programme now proceeds to the fourth module.

5.3.6 Section Traversed

When the moving conveyor belt is simulated, the position of the parcel is "moved" along the belt section. The run may be terminated prematurely if the parcels come over the sidewall as in 5.3.5, although parcels which project are moved along to simulate rolling in the direction of flow. If the run does not prematurely terminate (and it never did in the simulations tested), then when the loading point has traversed to the end of the section, having started at the beginning, the run is completed and terminates.

5.4 DETAILED DESCRIPTION - FORCE CALCULATION MODULE 4

Finite Element Method

It had been envisaged in the early days of the study, that it would be possible to use the finite element computing techniques to solve the loading forces on the parcels, base and walls. An examination was made of the existing programmes, which were either those developed by the structures analysis team at Brunel under Mr. Yettram or proprietary systems such as PAFEC from Nottingham (Henshell 1971) University. This showed that hours of programming were required to set up the packing programme to provide the output for the force calculating finite element system. However, even if this had been done, the time required to obtain solutions involving the equivalent of about 20 parcels, say 100 contact nodes, involved thousands of seconds of mill time, that is, anything from four to eight hours of computing time. It was therefore decided to abandon this method.

Particle Methods

The solutions by the assumptions of bridging angles due to Jenike (1954 etc.) and his co-worker Johannsen could have promise in these investigations. They are not completely amenable to computer solution and, additionally, correspondence with Dr. Jenike has suggested it would be an over-extrapolation to extend his theories to parcels even though they equal or are larger than the size limit of 6" cube he suggested. For these and other reasons these techniques were not pursued at the present time.

Simple Techniques

A simple system has been devised of calculating forces by resolving the parcel load into three equivalent loads acting at three contact points. The total loads are calculated by summing the forces, starting with the last parcel to be loaded, which has no upper forces.

5.4.1 The Rigid Link Method of Moments

This, less academically satisfactory method, was produced to give answers in reasonably short computer times. This assumes the parcels to be rigid and the contact points are joined rigidly and that no deflection occurs which is sufficient to alter the force pattern. It then produces a system which is statically determinate, so that the forces can be obtained by taking moments and resolving forces. This is somewhat difficult to do as a computer operation, capable of correctly calculating the forces with respect to sign, irrespective of the force, direction and parcel location in three-dimensional space, in any of the seven space sectors, through which force vectors pass from the parcel in the orthogonal space sector. (See Fig. 5.15, Page 376)

The last parcel has no forces on its upper contacts and so the weight acting at the centroid is then resolved into the three points of contact. These resolved forces are transmitted to the under parcels.

Each subsequent parcel can then be calculated, "unloading" the system. No parcel can arise that has more than three lower points to calculate the forces due to the method of loading. When the forces of parcel number one, the first parcel, have been calculated, all forces will have been solved.

5.4.2 The Trigonometric Method

This was very similar to the method of moments, 5.4.1, except trigonometrical formulae were used in the calculation. This reduced the problem of correctly assigning the direction and accompanying positive or negative value in three-dimensional space.

5.5 DETAILED DESCRIPTION OF FRICTION FORCES AND JAMMING DETERMINATION-MODULE 5

Friction Force

The concept for this system was that the friction forces would be calculated from:

$$\text{Friction Force} = \sum_{i=1}^{n} F_i \mu_i$$

where n = Number of parcels

F_i = Normal contact force on ith parcel

μ_i = Friction force specific to the ith parcel in a particular state or sliding condition for the specified material and wrapping.

This was also compared with the friction force calculated from the product of a mean coefficient of friction for all parcels and the mean load of all the parcels, but this was not accurate enough, and a method which summed all the forces orthogonally was used.

Jamming Conditions

The summation of the base and the sidewall friction forces are compared, or in other words, the total of the sidewall friction forces is subtracted from the total of the base friction forces. If the difference between them is positive then there is no jam. If the difference is zero or negative, then there is an incipient jam. The forces must then be recalculated as in the previous paragraph, but substituting the appropriate sliding friction coefficients for the base and substituting static friction coefficients for the sidewall. If the difference obtained by subtracting sidewall forces from base forces now becomes positive, the jam is said to be temporary. This is a jam which occurs temporarily, but breaks up subsequently of its own accord. This is because the change in friction force under sliding base-static sidewall conditions reduces the jamming force to the point where it cannot support the jam. If, on the other hand, the jam condition is still present, as shown by a negative difference in forces, then a permanent jam is reported. No case of permanent or incipient jam has yet been found in this work. (See Fig. 5.14, page 375)

Analysis

Every time a jam is found this is to be recorded, similarly with overloads, which could crush and damage parcels and loads below the threshold where no inter-parcel and sidewall contact is possible.

The classes are:

1. No jam or stress possible (very low packing with no parcels interconnected).
2. No jam but low stress possible (slightly higher densities).
3. Jam possible but does not occur.
4. Jam occurs but collapses.
5. Permanent jam occurs.

Probabilities suggested for assessment are:

1. That a permanent jam occurs.
2. That a temporary jam occurs.
3. That a jam of either sort, and also excessive loading, occurs.
4. That an overload occurs.
5. That conditions exist where a jam would not be possible.
6. That conditions exist where a jam could occur but does not.

In practice the jamming condition was not found, so that most of these classes did not occur. The flowchart in Fig. 5.4 shows the force calculation system. (See page 366)

5.5.1 Friction Forces

A calculation of the base and sidewall friction forces is made by considering whether a contact point from the registers is in contact with base or sidewall. If it is, then the register of base or sidewall contacts is set to indicate the contact. When all points have been considered, then the friction forces are found individually by finding each force and multiplying by the friction coefficient held on the data base, which had been established by sliding and static tests on each particular parcel. The static friction state is considered to hold for the base, and a sliding condition for the sidewalls, in the first instance. The opposite case, when sliding friction is used for the base, is only calculated if a jam condition is detected, as previously mentioned. The values are sub-totalled separately for base and sidewall until the registers have been completely used. An alternative programme changes the friction values of a selected number of parcels into fixed values for friction coefficient more typical of values established by research for plastic wrappings, since the original data included only a few plastic parcels (1%).

Plastic Parcels

With "simulated plastic wrappings" the appropriate coefficients are randomly substituted for the original data in Module 1, using values abstracted from research at the University by Eden (1971). This showed an exponential relationship existed for friction coefficient against humidity when other conditions were held constant, such that:

$$\mu i = \mu o^{Ki}$$

where μi = frictional coefficient of a given plastic material at relative humidity of i.

μo = frictional coefficient at relative humidity of 40%.

K = constant related to the plastic material composition, texture, and temperature.

5.5.2 Jamming Determination

The systems concept for this module is that it will sum the individual friction forces whenever parcels contacted the side or base.

Hence, if the parcels are being transported by the belt, the base friction is static and sidewall friction is sliding. Therefore the condition is:

$$\sum_{i=1}^{n} F_{K,i}\ \mu_{B,MST,i} > \sum_{i=1}^{n} F_{J,i}\ \mu_{W,MSL,i} \qquad (1)$$

where n = number of parcels in all.

$F_{x,y}$ = Force in the "x" direction of the "yth" parcel contact (parcels not in contact have zero force).

The subscripts of $F_{x,y}$ are given by:

x = orthogonal direction where

I = along conveyor

J = across conveyor (normal to sidewall)

K = downwards (normal to base)

y = particular parcel number from i=1 to n for the specific office parcel data under test.

Similarly $\mu_{a,b,c}$ = friction coefficient of material "a" in condition "b" for the parcel.

The subscripts of $\mu_{a,b,c}$ are given by:

a = either B for Base, or W for sidewall (e.g. steel, cotton) to index the correct coefficients for the surface.

b = from the combination of either MST (static) or MSL (sliding) friction for the specific wrapping against the specific belt or sidewall.

c = the particular parcel number so that the correct friction coefficients for the wrapping may be indexed.

If this is true there is no jam. Should this be false then the following condition is tested:

$$\sum_{i=1}^{n} F_{K,i}\ \mu_{B,MSL,i} > \sum_{i=1}^{n} F_{J,i}\ \mu_{W,MST,i} \qquad (2)$$

(The symbols are as for equation 1)

Should this equation be true, (i.e. condition (2) is true when condition (1) is false), then the jam forms, but breaks up and is incipient.

If both (1) and (2) are false then the jam forms and is permanent.

Thus this system declares:

1. No jam.
2. Incipient jam - forms but breaks up.
3. Permanent jam.

This is expressed in flowchart form in Fig. 5.14. (Page 375)

5.5.3 Analysis of the Jamming Conditions

The programme therefore gives only three of the six classes originally suggested. This is due partly to the programme not having the facility to load preset configurations of parcels, which would be likely to cause jams, and partly to using a straight conveyor section which does not provide a source of jamming. The other three outcomes would result if complex shapes, for example, and "L" turn or variable flow patterns with preset jam configurations were used. This could be the basis of further work.

The programme achieves a balanced number of contact points on each sidewall. The programme includes an endogeneous variable which could increase the number of sidewall contacts during loading. This was incorporated into the system so as to simulate the settling down of a full conveyor, which pushes parcels towards the sidewalls.

5.5.4 Parcel Pressure Calculation

The programme calculates the forces on the parcels and calculates the pressures for the maximum forces on each parcel, over the areas that each of the maximum loads are distributed. Obviously this will depend upon the compliance of the parcels. Each parcel has recorded in the data bank the nature of the parcel and this could be applied to an adjustment here. Since the model is based on the assumption that each parcel is a rigid body, the adjustments have not been programmed. The flowchart is shown in Fig. 5.4, which gives the system to calculate parcel pressures. (See page 366)

6.0 THE COMPUTER CONSIDERATIONS

As has been said before, the advantages of using the "inhouse" computer at Brunel, outweighed the disadvantages of the system, as it then existed. The facilities of the CDC 7600 were not yet envisaged, so any consideration of whether the file handling of the ICL system, using the GEORGE 3 Automatic Operator, is better than the CDC 7600 system, using SCOPE 2.0, is purely figurative.

The problems of the ICL 1903A system of hardware, software and operation, have therefore become an integral part of the research. Much of the following chapter is devoted to problems which were specific to the Brunel system at that time, and are typical of those likely to arise every time a system change is made.

These changes were to the hardware, such as the various core and disc additions, or of software, such as the change from GEORGE 2 to various marks of GEORGE 3 and the FORTRAN compilers.

Many of the terms used in this section are from the vocabulary that is peculiar to computing operations. The Glossary of Terms, in the frontspiece, page v, may prove useful to those unfamiliar with words used in this section.

6.1 COMPUTER CONFIGURATIONS OF THE ICL 1903A

The computer system used for the bulk of the work was an ICL 1903A. The configuration included in 1971-4, when the bulk of the computer simulation work was carried out :

Central Core Store	32 Kwds (1971), 64 Kwds (1973), of 24 bit words. The core to core cycle time is approximately 2 microseconds.
Random Access Magnetic Disc Memory	4 EDS8 consoles
Sequential Access Magnetic Tape Memory	4 decks (550 bpi)
Paper Tape Reader	300 characters/second
Paper Tape Punch	110 characters/second
Card Reader	300 cards/minute
Card Punch	100 cards/minute
Line Printers	1 medium 600 lines/minute 1 slow 300 lines/minute
Graph Plotter	Calcomp A4 flatbed
Scanner and Communications Processor	ICL 7903 telex ports
Terminals	110 baud, ASR 33 data dynamics type (9 terminals connected in 1973)

Most of the runs have been made in the single or dual processing mode, not multiprocessing. The MOP terminal could only be used for editing files, and the programme could not be run from the terminal, since the remaining core available to the programme was too small. The apparent run time was increased when dual processing was in operation, and so computer times varied according to the work load condition. The operating system was originally GEORGE 2, and later, GEORGE 3. The compilers used were XFAT, XFAE and eventually XFIV, all FORTRAN. The XFIV compiler was markedly superior for this particular research, as it offered extended features over the previous versions.

6.2 USE OF THE "EDITOR" OFFLINE OR ONLINE EDITING

At first sight the use of the MOP terminal under the GEORGE automatic operating system would appear to have such an enormous potential advantage over any other technique, that the use of the off-line editor might appear pointless compared with correcting cards in a card pack. To simplify the discussion for those not completely familiar with the ICL 1900 computer, the three techniques can be defined as:

1. Batch Operation using a card pack. A card pack was used to input the programme each time it was run. Any corrections were made by changing or adding cards as required. The card pack only just fitted into a steel box 12½" long, since 1650-1850 cards were needed. These would take a minimum time of 5½ minutes to read at full speed and the possibilities of a card being misread or missed out were great, especially when the card reader needed adjustment or replacement due to wear. The job was run under the BFORTRAN MACRO call for compiling.
2. Batch Operation using GEORGE files. A few job cards were input which called up a file in source language, i.e. FORTRAN. The necessary edit was made by means of the EDITOR operating under GEORGE and then the job was run by calling the file using the BFORTRAN MACRO call. This was all one computer job.
3. Terminal Operation. By means of the terminal, the files required were retrieved by the MOP system and edited using EDITOR. When the file was correct, the job was run using the BMACRO, under batch operation, since there was not sufficient core at that time to allow operation under MOP.

The advantages of each system are not obvious and different techniques have been used at different times and this is discussed more fully later in this section (see 6.8, 6.9 and 6.10).

6.3 THE BINARY PROGRAMMES - SAVE AND KEEP

The ICL 1900 system runs every job twice, if it is in source language, such as FORTRAN. When the programme was being developed or modified, there was little point in doing otherwise. Once the programme reached the point of stability, where it was to be used for a section of research, there were many advantages in retaining and using the compiled file in the binary language. The core size required for the programme was reduced from over 32K down to 17K, comparing the source to the compiled binary version of the programme. Similarly, comparing the time used, the time of occupation of central processor (mill time) for the compiled binary version was reduced to as little as one fifth of the compile, consolidate and run time for the source. The GEORGE BFORTRAN MACRO responds to an additional parameter KEEP which retained the source file, which was in the FORTRAN language. An additional parameter SAVE, plus another GEORGE file name, retained the binary compiled file. This enabled subsequent direct running of programmes either by the RUN or RUN JOB ICL MACRO calls or, for the programmes of this research, special MACROS, written by the author. The latter were necessary, since multifiling was used for the input, including a steering file, which was needed to define the conveyor and other exogeneous factors, and also the file of parcel data from the particular office, which was read separately.

Once again, a reminder is made to the reader that the Glossary of Terms will prove useful as an aid to those unfamiliar with the meaning, or unaquainted with the particular usage of words that are essentially "Computer Jargon".

6.4 USING THE ICL 1900 FILESTORE SYSTEM

With small programmes, the use of the 80 column punched card as an input medium,has many advantages for amending and editing the programme, since incorrect cards can be amended by writing a new statement and punching a new card,which is substituted for the existing card. As programmes become larger than the simple programme, which is usually about two to three hundred statements, then the card reader time,to input the programme to the computer,becomes a source of errors and lost time. To overcome this, a file copy of the programme is kept in the GEORGE system, and this may be up-dated or changed by means of the GEORGE facilities as corrections are required. Additional facilities make it easy to keep and maintain security copies, in case an amendment ruins the programme irretrievably, or if the system MACRO call is made with missing parameters, and the system is then allowed to erase the file copy. The exact location of a file, and whether it is a magnetic tape file or a disc file, are the responsibility of GEORGE, and there is no need to keep additional files on various magnetic media. It is prudent to keep the original card pack or an amended version punched by the computer. If files are used very infrequently, say annually, then there is a small risk of them being lost by the system, and a further facility is available for a user to copy out the files onto his own magnetic tape, which is outside the GEORGE system, and can be used to recreate the files at any time. Such facilities are especially useful when binary files are created using a particular compiler. A change of a particular version of "mark" of compiler can bring to light small errors in programming tolerated by the original compiler or extension statements beyond usual FORTRAN statements which are inadmissable for other computers. This, then, can cause failure of a source programme,which had been running satisfactorily under the previous mark of compiler.

6.5 THE MANAGING OF FILES - FILE LIST; FILESWEEP; COPY IN; COPY OUT

It is prudent to keep three copies of each of the programme files in the GEORGE filestores during the period of development, which necessitates amendments and editing of the programme. This may seem wasteful, but it is essential to be able to recreate any files lost through operator, programme or system error. The three files are usually known as generations, such that the first generation produces the second generation, then the second produces the third and so forth. To avoid high numbers, the files are usually labelled son, father or grandfather (the suffix S, F or G will be all the identification needed). When a new "son" file appears, then the existing son is transferred to father, father to grandfather and finally the old grandfather file is erased or "killed".

The files are listed in Table 6.1, which shows the number required. They were so numerous, that to avoid keeping too many sets of cards, the files were copied on to a magnetic tape. The COPY OUT routine does this and the JOB card list is given in Table 6.1. It will be noted that there are a second set of file names to identify the file within the tape, in addition to the file name known to the GEORGE system. These are also given in Table 6.1. The files can be copied into the system by using COPY IN, and any number of files from one upwards may be copied in by using the GEORGE facility.

The disc files are cleansed of little used files,by the FILESWEEP of the system, which clears out any unused student files after one week and staff files after one month. Accordingly, some sort of security is essential, since some files which are needed in the future may well not be used during any one month, while some other aspect of the research is being pursued.

6.6 GEORGE FILES FOR INPUT, OUTPUT, PROGRAMMES AND CONTROL

The use of GEORGE files for input and output is a highly efficient method of operation since the time required by the computer to access the file is only fractions of a second and the utilisation of the central processor unit (CPU) is increased, since the likelihood of being limited by the input/output facility is reduced. This is often called "I/O bound". The opposite, when the peripherals wait for the CPU, is known as "compute bound".

6.7 MACRO WRITING

Because the multifiling facility of the ICL 1900 system was used, neither the standard ICL MACRO calls, nor the inhouse BRUNEL university MACRO calls could be used with the binary file copies of the programmes. Accordingly, two MACROS were written, called PRUN and SRUN respectively, which would run the binary programmes, calling in the appropriate binary and data files, and producing output files as required.

The ICL publication, "GEORGE 3 and 4 Operating Systems" (ICL 1972, TP4267), was invaluable for writing these macros.

Only experience can provide the knowledge of what organisation is needed to run any programme efficiently, to ensure that the proportions of control exercised by the GEORGE MACRO and the FORTRAN IV programme respectively, are properly balanced to give the most efficient operation.

6.8 BATCH OPERATION USING CARD PACKS

Large card packs were used, ranging from about 1400 statements for the source programme, to about 250 to 450 data cards for each office chosen. Thus, the combined total of source, data and job pack, is from 1650 to 1850 cards, which was one whole steel box. Every time this was fed through the card reader, there was a chance that it would be misread or would misfeed a card. A card might become displaced or, even worse, the card box might be dropped and become shuffled. In the later years of this project, the card reader had become more and more worn, so that the input of a complete programme from the card deck was unlikely to be completed without error. Fortunately, the need to recreate the files from the card decks was something which only happened very rarely. The system kept its own security dumps, so that card copies were not needed, unless a major system collapse occurred. It is not really fair to the operators, or efficient, to use card decks repeatedly for editing. In any case, the cards themselves are subject to wear and damage as they are used, and new copies must be made after a pack has been in use for a little while, otherwise the free running of the computer becomes impaired, since the operators have to deal with the misfeeding or card damage as it occurs. After a pack has been through the reader some 8 - 10 times it is suspect, and it is unlikely to be serviceable after 20 times through the reader. A really worn pack becomes difficult to reproduce and many cards have to be re-punched since they fail on the comparison after reproducing.

Hence we may reject this technique from that standpoint alone. However, there is another drawback, in that the source is recompiled every time it is run, and this is unnecessary, since a binary compiled programme avoids the need for compilation. This saves one pass, reduces the core required and, if the trace error programme is deleted, makes further reductions in core and time.

With smaller programmes these problems are much less and many workers favour the use of card decks. In these large simulation programmes the difficulties were such as to render the use of card packs impracticable. Quite apart from the problems mentioned, it is not the easiest of things to find the correct card in the middle of a box and certainly slower than producing an edit.

6.9 BATCH OPERATION USING GEORGE FILES

This technique used GEORGE FILES for storage of the programme and edited the file as required as part of the job, together with any housekeeping to maintain personal security files. The simplest and easiest technique is the grandfather, father, son system. In this, the father is the latest version of the programme, and the grandfather is the next most recent version, both of which are retained. A new file called son, is to be formed from the father, or most recent file. Should the father file be corrupted or lost in the edit, and also the new son file, then the grandfather version is still available. If the grandfather is up-dated at the commencement of the edit, by copying into it the father file, then the most recent version is still available to recreate father and another attempt to form son can be made. This would be the practice whether offline or online editing is done. The weakness of offline editing is that any incorrect editing is not discovered at the time, and the actual run is put off until the next available occasion. The necessary skill is acquired very rapidly and the offline editor is extremely useful for producing special programmes with only a few modifications, and then running them immediately. Since the terminal core limit of 20K at the time of this research did not allow the running of FORTRAN programmes at the terminal, and since the compiler XFIV takes 32K of core space, the actual time comparison was in favour of offline editing, since it was quicker to punch the cards than wait for terminal responses. A variation on the offline editing was to prepunch the edits on paper tape using a terminal in offline mode. This speeded the terminal operation and was superior when programmes were run from the terminal. This was the case when COBOL language operation was performed from the terminal.

6.10 MOP TERMINAL OPERATION

The terminal operation was not available all through the day and was at two levels or tiers. The first level of operation allowed for the use of core up to 20K per terminal, but since the machine itself was only 64K, it is easy to see that if only two or three users formed core images and wished to run jobs, then the service offered to other users could be degraded very rapidly and this was the case. The practical limit of usage was five users on this level, but the situation was made more complex by the fact that there were three remote terminals, one in the computer unit, and the others in the Physics and Chemistry departments. Hence, although five people could be booked on the machine, only two of them would be visible in the terminal room in the centre, where nine terminals are located. This gave the misleading impression that a good service would be available. It was found that jobs were being put onto the machine via the terminal that did not finish for some hours after the terminal operation ceased. To overcome these problems, which were causing a deterioration to the standard batch operation, second tier MOP was introduced, that is, file editing on the terminal was allowed during the morning and the MOP first tier was moved to the early evening.

While this greatly reduced the degrading of the batch service that could be caused by some five users, against the 150 to 200 batch users on the same day, the results were hardly satisfactory. With second tier MOP, about eight users could be accommodated before the terminal service deteriorated to a completely unacceptable extent. This degradation was such,that no response of any kind was obtained for some minutes from a terminal,which prevented even logging in. Secondly, the eight users, which is small by any normal terminal service standards, were sufficient to completely clog the file handling capability of GEORGE, so that file retrieval could take more than the one hour allowance of terminal time. While this was partially overcome by asking for the files via the operator, some one to two hours before the time of a session, who then called for a retrieve via the command RV, there were still very long delays due to excessive retrieval times. Additionally, every file had to be asked for individually, since a complete user library could not be called in.

This problem meant that the one hour period was usually insufficient to bring the required files to the programme areas of the CPU.

6.11 THE STATISTICAL ANALYSIS PACKAGES STATANAL, ASCOP AND SPSS

There were difficulties in establishing, whether the difference between parcels from the various offices were significant or not, and the ICL 1903A computer was used to analyse the parcel data.

Initially STATANAL was tried out, but was found to be awkward in use and not suitable for this problem. ASCOP became available on the ICL 1903 and this was tested and discarded, owing to there being some doubt about the package, which was under development and had given some peculiar results in this and other work. It did show the advantage of using a statistical package and so the data was analysed on the CDC 7600 using the SPSS package. A number of versions are available and the smallest SPSS 100 was used for the majority of work to ensure a quick turnaround. This was only made possible by the installation, in 1975, of a high speed MODEM linking at 4800 bauds to the CTL MODULA 1 RJE (Remote Job Entry) Terminal. Previously the slow speed of the card reader (then linked at 330 bauds) and problems with both card reader and emulator, (which enabled the ICL 1900 cards to be read by CTL and CDC systems) had prevented the use of this system. Thus, in 1975 it became possible to run subsidiary programmes on the CDC 7600. File handling and storage problems, still precluded any serious use of the CDC 7600 for the simulation. Not to be overlooked, was the problem of converting the FORTRAN IV code to suit the CDC compiler, and difficulties with the fast and slow core transfers.

6.12 THE PREPARATION OF PROGRAMMES

The production of a programme which ran was not by any means the final stage before the experimental trials. There were many "bugs" (errors) which had to be removed and the more complex the programme became, the more subtle these were. A number of compilers had been used and each version of the compiled programme produced from the various compilers was different. In the period 1969 to 1970, when the configuration consisted of 32K of core store, with four tape decks and EDS 8 discs, the FORTRAN compiler in use was XFAT, a tape compiler requiring 16K. This compiler was changed at the end of 1970, after the installation of a further two EDS disc stands, and the increase of core store to 48K. The new compiler was the XFAE disc compiler, which gave FORTRAN in a somewhat similar version to the XFAT. This was for running under GEORGE 2 operating systems. When the configuration was further enhanced in 1972 by the addition of further core store to 64K, then a new operating system, which offered the user a file store facility, was implemented. This was GEORGE 3 and during the period 1973-74 the mark in use was 6.6, in late 1974 this was up-dated to 7.2.

During the whole of this period a convenient limitation on job size was around 20K. Most of the modules were well under this size from the time they were written, so that every test run was kept within the 20K and 300 second CPU time which ensured a rapid turnaround. The whole programme was always kept within 32K, since if it rose above this size, it became known as a "very large job" and turnaround dropped to once a week or worse. Jobs of a size requiring more than 20K were not a real problem in the later years, however, unless they were to be run from the terminal under the MOP system, which then had a 20K core limit. This range from 20K to 32K became known as "large jobs" and could only be edited from the terminal system, due to system limitations, and must be run as a batch job. However, a further complication was that the University had standardised the XFIV EXTENDED FORTRAN (FORTRAN IV) compiler which required 32K of core, without any allowance for the operating system. Hence, although batch jobs in general were not limited to under 32K, jobs needing to compile in FORTRAN, could not be run on MOP, since the XFIV compiler size exceeded the MOP core size limit. One or two ways of overcoming this were possibly available, since, for example, the XFAE compiler requires only 19K. The use of these would have involved "beating the system" and so were not employed.

At this stage much tedious testing was essential, to ensure a reliable programme resulted, which would consistently pack parcels in a simulation of the real world situation. When this was finally accomplished, the tests which had originally been only on data from Brighton office, were extended to all the other offices. To help in this, there were some modifications made to the print-out from the programme. To aid in the validation of the loading, all the locations of parcels were given; together with the positions of each corner; the attitude, i.e. whether plane up PLU, line up LU or point up PU; data concerning parcels underneath; and all the forces and parcels contacting a parcel from subsequent loading. This was a large number of pages of output - for example, to output the positions of each corner took up to 1000 lines of output alone - and to overcome this, it was possible in the programme steering to specify whether this positional and diagnostic data should be output or not. In the same way, since a binary version of the programme was used, it was necessary to write a GEORGE command language MACRO and in this there was no programme listing, which saved a number of pages of output. A further refinement was then written, so that it became possible for two input data files to be used. One contained the steering instructions for the run, the size of conveyor, which office the data cards should be, for checking purposes and so forth, and the other data file contained all the parcel data, each parcel carried its own identifying office code so that easy checking was possible. This reduced the data file input to four cards only, the remainder being kept as GEORGE files.

7.0 DISCUSSION OF RESULTS

7.1 THE CHECKING OF THE DATA CARDS

7.1.1 The First Data Checking Programme

The first requirement in data checking arose from the parcel numbering system. In the original concept each parcel carried its own number, with respect to the different offices, so that Birmingham parcels were numbered from 1 to 381 in columns 2, 3 and 4 and were prefixed by 1 in column 1 on the data card and so forth. The advantages of this were that, if a card was misplaced, it would only affect the loading pattern and the relevant matrices would be filled when the card arrived. In the event this caused more trouble than it was worth, since when the card reader started giving trouble there were cases where two cards went through at a time and the underneath card was never read. This caused the relative matrix storage line to be empty, since all matrices were set to zero at the commencement of each drop. This then gave rise to complications on the subsequent parts of the programme. Initially a comparison was made with the number of cards read as against the final filled matrix line, but this was very little use, since the problem was so protracted with the card reader that a new system was needed. However, as a first step, a data checking system was devised which examined every card for correct office and whether the parcel number was in sequence. If this was not the case then a warning was output. Additionally, the data for the parcel was checked for obvious discrepancies in the values for each attribute, indicating whether the value was outside limits or sufficiently so to cause programme failure. An additional problem with the data cards as punched, was that some alpha characters had arisen due to faulty action of certain punches. These caused the data checking programme to fail at that data card, since this is a "built-in" fatal error. By use of the FTRAP ERRS call it was possible to overcome the fatal error and carry on from the error point, output at this point giving a warning that a fatal error consisting of character "x" existed on card number "xxx" in field "xxx". This was only of use in putting the data cards, just over 2,000 in number, in order and eliminating gross errors and alpha characters in the data field. It was not suitable for the more subtle problems which arose, especially concerning the values of friction coefficients.

Values of Friction given by the Statistical Survey

It became obvious that the values for some of the friction coefficients on some of the parcels in the original survey left a great deal to be desired, and this came particularly to the fore when considering plastic wrapped parcels.

Polyolefine wrappings were only being used to a very minor extent when the survey was made, and it was easy to find manually, approximate values for these coefficients. These did not agree with some values for the friction of some ICI polyolefine materials carried out by the author some years previously and so enquiries were made to the Post Office Engineering Department to see if they had some more up-to-date information on the coefficients of friction of plastic parcels. They themselves were concerned with plastic parcels and some research was put in progress and in due course the results were made available. (Eden 1971). The main programme was changed by the insertion of a module, which gave a register of more suitable values of friction coefficients, and also a new data checking programme was written.

7.1.2 The Second Data Checking Programme

To establish more exactly the value of parcels from the Post Office Statistical Survey (Castellano, Clinck and Vick 1971) this programme was very much more sophisticated than the first and gave a statistical analysis of the size and weight of the parcel. The proportion of parcels of the different wrappings was also given and the mean coefficient of friction found for each group at each office. An additional feature was that the computer, plotted histograms of each physical dimension automatically, using the line printer (see appendix VII,p. 309). Table 7.1 (Page 378) gives a summary showing the respective percentages of each wrapping, naturally only relevant to the time of the survey.

7.1.3 The Data Parameters Checked

The first data checking programmes were relatively simple and comprised about 100 FORTRAN statements. At the time cards containing the data on each individual parcel were preceded on the data file by cards with various items of steering, including the four random number seeds. The second data checking series was designed to use the GEORGE 3 user file system and read two GEORGE files for data. The first of these gave the steering information for the office, conveyor dimensions, data on the percentage plastic wrapped parcels and their frictional properties, and instructions as to what extent diagnostic information on the load process was to be incorporated into the printout. The random number seeds were incorporated into the programme which, by that stage, was using the ICL 1900 random number generator FPMCRV.

The steps of the data checking process were:

1. Read conveyor dimensions.
2. Print out the conveyor length, width and height.

3. Read random number seeds.
4. Check random number seed is not equal to zero. (Early programmes only).
5. Read Office number.
6. Check bounds of Office number.
7. Print Office name; or a warning message if not recognised.
8. Read Belt and Sidewall materials codes.
9. Check Belt and Sidewall codes are acceptable.
10. Print name of Belt and Sidewall materials; error warnings as required.
11. Data card is read for a parcel.
12. Convert the length, breadth and height to nearest inch, increasing any dimensions less than one inch equal to one inch.
13. Check the Office number on card agrees with the Office already defined for the data.
14. Print out a warning if the individual parcel data card is either not defined or incorrectly defined as to Office, in case a card has strayed or been misplaced.
15. Check that the individual parcel data card sequence number is correct.
16. If the card is incorrectly placed, give a warning, indicating both the actual and expected sequence numbers to enable relocation to be carried out.
17. Check whether weight is inside Post Office regulations; classify into minor and major infringement.
18. Output a warning and actual value if the weight is above specification.
19. Check that the length is inside the maximum value possible if parcel conforms to Post Office regulations, and classify into minor or major infringement.

20. Output a warning, giving details of length, if infringement occurs.
21. Check width, in a similar way to length, and output warning.
22. Check height, in a similar way to length and breadth, and output warning.
23. Check that the girth is inside the Post Office regulations; (Post Office 1971b) that is: Length and Girth must not exceed 72 inches.

    Girth is half the sum of breadth plus height.

    $$G = \frac{(B + H)}{2}$$

    where: $L >= B >= H$

    then $\Sigma\ (L + G) <= 72$ to meet Post Office regulations

    where: G = Girth of individual parcel as defined above

    L = Length of individual parcel i.e. the longest dimension

    B = Breadth of individual parcel i.e. the intermediate dimension

    H = Height of individual parcel i.e. the shortest dimension

24. The programme may list the cards, according to how the data checking steering information is preset.
25. The mean and standard deviation are calculated for length, breadth, height and weight.
26. The histogram points and class breakdowns are established for length, breadth, height and weight.
27. The parcel data, which had been stored in a matrix, is used to produce a histogram.
28. The statistical data and histogram is output for each variable.

Some of the functions need not have been programmed if the SPSS package had been available at the beginning of the research. Appendix VII, p. 309, shows the statistical analysis carried out on the ICL 1903 using programmes written by the author. Further analysis used the SPSS package on the CDC 7600, shown in Appendix VI. (Page 298) Additionally, some analysis of friction was carried out on the CYBERNET SIGMA 7 using the STAN package. Very little use was made of the 1900 ICL Software for this statistical analysis. The ICL package STATANAL was found of very little use and the NAG (Nottingham Algorithm Group) package called ASCOP was only partially implemented at the time this research was concluded. However, some use was made of ASCOP, but it was, in general, found inferior to SPSS. The SPSS package is more fully discussed in section 7.7. (Page 230)

One feature of the ICL machine operating software was particularly useful in the data checking programmes. FORTRAN programmes are normally operated at run time in such a manner as to fail if there is incorrect data in the data input. For example, if alpha characters or real numbers are found in integer input data, then the programme ceases to run and no output results. By using special steering information in the ICL steering segment prior to the MASTER segment in FORTRAN, and specifically the command "FTRAP ERRS" it is possible to output a warning of the execution error and resume the programme. There are limitations to controlling failure of a run, depending on the computer, and this is discussed in Section 7.4.2. (Page 183) The data itself had many errors which arose in punching; one common problem was where "u/s" was given in the data table instead of a numerical value, to indicate "unstable value". As it was known that any alpha characters would cause failure the columns were left blank. Unfortunately, the data check programmes did not check this, since this problem had not been foreseen. The computer simply read the blank columns as zero, and anomalies started to arise. The correction of this error is relatively simple in the SPSS statistical analysis programme. For the data, programmes were written which corrected the omissions and punched fresh cards to enable the data to be read into the data checking programme. This was used with GEORGE 2 prior to the adoption of GEORGE 3 and the user file system.

The distribution of size and weight were included in the statistical analysis and plotting of the various offices, which considered length, breadth, height and weight for graphic and numerical analysis, and friction coefficients for numerical analysis, together with an analysis of the parcel wrappings for each group.

7.2 ANALYSIS OF THE PARCEL DATA

Analysis of the parcel data brought benefits that had not been foreseen. At the time the data was collected, the use for wrapping purposes of plastics, such as polythene and other polyolefines, had not been widespread, as will be seen from the analysis in 7.3.1. (Page 165) The effect of these materials on the friction behaviour of parcel conveyors, as reported from the parcel offices, was not borne out by the results of the analysis of the parcel data and so further research was necessary. Initially the nature of the friction of plastic wrappings against conveyor belt and sidewall materials was investigated. The results of this and also the initial parcel data checking, confirmed that the classic view of Coulomb friction was not upheld, as far as the ratios for static and sliding friction were concerned. This is discussed in the section 7.3.1 in Results of Supporting Studies. (Page 165)

Another aspect of the data analysis was the question of whether it was possible to consider all parcels as consisting of a single material, very inhomogeneous, which could be regarded as "parcel". There were two methods of attack here, one consisting of the initial analysis, discussed in this section, and the other was the work using statistical packages available on the ICL 1900 and CDC 7600 computers which is discussed in the sections on supporting studies (Section 7.3) (Page 165) and statistical packages (Section 7.7, Page 230).

7.2.1 Distribution of Types of Wrapping

The overall distribution of the parcel wrappings for the various offices can be used to estimate whether the parcels are all from similar populations or, in other words, whether there is one species which can be regarded as "parcels". The distribution for each of the offices is given in Tables 7.2 to 7.7, (Pages 379 to 381) together with the distribution for all parcels (Table 7.8) (Page 382), in a slightly different form to that given in Table 7.1 (Page 378). The sacking, wood, fibre and other wrapped parcels are all grouped together as "other" in the series of tables 7.2 to 7.7 (Pages 379 to 381). The differences in percentage of various wrappings was examined by means of chi-squared comparisons. This cannot be carried out from the percentage values, but is calculated on a basis of the number of parcels in each group. The values are tabulated from 7.9 to 7.11 (Pages 382&3). Examination of these tables will show a barely significant difference between the offices in the distribution of wrappings at just over the 1% level. Despite the difference in sample sizes, NWPO being smaller than the rest, the differences are not related to sample size. Two of the larger samples, from Brighton and Liverpool, show differences in wrappings distribution. Of these two, the Liverpool office shows the greatest variation in the percentage of cardboard parcels, but the values of paper, plastic and others all differ to lesser extents from the expected values. On the other hand Brighton office shows a variation in the "other" wrappings and to a lesser extent for the plastic. A more detailed examination of the data shows this is due to there being no other wrappings than paper, cardboard or plastic shown for the 381 parcels in this sample. This is probably due to sample variation, since the sample is limited in its nature due to the cost of extended sampling. This explanation cannot be extended to explain the difference in the Liverpool sample, which appears to have different characteristics. As a further test the Brighton and Liverpool samples were removed from the group and the χ^2 test carried out again. With the Brighton sample removed there is still reasonable evidence of wrapping differences and chi-squared is just significant at the 5% level (See Table 7.15). Values are given in Tables 7.12 to 7.20 (Pages 384 to 388). However, when the Liverpool sample is removed the differences in distribution are no longer significant. (See Table 7.20) This demonstrated that the Liverpool differences are causative, and unlikely to be due to sample differences, while the Brighton sample may show a difference due to sampling variation. Similarly the variation in cardboard wrapped parcels for Croydon and NWPO, which is only slight, may possibly be sample variation. However, it is important to realise that the sample size of 240 to 419 is a reasonably large one to detect the cardboard parcels, which are present to about 34% of the sample, whereas to detect the plastic parcels (about 1%) and "other" wrappings, sacking .5%, wood .2%, and fibre and other .3%, requires large samples. Examination of Table 7.8 (Page 382) shows that, in the 2087 parcels, at that time there were only 18 plastic wrapped, and 21 "other". These 21 "other" parcels can be further subdivided into 11 sacking, 4 wood and 6 fibre and other. Since these unusual parcels are likely to be causes of disruption and jamming they are of interest, but the costs of surveys and tests might be prohibitive. A problem is the time lag between survey and publication of results, because the nature of the parcel and its wrapping changes continually. The Post Office suffers from being a national carrier, which implies that a parcel service must be provided to all comers. This means that the more profitable parcel operations can be creamed off by private enterprise and, to some extent, nationalised undertakings such as BRS Parcels and National Freight. It might be simpler to restrict the Post Office parcels service to a more regular size, shape and wrapping to enable conveying equipment to operate more efficiently and economically.

7.2.2 Friction Coefficients of Parcels

The parcel data used as a basis for the report by Castellano, Clinch and Vick (1971) included a set of coefficients of friction obtained by a conventional sliding plane technique using the parcel as a slider on a plane of steel or cotton, rubber or Scandura belting. Scandura is a particular type of elastomeric surfaced conveyor belting. These materials were analysed and the average coefficients were calculated. The results are tabulated for each material in Table 7.21. (Page 389) The values given by the data checking programmes were very interesting, in that they gave values which did not agree with conventional theories for static versus sliding friction. The values given for sliding friction are higher than the static friction for any combination, and in some cases are considerably higher than 1.0. This is of course, not possible theoretically, as far as the older conventional theories are concerned. This is discussed in Section 7.3.1. (Page 165) Further to this, the values for the few plastic parcels present, given in Table 7.21, p.389, are always estimated as having much the same frictional coefficients as cardboard and brown paper. This is discussed in 7.2.1. (Page 159) The only wrapping material with different characteristics is sacking, according to analysis of data from the survey. For sacking to be the only wrapping with unique values does not agree with previous work by the author on the inclined plane sliding characteristics of ICI polyolefines. Some further research was instituted on this, and this lead to the discovery that relative humidity had a marked effect on the friction characteristics of parcel wrapping and belt conveyor structural materials. This is discussed more fully in 7.3.2. (Page 173)

One further consideration was the question of stringing and jamming. The effects of stringing and banding,in jamming,is much more than their effect on friction performance, which is presumably due to catching and snagging,at gaps in the conveyor,between a sidewall and any other discontinuities. There was no attempt to model this because it was felt that causative influences, such as string jamming and catching in the conveyor, and interference caused by "awkward" parcels or configurations of parcels, should be the basis of further work.

7.2.3 The Idealised Parcel Material

It became apparent early in this project that if an idealised material could represent all parcels, then the problems of writing and creating a simulation would be markedly reduced. Accordingly, the parcel data was analysed with a view to establishing this. It gave only limited information, however, so that in a first analysis, only frictional properties and size and shape of the parcel could be considered. Section 7.2.2 (Page 161) discusses the friction aspects from the data. An analysis of the shape and size has been carried out in Section 3.4.1 (Page 67) and some of this analysis was applied to the data. Particularly the "Volume of the Group" $\bar{V}$ and the "Shape Factor" S_v were calculated using the basis outlined in Section 3.4.1. (Page 67) The results showed a surprising coincidence between the six parcel offices and a marked difference to the letter packets at WDO. Since the differences between the parcels had been stated to affect the behaviour of the parcels in conveying, it was felt that other indicators might be helpful. Therefore, a new measure was devised based upon the product of (average length, multiplied by average breadth, multiplied by average height) and called P for simplicity in use. These results are tabulated in Table 7.22, (Page 389) which gives the average volume, and in P.390,Table 7.23, which shows the values of P, $\bar{V}$ and R_p (a useful ratio of P to $\bar{V}$ ($^P/_{\bar{V}}$))and finally S_v. The usefulness of these analyses is limited, since they only serve to intensify the differences in the dimensions. It is true that they select the offices where parcels have different characteristics, for example Liverpool, which shows an S_v which is the highest, whereas the value of $\bar{V}$ is the lowest and R is about average. On the other hand, the parcels at Birmingham and Croydon show markedly low values of S_v, which indicates regularity in the dimensions (nearer a cube). This could possibly be related to the number of types of jams, if the data were available. The analysis shows that measures of physical shape and size may be derived, but relating these measures to jamming performance is beyond the scope of this thesis, owing to the difficulty of gathering information. It was possible to extend the study of the composition of parcels further by a study of the stiffness and modulus of parcels, which is discussed in section 7.3.3. (Page 178) This area might be very fruitful for future projects. If a good statistical analysis package and the data were available, then it would be possible to establish the possibility of using statistical methods in the design of conveying systems for a material so variable as "parcels".

7.3 RESULTS OF SUPPORTING STUDIES

Some aspects of the simulation modelling brought to light areas of study which were required. The three main areas covered were an analysis of the frictional behaviour of conveyor constructional materials, and parcels, the effects of relative humidity on the performance of materials, and the analysis of parcels material properties, especially stiffness. Since they represent research independent of the simulation model, carried out on these specific areas, they are reported upon separately in this section.

7.3.1 The Analysis of Frictional Effects in Conveying

The classic view of frictional behaviour quotes the work by Coulomb in 1781, and gives the value for sliding friction as being about 25% less than the static value. For example, Fig. 7.25 (Page 391) shows the situation according to Shames (1959) and is taken from page 158 of his book. Higdon and Stiles (1962) review the work of Coulomb and Morin in a similar vein. (See their Chapter 5, p.204).

The visual studies of the parcel belt conveyors, which were carried out by the author, accompanied by a Post Office Engineer, at WDO, indicated that the sliding mechanism and such incipient jamming as was seen, was a function of the static and sliding characteristics of the materials. The mechanism of the parcel jamming was clearly one of jams which formed and then collapsed. This happened when an apparently increased traction and reduced restraining force could no longer support the parcels remaining stationary. Despite classical theory, the author felt that the only possible explanation was that static friction was less than sliding friction. This was borne out by a quick scan of the data by eye from the sample of 2087 parcels, which showed that friction ratios were greater than 1 for sliding/static coefficients in every case taken. A detailed study of the ratio was then carried out. It could be possible that this ratio was of more relevance to conveyor performance than the absolute value of the static coefficient of friction, as far as the behaviour in the formation and collapse of jams was concerned. Tests of belt materials had shown that it was not enough to select a belt material of high friction coefficient and couple this with a sidewall material of low coefficient. In Table 7.24 the values of the ratio of sliding to static friction coefficient are shown for steel, and for belting made of cotton, rubber and scandura. These ratios are derived from the data of Castellano, Clinch and Vick (1971) and confirmed by experiments carried out by the author and J. Eden (Eden 1971, Post Office 1971c). A laboratory test rig was constructed with a variable speed rotating turntable covered with the belt or sidewall material. On this was placed a one inch square slider, the rubbing surface of which could be covered in the various parcel wrapping materials. This slider could be loaded, normal to the disc, with the desired deadweight. The restraining force on the slider could be measured by a torsion spring, suitably calibrated. The speed range was from 50 - 250 feet per minute, and the pressure loading of from 0.01 to 1.00 lb/in^2 was applied to the surfaces in contact. The rig is shown in Fig. 7.27.(Page 392)

The increase in friction coefficient, as the conditions change from static to sliding, is critical in the jamming behaviour of parcel conveyors. A parcel in normal transit, is static on the belt, and sliding on the sidewall. Thus the higher coefficient is applied to calculating the sidewall drag, and the lower coefficient applies to calculating the traction force. If a parcel jams, then the position reverses, and the lower coefficient must be used to calculate the sidewall drag and the higher coefficient must be used for the traction force. Hence, the tendency will be for any jams which form to break up due to the reduction of dragging forces and increase in traction forces. This tendency will be increased by high ratios of sliding to static friction, given in Table 7.24. (Page 390)

It will be seen that the high ratio of steel makes it particularly useful in dispersing jams which form. When a jam forms, the friction force pulling the parcel along the belt increases by the ratio shown in Table 7.24, (Page 390) which for a cotton belt would be 1.84, if we use the average for all parcels as a basis for discussion. In the same way the friction force from the steel sidewall will be reduced by the ratio 1/2.82, using the value for steel given in the table, which is 2.82, taking again the average value for a steel sidewall. This tendency to change can be a useful evaluator for comparing various belt and sidewall materials. If a low ratio is found for forces after a jam forms, compared to forces before the jam formed, then the material combination tends to restrict the formation of jams. This is not related to the value of the coefficient of friction but, rather, to the increase in friction coefficient from static to sliding conditions.

Thus, when the parcel is stationary with respect to the belt,

Let the pull along the belt be P

and the drag from the sidewall be D

And, when the parcel is static with respect to the sidewall,

Let the pull along the belt be P^1

and the drag from the sidewall be D^1

then, for the cotton belt and steel sidewall the ratio of forces is:

$$\frac{D^1}{P^1} = \frac{D}{P \times 1.84 \times 2.82} = \frac{0.193\ D}{P}$$

In other words, the restraining drag is reduced to approximately one fifth at the time when the forces become equal and the parcel stops moving with the belt. This particular value uses an average figure for all parcels. It follows that, unless the restraining drag on the sidewall is five times the traction force, the jam will collapse and occur only incipiently.

This coefficient can be used to evaluate various combinations of belt and sidewall materials.

$$\begin{matrix}\text{Coefficient of}\\ \text{Friction change}\end{matrix} = \frac{1}{\begin{matrix}\text{Change ratio}\\ \text{in belt material}\end{matrix} \times \begin{matrix}\text{Change ratio in}\\ \text{sidewall material}\end{matrix}}$$

The values of the coefficient can be calculated and they will be found to vary with parcel wrapping also. In Table 7.26 (Page 391) the values of this coefficient of friction change are given for steel with a belt of either cotton, rubber or scandura, and also a parcel of either paper or polythene wrapping. The table also shows the values for a conveyor sidewall made of either varnished or plain maplewood. The friction values for these had been obtained from the laboratory test rig, shown in Fig. 7.27. (Page 392)

The known advantages of steel plates on the sidewalls are illustrated by Table 7.26. (Page 391) Under the most favourable condition of a paper parcel with a steel sidewall and a rubber coated belt, a value for the ratio of the force dragging the parcel compared to the belt traction force, is given as 0.195. In other words, the drag due to the sidewall must be five times the traction force to cause a jam. If the values for wood are studied, even though some caution should be exercised in view of the derivation of the values from laboratory tests, rather than sliding tests on a large quantity of parcels, then it is seen that in the worst case, with plain maplewood against a paper wrapped parcel on a scandura belt face, the drag from the sidewall need be only one and a half times the traction force to cause a jam. In the same way, when the results of the simulation are discussed in Section 7.5 (Page 189), it will be seen that the presence of various plastic parcel percentages seems to make little difference as far as jamming is concerned. This would appear to be related to the favourable values of the coefficient of friction change for polythene wrappings.

The rubbing speed of the parcel/belt or sidewall interface is also of significance in the friction behaviour. The test rig shown in Fig. 7.27 (Page 392) was used to evaluate this, and also the effect of contact pressure. The friction and wear of rubber has been well reviewed by Schallamach (1968). Grosch (1963) studied the friction of several types of rubber against hard surfaces, keeping the sliding speeds less than 30 millimetres per second (approximately 6 feet per minute). The reason for this was that above this speed self-heating occurred, as reported by Schallamach (1956). Further work was covered by Grosch and Schallamach (1966) on temperature effects on friction of elastomers. The temperature effect noted by Schallamach (1956) was present in the results of the laboratory tests and seemed to be dependent on speed and contact pressure. Fig. 7.28 (Page 393) shows the effect of rubbing speed on dynamic friction for maplewood, both plain and varnished against polythene and brown paper. The self-heating effect discussed by Grosch is seen to affect the friction coefficients of the polythene, but the major effects occur at around 800 feet per minute and above in the range tested by Schallamach (1968), rather than the 6 feet per minute of Grosch (1963). This higher speed effect was influenced by the type of surface. (See Fig. 7.29). (Page 394) To reconcile this difference some lower speed tests were made. This time the contact pressure was varied, and it will be seen that the coefficient

of friction will change at the low speeds of Grosch, if the contact pressure is above about 0.1 lb/in^2. (See Fig. 7.30). It would seem
(Page 395)
likely that Grosch allowed a safety margin to avoid any occurrence of distortion due to self-heating, and worked in the area where the curves of Fig. 7.30 rise steeply near the y-axis.
(Page 395)

A study of the literature had shown that for the pressure/friction coefficient a relation of the type:

$\frac{1}{\mu} = a + bp$ where μ = coefficient of friction

a, b = constants

p = normal pressure

existed. For example, see papers by Thirion (1946) and Denny (1953). Accordingly, the laboratory rig was used to evaluate the effects of contact pressure on friction coefficients and the results are plotted for maplewood against brown paper and polythene in Fig. 7.29. The
(Page 394)
failure of the specimens of polythene on varnished wood at pressures greater than 1.7 lb/in^2 is of interest, since the author's programme gave values for contact pressure for the lowest parcels which were occasionally higher than 10.0 lb/in^2 and fairly frequently above 1.7 lb/in^2. The highest value, ignoring compliance, was 14.4 lb/in^2. This is discussed more fully in Section 7.5.4. One further study was
(Pages 211 to 213)
made in this area and that was to test the inter-relation of contact pressure and rubbing speed upon friction behaviour. This is shown in Fig. 7.30 and reveals some very interesting features. The average
(Page 395)
pressure results from dividing the average parcel weight by the average area, which is given by the product of the average length, breadth or height. The value ranges from 0.037 to 0.120 lb/in^2 and it can be seen for the sample plot of brown paper on steel that fairly constant values would result from these pressures, irrespective of the rubbing speed, over the range from 0 to 200 feet per minute.

However, the parcels at the bottom of a conveyor would have pressures far above the levels of Castellano(1971). Using pressures from the simulation, the graph could be expected to show values for the friction coefficients (Fig 7.30,page 395) far in excess of those found in sliding tests.

A paper by Webber (1972) is of great interest, in that he found with rubber, that the pressure dependent friction characteristic was unreliable. To quote Webber: "In view of the departure of rubbery materials from the strictly Amontons-Coulomb behaviour an analysis has been made of the effect of variable friction coefficient on belt tension". His analysis showed that the coefficient of friction was area dependent, rather than pressure dependent, and that for areas greater than about 500 mm^2 the friction coefficient was 0.8 or greater. The maximum coefficient was around 1.4 to 1.5. This compares to the value of about 2 found by Schallamach (1968). Webber quotes textbooks as giving unity as a typical value friction coefficient, whereas practical articles give a value of 0.2 to 0.3. Webber found his values for the dynamic friction coefficient, for varying areas, and then adjusted the values to an effective friction coefficient, which correlates well with rubber performance in power belts.

This "area dependence" of the friction coefficient with plastic wrapping, is of great importance with plastic parcels, since the variation in the coefficient, according to Webber's paper, is around 2 to 1 for real, and about 4 to 1 for effective, friction coefficient, as the area of contact changes from something under 500 mm^2 to anything greater than about 2000 mm^2. That would be the difference between a parcel with a corner in contact with a friction surface, changing position so that a few square inches are in contact with the friction surface. This is the most likely explanation of the reported behaviour of the plastic parcel in causing jams, under conditions where a jam would not be expected to occur. If this effect noted by Webber, is compounded by the atmospheric condition, such as humidity and extent of acid dust particles and other active contaminants, then it is easy to suggest explanations of the peculiarities at offices such as Peterborough, with a high influx of plastic wrapped parcels in an inland rural environment which is relatively dry, or alternatively the humid coastal locations of Liverpool. In both of these offices, the effects of local mail order companies, distort the nature of the parcel traffic from the average.

The reason for the low value for the coefficients of friction for plastic wrappers, even though the whole parcel was in contact, seemed to be that the surface of the plastic had become abraded, and coated with dust and fibres from the paper and cardboard parcels, which predominated in the samples of parcel data. This was confirmed by laboratory tests, using a plastic slider on steel or wood and dusting it with french chalk, which reduced the frictional characteristics considerably. (Post Office 1971c). This gave similar results to Schallamach (1968). The relative humidity also affected the frictional coefficients, as discussed in Section 7.3.2. Consideration of the (Overleaf) operational conditions of the typical conveyor in a parcels office, which created a local environment of its own, also emphasised the importance of the fact that many offices operate under industrial conditions. Tests of environmental effects were felt to be outside the scope of the present work, but there seemed to be an area of laboratory research, in dusting the plastic slider with various mineral and organic powders, while operating the rig in a controlled atmosphere containing typical industrial contaminants, or even salt spray, to simulate the coastal offices. Schallamach (1968) carried out some experiments on rubber, applying various dusts.

It would seem the future changes and trends in wrapping materials will have a great effect on parcel conveying. The costs of oil will affect the use of plastic materials, although the North Sea oil supplies, and the possibility of oil off the West Atlantic Coast and the Irish and Welsh Channels, may all tend to reduce the costs of plastic in the next twenty years. On the other hand, the costs of wood fibre materials, such as paper and card, are likely to increase markedly with increasing demand and reduced supply. The percentage of plastic parcels present in the parcel traffic mix affects the frictional characteristics and, therefore, the probability of a jam. This is examined later, in Section 7.5.4.4. (Page 225) Despite the fact that the plastic itself does not absorb water into its structure to any extent, it would seem that water films on the plastic surface have an effect on the behaviour, so the study in the next section was carried out.

7.3.2 Effects of Relative Humidity

It became apparent that the variables studied thus far did not completely explain the frictional behaviour of the parcel, belt and sidewall materials, and so consideration of the environment was necessary. Controlling the ambient temperatures of the test rig below 20°C was difficult. Due to various self heating effects already discussed, and the limitations of the test rig, further evaluation was felt to be outside the scope of this study. The test environment could vary the relative humidity, which was expected to have some effect on materials based on wood fibres, that is the cardboard and the paper. (Relative Humidity (RH) is discussed in Appendix VIII). Once again the laboratory rig was called into use and the turntable and arm were enclosed so that crude control of atmosphere could be carried out. It was felt that the effects were so noticeable that simple apparatus would show the dependence, and in any case this project was not so wide in scope as to involve more than a cursory study of this area. The results were most revealing and are plotted in Fig. 7.31 (Page 396) for static tests on mild steel versus brown paper. It was shown that the coefficient of friction, even for the static case, was increased by a factor of approximately four times, as the humidity went from 30% to saturation point. This variation in friction coefficient, with change in humidity, coupled to the change with temperature and the self heating effect, would explain the wide range in friction coefficients quoted in the literature as discussed by Webber (1972). Tests were extended to cover sliding tests, for both brown paper and polythene, and it was found that both of these materials behaved in a similar manner. The results are plotted in Fig. 7.32 (Page 397) and show a typically exponential form. From this study it was felt that it would be perfectly feasible to model the effect of relative humidity, given that the coefficients were known at humidities around 20 to 30% RH. The expression which fits this relation is:

$$\mu = b \exp (aRH - c)$$

where μ = friction coefficient

RH = Relative Humidity

and a,b = constants for relation between friction coefficient and RH

c = constant related to μ in dry conditions

One approach to calculating the coefficient of friction at different relative humidities would be to solve the expression using LOG and ALOG intrinsic functions, taking logarithms thus:

$$\ell n\, \mu = (aRH - c)\, \ell n\, b$$

This may be expressed in FORTRAN as

```
REAL MU
MU  =  ALOG ((A*RH - C)*LOG(B))
```

This calls the functions LOG and ALOG, which lengthens the computer time, as does the form of the equation, which is relatively complex.

Another algorithm was created, which was simpler to compute because the relation was re-expressed as a recursive, thus:

MUST = MUST * PEXP

MUST (on LHS) = new friction coefficient

MUST (on RHS) = old friction coefficient

PEXP = multiplier

This expression was used for three DO-loops to give the value for 40, 50, 60 and 70% RH, as the friction coefficient was raised by the multiplier from the base level, three times recursively. It was felt that 70% would typify the saturation relative humidity of a parcels office.

To evaluate the multiplier PEXP, some tests of friction coefficient for polythene against mild steel were performed with the polythene in a variety of surface conditions. These are given in Table 7.33 (Page 398), which demonstrates the exponential form already seen previously in figures 7.31 and 7.32 (Pages 396&7). The results are published in Machinery Development Report No. 38 (Post Office 1971c). The multiplier PEXP was calculated for the 10% steps in RH shown in Table 7.33 (Page 398) and the results given in Table 7.34 (Page 398). The range of PEXP was from 1.06 to 1.27, according to the conditions of the polythene surface. The scratched, dusty and greasy surfaces gave a mean of 1.13, but with damp polythene the multiplier rises to 1.22 on average, for the dampened surface gave variable results. Taking all the different surface forms of polythene into consideration, the overall average is 1.15 and this was used in the model as a typical value.

A further application of the effect of relative humidity came to light, when the average value for all offices, of the brown paper and polythene against steel, friction coefficients was considered, using the SPSS package and the data of Castellano (1971).

They were:

All offices	Static coefficient steel/paper	0.2113
All offices	Sliding coefficient steel/paper	0.5745
All offices	Static coefficient steel/polythene	0.2020
All offices	Sliding coefficient steel/polythene	0.5228

The value for the static coefficient lies within the usually quoted range of 0.2 to 0.24. The sliding coefficient for brown paper/steel would indicate a relative humidity of above 80% RH from Fig. 7.32 by interpolation. This is above the expected saturation value of RH for a parcels office. If this value for relative humidity, is then applied to Fig. 7.32 (Page 397) using the curve for polythene, the expected value would be 0.90 whereas the value obtained from the data above is only 0.5228. This latter value is only slightly different from the dusty polythene value, given in Table 7.33 (Page 398), of 0.55 (for only 70% RH). The only value from Table 7.33, which is near to the parcel data average, is the value for a dusty surface on polythene. The polythene parcels probably have surfaces covered with paper or wood fibres. This adds weight to the theory that the nature of plastic wrapped parcels will change, according to the percentage mix with other parcels wrapped in woodfibre based materials (brown paper or cardboard). In this connection, it is interesting to note that the rubber belting - "Grip-Faced Rubber Belting", gave a friction coefficient of 0.97 static and 1.155 sliding, against all parcels, which is much more in agreement with published figures. Whether this is due to a fundamental difference between the essentially plastic behaviour of polythene, against the elastomeric nature of rubber is beyond the scope of this project, but it might be the case, because the scandura, which is a synthetic rubber (elastomer) belting, gave values for friction coefficient, under the same circumstances, which were 0.57 static and 0.635 sliding, which lies between rubber and plastic and slightly closer to plastic. Obviously much more meticulous research is required to model the behaviour of plastic wrapped parcels, and conveyor belt materials, but some of the major factors have now been evaluated in this work. One further point in the effects of relative humidity, was to investigate the inference that the relative humidity could be as high as the predicted level, of over 80% RH. Even though the weather in Britain has become appreciably drier since the parcel survey was conducted, the figure seemed high. However, Hudson and Chandler (1965) quoted an average of 84% RH for Sheffield, with an average rainfall of 30 in. at an average temperature of 48°F. To find figures for humidity for the parcel offices, which related to the present day, seemed to be difficult, since the only relevant publication by the Meteorological Office was issued originally in 1938. (Meteorological Office 1938). Results calculated from this are shown in Table 7.35, (Page 399) which lists the values for average relative humidity and temperature and gives also the minimum figure for relative humidity, on a monthly average basis.

The value of RH inside a parcel office, with the large amounts of steel in roof structures and conveyors, chutes and glacis, was likely to be higher than the figures tabulated, except on colder days, due to a process of condensation forming on the steel at night and evaporating during the working periods. When temperatures in the offices dropped to less than 60°F, which might occur in winter, the condensation would be unlikely to evaporate, because saturation humidities would be lower. At 41°F the saturation humidity is 60% RH, so it is probable that values will be lower in winter than in summer. An additional factor is that brown paper and cardboard absorbs water and will release it in the vicinity of the belt. This is due to the hygroscopic nature of the chemicals and fibres in the paper and cardboard. Therefore, even if the humidity in the open areas in the parcel offices ranges from 40% to 70% RH, which has been established by measurement, in the vicinity of the parcels on the belt the humidity could be higher, due to emission of water vapour from the parcels. It therefore follows, that the extrapolated figure of over 80% RH may be reasonable for the offices, if measured close to the conveyor belting. This is due to the combined effects of the steel structure, condensing and evaporating moisture, and the parcels acting as reservoirs of moisture, when the wrappings are hygroscopic.

One final point is that the behaviour may be affected by the action of chemical vapours emitted by belt materials (mainly acid chlorides) and also packaging materials (mainly sulphites, or acid sulphites). Examples of such vapour emission are quoted by Campbell and Packman (1944) and Rance and Cole (1958). The effect will be intensified by the locally high RH at the region of the conveyor belt and parcels. It is possibly a source of the unusual behaviour of the parcel and belt friction in conveying.

7.3.3 Stiffness of Parcels

The theoretical considerations in Sections 3.5 (Page 74) and also 2.4 (Page 47) indicated that it would be advisable to establish the nature of the material properties, and find the values for the elastic modulus. The Post Office were interested in this, and were kind enough to provide the data for live mail, which was tested in a three point loading to determine the deflection under load. The data was supplied for 70 parcels. The orientation of the parcel for three of the six possible orthogonal planes was tested and the arrangement of the loading system is shown in Fig. 7.36 (Page 400). The stiffness or Load/Deflection relationship was linear. The values for 70 parcels were tested by a simple regression programme and the correlation coefficient only rarely dropped below 0.98. The results are shown for the first two parcels, in Table 7.37, page 40 the other 68 parcels being essentially similar. Parcel 1. Plane 2, shows the effect of the parcel collapsing. The fourth point in which the load is 20 lbf gave a deflection of 0.250 inch, which meant that an increment of 5 lbf gave an incremental deflection over five times greater than the previous three increments of 5 lbf. The parcels thus show load/deflection curves similar to some solid materials. The "plastic hinge" behaviour of parcel 1 was not exceptional and many parcels showed this. The interesting feature was that, although the stiffness was virtually linear in the elastic region, calculations using the Interdata computer, on-line, to obtain the moment of inertia and the modulus of elasticity for the three orientations, gave an apparent variation for elastic modulus of a couple of orders, depending on which way the parcel was oriented. The range was from less than one to several hundreds (see Figure 7.38 and 7.39). (Page 402 to 404) Obviously any calculations which assumed the parcel to be composed of a solid material, homogeneous in character, gave enormous errors. It could be possible to extend this project into an examination of parcels and consider them as thin-walled structures, based upon the consistency of load/deflection readings. The author felt, however, that solutions for the forces could be estimated by other techniques for this first attempt at modelling the conveyor and thus save time. Further research could be made into more sophisticated methods of force prediction in the future, if the urgency of the problem and the nature of the results warranted it. This research area was therefore discontinued.

7.4 THE SIMULATION MODEL AND THE COMPUTERS USED

The long period of time through which this project has been evolving has resulted in a wide range of computing facilities being made available. At the commencement of the project, the installation of the ICL 1900 was the first opportunity to use a large, fast, third generation computer, for work of this character. At the completion, the much enhanced 1900 configuration is rapidly becoming obsolescent, and it would be fair to say that the opportunity to use the much larger and faster CDC 7600 would mean that, if the project were being started now, then the CDC machine facility would be used in addition to the 1900, and would considerably speed the project. With CDC 7600 the languages and operating systems are more sophisticated, so that other languages, particularly the simulation languages, could be used. This section discusses these considerations and, finally, the interfaces and interactions between the model, the system and computer configuration.

7.4.1 The Computer Used

The computer used for the simulation modelling was, essentially, an ICL 1903A of 64 to 96K words. As has been said, at the commencement of the project, the opportunity to use what was then such a big, fast machine, was the key step which made the simulation possible. As time went on, various enhancements, such as the MOP terminal operation for on-line editing, made the use of the ICL 1900 for this project, more and more of a vested interest. At the beginning, only a fraction of the facilities were used for the simulation, whereas the final version, on which the tests were performed, made use of the multifiling capacity of the machine, and the GEORGE 3 and MOP operating system, to such an extent that the machine was being stretched to near its limit. There had been major problems with the hardware, particularly the card reader, and the communications processor, which had been a source of delays. On the other hand, once the terminal system had become sufficiently far advanced, and the core availability such, as to allow FORTRAN to be run from terminal, for programmes under 20K words of store, then it became possible to progress very quickly indeed. In the next section, the use of the operating system MACROS will be discussed, but the feature of the machine, in that large programmes could be run, by inserting only six cards, was of great use in completing the study.

Not all the hardware enhancements were satisfactory; there had been high hopes that a large flatbed plotter would be provided by the Computer Board. Unfortunately, when it came, it was too small a size for this work, and the ICL software was unsuitable. A major problem was that, if the plotter was used as an on-line peripheral, the rate of throughput of other jobs through the machine sank to close to zero. On the other hand, when the graph plotter output was put into a file, to be plotted using the graph plotter as an off-line peripheral, many unexpected problems arose. The control of the size of the characters of the titles proved to be more difficult than necessary. Eventually the University Computer Unit provided some software, but it was so limited that it was of no interest, since the examination of the loading of parcels by plotting the corners manually had proved a simpler, quicker method.

Many machines were used for this project, and Table 7.40 lists the (Page 405) machines and the purposes for which they were used. Simulation trials on the smaller on-line machines, such as Interdata, Hewlett-Packard or DEC, showed that the advantages of rapid calculation and immediate access, were not as effective as soon as the simulation became at all complex. It was all too easy to fill the available core quickly and, even when the advantage of easy overlaying by the use of "chaining" was possible, the longer running times tended to nullify even this. The use of BASIC language on these machines is ideal and the author felt it to be superior to conversational FORTRAN. The degree to which the machine will sense incorrect programming as the line is entered is important, and the extensions to BASIC seem, if anything, to be more prolific than to FORTRAN. The fast interactive big machines, such as CYBERNET SIGMA, had very sophisticated forms of BASIC and programmes were nearly always error free at run time. This made them more economic than they would seem to be from their expensive cost of around £600 per hour of computer time, but this was only measured on a basis of the use of time in the processor. This was usually very quick and, if multiprogramming was in operation, the charge was calculated on the actual time spent in calculation. There was no connect time charge. On the other hand, a virtual connection time existed, since remote processing creates telephone bills and these could be so substantial that they were in excess of the computer costs. For example, when the Open University computer in London was out of action, the next available was in Newcastle-on-Tyne. The telephone costs to reach there were greater than the hourly cost for the alternative LEASCO computer plus the associated telephone costs, because the LEASCO service was available locally. These smaller computers were both Hewlett-Packard 2000 series and the programmes were interchangeable except for very minor differences, easily corrected. Commercial costs at that time for the LEASCO were approximately £5.00 per hour during office hours and 50p, subsequently raised to 75p, for evening rate, when the telephone cost was also minimal. For small analysis, statistics and so forth, the Hewlett-Packard HP 2000 was an excellent machine. The Interdata and DEC were slightly less effective. The MINIC was very much less so, and very limited. The outstanding advantage of terminal operation,is in rapid editing and correction of programmes. Once this is done, the programme will be run more effectively in batch mode, by the use of the tape reader, if the machine will accept input from the terminal tape attachment. The ICL machine would not accept paper tape from the ITT Creed terminals without considerable manipulation, due to the problems with separators (commas, spaces and semicolons) and particularly the carriage return-line feed,required by ICL 1900, and the "TC" transmission characters.

Running the simulation model is essentially a batch requirement and there is little advantage, if any, in running the model from the terminal,since the run time would cause an appreciable wait. On the other hand, the statistical packages, such as SPSS or STAN (a Cybernet package) (see Section 7.7) (Page 230) are equally large, but are much superior,when run from an on-line system. This is because the answers do not take excessively long to produce from statistical packages and the next step cannot be predicted,until the present one is completed. The remote job entry,batch terminal,of CDC machines is useful in this connection, since a rapid turn around of the programme is possible. When the flow through of other work is slack, then as many as 20 or 30 runs per day become possible.

7.4.2 The Choice of Languages

The standard MACROS used by the University at the time of the simulation modelling,gave much monitor file listing and programme listing,that was not necessary. The use of MACROS written by the author,enabled these superfluities to be removed and with the use of binary programmes, previously compiled, cut the run time of the simulation considerably. The excellence of GEORGE 3 operating system and language,must be mentioned here. This is in contrast to much of the other software available from ICL. In conjunction with the multifiling capability of the ICL machine and the EXTENDED FORTRAN language, it was felt that the flexibility gained by the operating system GEORGE 3 extended the effective size of the machine. This gain was nullified by the increased run time, when the machine was engaged in complex operating procedures. The data bank of files was invaluable, enabling steady growth of the model. This technique is discussed in a paper by Rourke, Boyd and Liu (1975) describing how an Integrated Manufacturing System could develop from the extension of these modelling techniques.

To a large extent the author's computer software was growing during the project. Reference to Table 7.41 (Page 405) shows the five compilers used during the course of the project; the changes being enforced because the computer facilities were enhanced. The increase in size from the first magnetic tape compiler to the current magnetic disc compiler, although it increased the overhead, also increased the facilities available in the version of FORTRAN. To maintain flexibility of the programme, so that it could be transferred without too many alterations, the version of FORTRAN used in the programme rarely went beyond the level of FORTRAN II.

The ICL version of BASIC is not particularly good, even compared with many of the minicomputer BASIC languages. This is not really surprising, since the computer architecture of the 1900 series was not conceived with interactive terminal operation in mind. It is an excellent batch machine. Some idea of the complexities of multiprogramming and multiaccess are discussed by Barron (1971), who quotes in connection with multiprogramming the words of R. L. Stevenson, "Extreme busyness ... is a symptom of deficient vitality". The limitations imposed by the MOP terminal system on the available user core, the lack of core-swapping facilities and the general communications problem on the older, smaller machines, is all symptomatic of the constraint imposed by the original architecture. For most of the time of the project it was found to be more effective to "single-shot" programmes (that is, to have only one programme in the arithmetic unit at a time) rather than allow the multiprogramming that more recent enhancements made possible. With the total replacement of the core and general uprating to a 1904A machine, coupled with software changes to a new operating system (GEORGE 4, accompanied by paging), then a totally new approach to the running of programmes will occur. At the time of the project, transfers made by the machine (machine overhead) required 48 to 64 K words of store normally, and millions of transfers were made during a ten hour shift. These problems made the choice of FORTRAN the optimum for the main simulation. Terminal editing was a useful feature which speeded the turnaround.

The analytical programmes fell into two types, with further subdivisions. The two main divisions were into analytical programmes, written by the author for data checking or statistical analysis, or alternatively the statistical packages, which are separately discussed in Section 7.7. (Page 230) The specially created programmes were further subdivided into those written in FORTRAN for batch operation, and those in BASIC for interactive terminal operation. The choice of technique was determined by type and size of the "computer job". The checking of the parcel data for over 2000 parcels, each with over 20 variables, was a large FORTRAN batch job. The analysis of the 70 parcels tested for their mechanical properties (see Section 7.3.3, page 178) was carried out on an interactive computer terminal in BASIC.

Numerous small statistical checks derived from the results of the main programmes were BASIC interactive terminal work. Most "jobs" could be labelled as clearly batch or terminal type work. Some very few cases lay intermediate between the two or, more likely, comprised elements of both. Comparisons between the two methods become difficult and similar to asking: "Is it better to walk to work, or use a car?" This obviously depends upon how far it is to work, what sort of climate, how busy the roads are and other subsidiary questions. The analogy can be extended further, since just as there are different requirements favouring one method or the other, so there are other alternatives to the two methods available. Comment as to which technique is the "best" must always be qualified with "best for what purpose?"

In the same way, it is different to make comparisons between the use of the CDC 7600 and ICL 1903A computers using FORTRAN for the simulation and the large analytical programmes. The CDC was much faster, but less convenient in operating control via the operating language. It was felt the SCOPE was an inferior operating system from the user's point of view when compared to GEORGE 3. In the same way, the optimising facility of the CDC compilers was useful, but their error tracing was less useful than the ICL TRACE facility. A rather glib approximation as to a machine comparison was that if a large programme was working, or if a package was in use, the CDC was clearly superior. On the other hand, the creation of large programmes was easier on the ICL 1900, especially if the programme was written in modules and use made of the multifiling capabilities and operating system control of GEORGE. A great help in this was the ability of the operating system to trap any non-fatal errors by FTRAP ERRS and suitable programming, which allowed the programme to restart and carry on without operator intervention. Obviously a default, which is intelligent enough to anticipate likely faults, is an essential part of this technique. This is not always easy to arrange.

7.4.3 The System/Model/Configuration Interaction

Once the basic constraints of the computer, the real world system, and the resources available for measurement and research were all determined, then the model could be created. During the growth of the model, the influences of the constraints were bound to have their effects on the final result.

The work that had been carried out to analyse the parcels traffic by Castellano, Clinch and Vick (1971) was a fruitful source of information. The inferences to be drawn from the analysis made by the author in this project,using their data,were inconclusive as to the nature of parcel populations. The parcels traffic is changing fairly rapidly and, while the general results available from the survey would help to reduce the amount of work involved in a survey of current traffic, to keep abreast of the nature of current traffic is a considerable task. The most likely method would be to abstract a number of fairly small samples from the different offices at regular intervals. While the variation of sample mean,to population mean,would then be high for any one sample, the average of the predictors from a wide range of offices,would be a good estimate of the overall nature of the traffic.

As far as the problem of jamming is concerned, it would be wise to try to create some sort of recording system, before attempting to simulate the more complicated L-turns and other conveyor and chute configurations. The results of this research indicate that jamming is likely to be causative. Therefore the likely causes should be isolated by careful observation before any further extension of simulation work is made.

7.5 RESULTS OF THE MODEL

7.5.1 The Choice of a Computer Simulation

It would be considerably simpler to model the behaviour of Post Office parcels if a queueing model based on discrete mathematics could be used. The Post Office conveying systems use a series of chutes, glacis and conveyor belts of widely varying type to form a Parcels Office. It would be necessary to use models of considerable complexity, the problems of which could no doubt be overcome.

Khintchine (1960) favours simulation where a definite solution is required rather than a general one. Disney (1963) comments on this, and notes the importance and the effect of interactions. Phillips and Skeith (1969a) suggest that computer simulation is a useful aid to mathematical analysis and also emphasise that, where a general result is needed, then queueing mathematics is favoured. On the other hand, if a specific behaviour is to be modelled, then a simulation is better. That is, to predict the occurrence of jamming as a probability, it is likely that queueing mathematics will provide all that is necessary, once the theoretical approach was validated by actual observation and possibly simulation. On the other hand, if it is desired to isolate specific causes of jamming, then a computer simulation is the favoured method. Even though a jam never occurred with this model computer simulation throughout the whole project, it would be simple to extend the programme so that causative factors such as difficult parcels or configurations, or strings jamming in sidewall/belt interfaces, were modelled and their effects noted. This point of view is supported by Phillips and Skeith (1966b).

In making the decision to write a computer simulation, the intermediate stage was the analysis of the shape, size and material of parcels to establish if it would be reasonable to theorise about a single idealised parcel material, as has been discussed before. This was not a feasible approach, but this only became apparent after considerable study and research had been applied to the work of others, for example Jenike (1954 to 1970) and Castellano et al. (1971). It was thus a necessary part of this research to study the nature of parcels, and so data analysis became an integral part of the study.

Programme Description

Programmes were developed for two-dimensional and three-dimensional models. The two-dimensional programmes were abandoned very early on in the study and effort concentrated on the three-dimensional versions. The "P" series, which consisted of the "Flat-Load" and "Tilt" versions, showed promise early and development of these programmes continued while other types were abandoned. The "P" series programmes loaded parcels on the basis of a consideration of "point-up" or "line-up" or "plane-up" classification of the loading of a parcel. A feasibility run on the flat-load or plane-up only loading soon showed that packing densities were obtained of around 25%, parcels by volume, in a given conveyor volume. This was because of the premature "cut-off" of further parcel loading as soon as the current parcel showed above the sidewall after loading. This was altered subsequently. Concentrating on the "Tilt" programme has produced approximately 200 programme versions, based on four programmes in two groups. PD1 and PF were the first successful groups. They were abridged programmes which loaded parcels only, so that the results could be compared to figures given for trial tests at WDO. PG and PM were full programmes calculating forces and friction. They required a large core store and were, therefore, slower to progress. This second group calculated the jamming forces. From the programmes PF and PG the final Tilt Programmes TL201-204 were produced.

General Aims

In programmes of this complexity there is a tendency to be too ambitious in the systems analysis and, therefore, to try to produce an exact model which is too complex to be made operative in an economic sense. This has been the cause of much delay in the completion of the project. Accordingly, the final versions are simplified versions of many more complicated loading systems which were tested. Wherever future development might call for more complex routines, the programme structure has been maintained. In the interests of obtaining production runs the model has had to be simplified in certain decision making areas.

The general aim may be said to be "To produce estimates of loading which can be validated and the model developed to the point where it will reproduce the loading of the tests, when using similar parcel sizes". This has been achieved.

In drawing up a logic sequence which models a Post Office conveyor, a certain background knowledge is essential. Credit must be given here for the thoughts of authors, whose works are not directly relevant to the thesis, yet who laid the foundations for the systems analysis techniques. Two particularly important authors for systems analysis were Nadler (1967, 1970 and 1976) and also Nadler and Smith (1963) and Cloot (1974) for his diagram technique, which was considered a superior form of logic diagram for this particular project. Naylor et al. (1966) and Naylor (1969) were invaluable sources for programme writing.

7.5.2 Trials of the Final Programmes (TL 200 Series)

These programmes ran well and all the subsystems worked correctly in their modular form. The final adjustment of the complete model followed, as errors were recognised. This was a slow operation, since turnaround on the complete programmes was, at best, at least 24 hours and on average about two days. Initially fatal execution errors occurred, that is, the programme ceased to run and failed. Once these were cleared the remaining errors needed to be searched out by checking and rechecking the results, looking for the inconsistent or inaccurate, and checking the FORTRAN programme, statement by statement, in the relevant area. Fairly extensive testing was required in certain areas, such as parcel forces, loading and pressures, to adjust the programme to its final version. This was done by adjusting the programme until spatial relations of the parcels and the force calculations were acceptable. This was tedious and could have been speeded up to a considerable extent if the programme could have been run from a terminal. This was not possible because every time an alteration was made to the programme, the recompiling that was necessary called for considerably larger user core area. This was above the MOP user core availability, so batch mode was used and the turnaround was reduced. The four versions of the programme were all approximately 1300 statements of FORTRAN in length and so were fairly complex. Many of the changes had to be made to all the programmes, although tests were confined to one version initially, and alterations to the other versions made in reasonably large numbers to avoid wasting compilation time. This could be overdone, since the models were not entirely identical, and some alterations did not work as expected in all the four versions of the programme.

The Four Programme Versions

Once the loading of the parcels had been carried out the calculation of the forces was carried out. There were two alternatives in the loading, one was to load the parcels by random placement, as in an open topped container into which the parcels had been dropped to give a form of static loading. The alternative was the moving belt simulation, which moved the parcels along the conveyor as they were loading, to represent the action of the moving belt. Similarly, in the force calculation, two methods had been proved to be successful. One was based on the method of moments and the other on trigonometry. In such a complex network of forces the basic assumption that no compliance existed was maintained. To make use of the facility built into the system to identify the compliance of each parcel would have considerably increased the complexity. This was felt to be beyond the scope of this research and would have resulted in a programme of such a core size and running time that it would be impracticable for the computing power available. Further decisions were made by the force calculation module in distribution of the loads exerted by other parcels and the parcel weight, so that it would resolve forces onto parcels lower in the conveyor. These decisions, when coupled to the arrangement of the computer programme to minimise the calculation time and programme length, were such as to make the calculation of the final forces a somewhat precarious business. The resultants were the small differences of fairly large components and any loose approximations could lose or alter the forces unreasonably. Hence when the force modules were used in the programme,their performance was self-determined to a considerable extent. There were three versions of the force calculation module. The first version did not make many assumptions about the resolution of the forces, but could fail when trying to make a decision as to the resolution of the forces. It would then arbitrarily divide the forces between the three contact points previously chosen. This adjustment by arbitrary division predominated, so a programme was created to always divide arbitrarily, which reduced the time for the computer run considerably. This was called the second force calculation system and gave similar results to the first. However, neither of the two programmes was sufficiently representative of parcel forces. Accordingly a third calculation system was created with a completely new approach based upon trigonometrical analysis of the forces. This was far more successful than the previous two systems, giving much more realistic force values, and it was used for the final results.

The programmes are:

TL 201	Moving Belt	Second type Force Calculation
TL 202	Random Placement	Second type Force Calculation
TL 203	Moving Belt	Third type Force Calculation
TL 204	Random Placement	Third type Force Calculation

The random placement models both gave loadings consisting of an average of 65 parcels and about 35% packing density, when the conveyor was "full", which was defined arbitrarily. The moving belt model would accept much more dense packing without declaring the conveyor full. Loadings of 99 parcels could be accepted without being full, with up to 62.3% packing density. This is likely to be due to the simulation of a "shaking-down" effect in the moving belt model. Both models would simulate the effects of varying humidity and various proportions of plastic wrapped parcels at will. The forces superimposed on a given parcel could be from up to 10 other parcels, and this proved adequate but not excessive, since occasionally an overflow routine was used for more than 10 contacts. Speaking generally of the many thousands of parcel placements which were made, very few had more than three parcels in contact.

Comments on the Programme

Any algorithm which will handle all cases presented to it, and be in a form which will handle three orthogonal direction calculations for each of three different contact nodes, adding to them the resolutions or moments of up to 30 contacting points, will be a very sophisticated algorithm indeed. There are ways of overcoming the drawbacks of this, by reducing the decisions to be made at any one stage. These ways must avoid or overcome cases where the overflow or underflow condition is produced in the computer locations, or cases which try to divide by zero. This may tend to occur a number of times in any calculation and would cause execution failure, which would lose the computer time expended to that point in the run. The programme was developed to the point where the final calculation systems gave sidewall forces which averaged 1.86% of the base forces, when tested on a conveyor section of 40 inches wide by 36 inches high. 29 test loadings were made using 1822 parcels from all offices. These loadings were all similar, with an average percentage ratio of parcel volume to conveyor volume of 37%. A survey of a sample of 270 test runs for a wide variety of conveyor widths, sections and parcel to conveyor volume ratios, showed that the highest value was 11.02% for the ratio of sidewall/base forces with a parcel/conveyor volume ratio of only 12.34%. In one loading, the sidewall/base force ratio was 6.27%, yet the parcel to conveyor volume ratio was only 4.25% with nine parcels in the section. These relatively high values of sidewall/base force ratios of over 6% occurred at random over a wide variety of loadings. They were more common with the model which simulated the "moving belt" but, even so, occurred over the whole range of parcel to conveyor volume ratios. The cause of this high force was, therefore, felt to be related to certain parcel configurations rather than the congestion caused by a large number of parcels in the section. As far as jamming is concerned, it appears from this simulation model that, without some causative factor occurring, a jam would be very unlikely. However, it appears that causative factors do exist, making jams more likely in straight conveyors, even if only slightly more likely. Certain parcels are found to be subject to extremely high forces or pressures, not usually both on the same parcel, which are probably due to the "configuration" of the parcels in the local area. The local increase, usually only one or two parcels being involved, is by 11 times for force and 12.6 for pressure, based on the results from 1822 parcels in 29 drops. Combining this configuration effect,with the effects of unfavourable packing factors which maximise sidewall friction forces, then a crude guess suggests that on one day in three years,a jam might occur in a straight conveyor due to this cause. Further research to give a graphic presentation of the packing would help to explain the phenomenon of these "hot-spots".

Random Number Generators

While good random number generators were available with the software on the 1900 system,they had two drawbacks. The first was that the form in which the random generator was given,was not entirely suitable for the programme as it was outlined and the second was that this subroutine for random number generation,was on a set of discs which originally were not usually on the computer,so that special arrangements were made to provide these,whenever the random number generator was required.

Initially the ICL subroutine was discarded and a random number generator routine was developed,which was incorporated into the programme. While it was certainly not so random as the 1900 software generator, it had the advantage of being able to produce a number of random number streams at once and remember the different generating constants.

The Computer Unit had been pressed for some time to make the ICL random number routine generally available. As the disc capacity increased, the subroutine was made available by the Computer Unit all the time and the problem of the random number generator was resolved. Subsequently the ICL routine FPMCRV was used at all times, as it was superior to the generator written by the author.

The Programme in Operation

Initialisation: The initialisation of the office, the size of the conveyor, the selection of the base and sidewall materials are not substantially different from the earliest versions of the programme and have run many hundreds of times.

The original programme would move any parcels which dropped outside the sidewall to the inside of the sidewall. This has been altered so that parcels which drop outside are relocated. A modification of this programme was tested in which parcels were dropped in a band down the centre of the conveyor and distributed with a bias to the centre and less and less to the outside. It was of no advantage and, in fact, might be better if the bias was more towards the conveyor sides.

The search for the parcel corners looked originally only in the area of the rectangle, which is orthogonal to the parcel corners. This abridged version had very simple rules indeed, but there were versions such as PG and PM which were more complex, and which rejected certain corners and ascertained the relative angles of obliquely aligned parcels. These needed a search which did not automatically reject any parcels outside the orthogonal "falling area", but rather checked whether the sides of the parcel underneath appeared in the area under the parcel. Such complications proved to be necessary. On these more complicated placing procedures, the TL 201-204 programmes were based.

The first stage of the programme can produce much output, if the "diagnostics switch" is set to "on". Details are then given of the conveyor and office, checks are made and warnings given, if ever misplaced cards are included from another office, or if the wrong data file is called up. Each parcel is described and the location, orientation and "falling area" is given. A running check of parcel dimension and girth is also produced. When decision making occurs there is an output of "routes taken", except where the parcel is put directly down on the base. For every fresh loading which occurs if the parcel overlaps the sidewall, new information is output. The next process is the positioning of the parcel in the conveyor. This is in two stages. The first determines the possible points on parcels already in the conveyor, on which the new parcel may be placed. The second stage is run through a series of heuristic rules which select one of three loadings for the parcel in the conveyor. They are the plane up (PLU), line up (LU), or the point up (PU), which were discussed in Section 5.2.4. (See page 118)

Finding the Highest Corners: The procedure is largely a routine computer sort into the highest points from anything up to the last 100 points. The sorting is slightly different according to whether the parcel is orthogonal or rotated, since the relative positions of the "corner areas" move with the corners of the parcel being placed. Much additional data are recorded temporarily, other than simply the "corner type" and "corner area", during the time the programme is loading a parcel. The only permanent storage is the co-ordinates and "type and area" of the points underneath the parcel, in matrix form.

Rules for Loading: There are four types of corner underneath the parcel and four types of corner on the bottom of the upper parcel, so in this simplified model there are 16 types of corner arrangement. This is modified by the angle of rotation of upper and lower parcel, and also the attitude of the under parcel. (Whether it is PLU, LU or

PU, which then alters the type of loading). The degree of sophistication of the model in selecting the necessary attitude and correct corner points may have been too great. The author took an "engineering approach" and sought realism in the model in this area and incorporated a structure, which allowed for optional incorporation of further branching, if it had proved necessary. The very powerful "computed GO TO" statement of FORTRAN, was invaluable in this area. This need for flexibility, was the basic reason for the programme structure. This complicated part of the programming was therefore completed, enabling the decision statements to be altered at will. The structure of the loading is now such that simple steering enables it to operate. It is also simple to extend the decision making, to a selection from a choice of six possible corners. However, some analysis of computer tests of the various more complex methods have shown them to be no better, and sometimes worse than the simple ones used in the abridged model, in this straight conveyor model. The computer times are considerably increased by increased complexity at this point. If the corner type is intermediate with respect to the area (i.e. type 2 or 4 in area 1, (see Section 5.2)) (Page 115) then the parcel is loaded LU, with either of the opposite two faces high. In the simple model the new parcel rests upon the next point in the list, irrespective. Some selection here would reduce the preponderance towards LU since, if the next underpoint is not suitable, then PU would be quite simply the best loading for these cases. However, for the moment the simple rule is used.

At the end of this section the programme sets the variables for the particular form of loading that has been selected and moves on to the next section.

Storage and "Conveyor Full" Section: This has seven sub-sections:

(a) Alters any parcels placed as PU (point up) if a check shows that the lower two points of the three supporting points are at the same height. This is the equivalent of an LU loading and the parcel is therefore reclassified as LU, and the correct side is declared as "up". Parcels resting on the base and one point are in this category.

(b) Stores data for PLU on the base.

(c) Stores the corner points for the parcel being placed.

(d) Stores data for the parcel being placed.

(e) Checks if the computer stores are already filled; this is essential otherwise the programme fails without any output.

(f) Checks to see if cut-off arrangement is satisfied for "conveyor full".

(g) Outputs parcel positions and data.

Of these sub-sections (a) to (d) have been well tried on many programmes. Section (f) is always present but needs alteration at many points through the programme if the store size is increased. The storage of the abridged version is only about 16 K words for 100 parcels, so among the many modifications was one with extended parcel stores for 125 parcels. However, this increase in storage reduced the rate of testing so this was abandoned, since there seemed no resulting advantage to compensate for slower turnaround as the extra storage was virtually unused.

Force, Load and Pressure Calculation Sections: Two more sections complete this part of the full programme and although they are less complex than the previous section, they need large areas of core storage.

Choosing the Underparcel Contact Points: This has three sub-sections:

(a) Pre-setting of nodes.

(b) Loading of co-ordinates in the matrices.

(c) Loading the registers with the underparcel numbers.

The pre-setting of the nodes, once established, was used throughout and was fairly simple logic. The second and third sub-sections were completely revised halfway through the development of the final programmes, both to improve them and to aid in the use of the third force calculation system.

The Force Calculation Section: This has four sub-sections:

(a) Calculation of forces at nodes.

(b) Calculation of friction forces.

(c) Calculation of loads on individual parcels.

(d) Calculation of pressures on individual parcels.

This section required considerable development and three main versions were produced. The final version, as has been described, used a trigonometrical method to calculate the forces at the nodes and gave reasonable results.

7.5.3 Classification of the Analytical Variables

The variables which were incorporated into the model may be classified in a number of ways. From the systems point of view the model had the exogenous and endogenous variables to simplify operating and programming control. From the point of view of analysis of the results, the division of variables is rather different. To aid the analysis the variables are divided into those independent or controlling variables which are used to control the model and, alternatively, those parameters used to evaluate the effects, or in other words the dependent variables. The ones used were as follows:

INDEPENDENT VARIABLES (Controllers)	DEPENDENT VARIABLES (Evaluators)
Loading (static or moving belt)	Number of parcels
Traffic intensity	Packing density
Width of the conveyor	Total weight of parcels loaded
Materials - parcel wrappings	Maximum load on a parcel
Materials - belting	Maximum pressure on parcels
Materials - sidewalls	Maximum sidewall/base force ratio
Environment - humidity	Average sidewall/base force ratio
Environment - dust	Base/sidewall contacts
Parcel attributes	Overlapping by parcels
Office characteristics	Computer usage

To aid in comprehension,the results of the computer model will be discussed,by considering each of the independent variables in turn and noting the effects of the change in the independent variable. Naturally, some overlapping is inevitable and some of the finer detail will be obscured by this approach.

7.5.4 Evaluation of the Effects due to Change of Independent Variables

This section analyses the effects of changes in the variables considered as independent or "controllers" in Section 7.5.3, upon the variables considered as dependent or "evaluators". The "controllers" are divided into the following:

LOADING (STATIC OR MOVING BELT)

TRAFFIC INTENSITY

WIDTH OF THE CONVEYOR

MATERIALS

ENVIRONMENT

PARCEL AND OFFICE ATTRIBUTES

Two computer programmes were used in this analysis, written for interactive terminal usage, on the INTERDATA 70. The MSD programme produced means and standard deviations and single sample t-test for parcels data. (See figs. 7.42 and 7.43). (Pages 406 & 408) The CO2 programme (see figs. 7.44 (Pages 409 & 411) and 7.45) was used where data was to be correlated from two parameters, one dependent and the other independent. The programme also gave the mean and standard deviation in both x and y. If there were further y variables to be tested, the programme gave the opportunity to enter these. This proved invaluable, as the programme could be re-run without entering the values of x again. If the error was spotted before the return key was pressed, then a line cancel could be used. If the error was such as to fail the programme, caused for example by two decimal points, or a data transmission error from the ASR 33 Data Dynamics tele-typewriter, which was far older than the computer and not in good condition, then it was possible to re-start the programme before the failure and re-run. A further useful INTERDATA feature was the ability to alter any variable by direct entry.

7.5.4.1 Loading

The static model places parcels at random over the area of the conveyor, in a manner which would be typical of the emptying of parcel bags over the first conveyor. The moving belt model places parcels along a line at random and the line moves along the belt to simulate a moving belt. There are noticeable differences in packing between the two models. Table 7.46 (Page 412) makes a comparison of the two models. An analysis of these figures is shown in Table 7.47 (Page 413), which gives the ratio (R) of moving/static packing parameters for various offices and conveyor widths.

$$R = \frac{\text{Moving Belt Parameter}}{\text{Random Placement Parameter}}$$

It will be noted from Table 7.47 that the Croydon parcel data shows remarkable consistency in the ratio R, for number, packing, density and weight. The effect of width of conveyor is only slight, if a comparison of results from loading a width of 40 inches is compared to loading the range of widths from 32 to 72 inches in steps of 4 inches. Table 7.48 shows the comparison for the Croydon office for static loading, based upon a sample of three runs, for a range of widths from 32 to 72 inches. The values for this test sample of loadings vary in a way which suggests that parcels are not a homogeneous material.

If we consider the values for an average number of Croydon office parcels for the 33 test loadings for the range of conveyor widths from 32 to 72 inches:

For average number of parcels: Mean = 67.48

Standard Deviation = 11.03

Standard Error of the Mean $= \dfrac{11.03}{\sqrt{33}} = 1.92$

95% (1.96 σ_E) Confidence Limits of the Mean = 65.56 and 69.40

For a sample of 21 test readings of Croydon parcels for a 40 inch width conveyor, the mean of the average number of parcels lies outside the confidence limits for all widths:

For average number of parcels: Mean = 64.81

Standard Deviation = 12.93

Standard Error of the Mean $= \dfrac{12.93}{\sqrt{21}} = 2.82$

95% Confidence Limits of the Mean = 61.99 and 67.63 for $\pm 1.96\,\sigma_E$ which indicates that larger samples would give a closer evaluation.

For a larger sample of 96 test loadings of Croydon parcels, loaded by the random placement model into a 40 inch wide conveyor, the following results were obtained:

For average number of parcels: Mean $= 66.59$

Standard Deviation $= 11.67$

Standard Error of the Mean $= \frac{11.67}{\sqrt{96}} = 1.19$

95% ($1.96\ \sigma_E$) Confidence Limits of the Mean of the Sample $= 65.40$ to 67.78

At the 95% confidence level the limits of the ± 1.96 sample standard deviations are 42.53 to 90.65 parcels. Three of the sample loadings ? in the 40 inch wide conveyor, each of which totalled 40 parcels, were outside these limits, which is acceptable. Three loadings in the varying width conveyor were also outside these limits. They were the 40 inch width sample of three loadings, which gave one parcel loading of 40 parcels; the 44 inch width sample of three loadings, which gave one loading of 91 parcels; and also the 52 inch width sample of three loadings, which gave one loading of 99 parcels.

We can test the difference between the sample of 33 test loadings of varying width conveyors against the sample of 21 test loadings on the 40 inch fixed width conveyor by the method of Moroney (1951). Using the standard error of the difference of means to test the Null Hypothesis we get, using the notation of Daniel and Terrell (1975):

$H_o: \mu_1 = \mu_2$

and $H_1: \mu_1 \neq \mu_2$

where μ_1 = mean of number of parcels loaded into a 40 inch width conveyor

and μ_2 = mean of number of parcels loaded into conveyors of 32 to 72 inches wide

Standard error of the difference:

$n_1 = 33 \qquad \bar{x}_1 = 67.4 \qquad \sigma_1 = 11.03$

$n_2 = 21 \qquad \bar{x}_2 = 64.81 \qquad \sigma_2 = 12.93$

Difference in the Means $= 67.48 - 64.81$

$= 2.67$

Variance of the difference $= \hat{\sigma}^2 = \dfrac{33 \times 11.03^2 + 21 \times 12.93^2}{21 + 33 - 2}$

$= 144.72$

Standard error of the difference $= \hat{\sigma}^2 = \sqrt{144.72} = 12.03$

Best estimate of $\hat{\sigma} = \sigma_\omega = 12.03\sqrt{\frac{1}{33} + \frac{1}{21}}$

$t = \dfrac{67.48 - 64.81}{3.358} = 0.795$ for 52 degrees freedom

The critical value at the 95% level for "t" is 1.67 and on this basis we accept the Null Hypothesis.

This variability of the parcels was greater than any effect due to changing the width of the conveyor. Table 7.48 (Page 414) shows values for the samples of three test loadings. The averages shown are all inside a plus or minus one standard deviation of the mean. This assessment would indicate that the effects of width upon loading are not likely to be significant.

Applying the F-test to the Null Hypothesis:

$H_o: \mu_1 = \mu_2$ where μ_1 = mean for number of parcels for 40 inch width conveyor

and $H_1: \mu_1 \neq \mu_2$ and μ_2 = mean for number of parcels for 32 inch to 72 inch conveyors

we get $F = 1.399$ for 20 and 32 degrees freedom

The critical values are:

at 95% confidence F = 1.92 for 20 and 32 degrees freedom

and at 99% confidence F = 2.53 for 20 and 32 degrees freedom

We therefore accept the Null Hypothesis, that there is no significant difference in packing intensity between samples of different widths.

The variation in loading a mixture of all parcels from the offices for fixed width, compared to varied widths, as shown by the values for R in Table 7.47, (Page 413) is likely also to be due to chance. For a conveyor section 40 inches wide by 36 inches high, the ratio R varies from 1.53 for number of parcels, to R equals 1.78 for packing density (that is, the percentage of the volume of the conveyor occupied by parcels) and to R equals 1.58 for the weight of parcels. These figures were obtained over 95 different packing arrangements from just over 400 runs with the sample data. It is interesting that the figures for the range of widths vary in an essentially similar manner even though, in this case, the sample had to be limited, because each test of three runs was carried out on all the eleven widths for each of six offices to obtain one set of data. That is, 198 runs for one test point, which obviously restricted the test. However, the figures are close to those for the 40 inch wide conveyor, with the same trend between number, packing density and weight. The ratio R is remarkably consistent with the Croydon parcels. This might be due to the fact that the sample of parcels from offices contained over 2000 parcels, whereas there were only 315 parcels in the Croydon sample. Calculation of the number of ways that 67 parcels can be loaded from a choice of 315 was just within the capacity of the computer used and gave the result of 0.1253×10^{71}. This argument can be dismissed as unlikely. Nevertheless, some further statistical analysis was carried out on the values for the number of parcels loaded for Croydon compared with the data from all of the offices.

The Null Hypothesis was tested by the Analysis of Variance technique (Daniel and Terrell, 1975) for the varying width conveyor using the eleven samples of three test loadings and also for the seven samples for the 40 inch width conveyor, as shown in Table 7.49. (Page 415) The Hypothesis was:

$$H_o: \mu_1 = \mu_2 = \dots\dots\dots\dots = \mu_n$$

and $$H_1: \mu_1 \neq \mu_2 \neq \dots\dots\dots\dots \neq \mu_n$$

where n was 11 and 7 respectively.

The effect of varying the width of the conveyor was possibly significant at the 95% level, but not at 99%. The 40 inch wide conveyor tests showed no significant difference. Thus, the further testing showed only a possible significance at the 95% level of confidence between the width of the conveyor and the packing of parcels. It was concluded that the significantly higher packing densities (see Table 7.46) (Page 412) shown by the moving belt model, were due to the way in which parcels were simulated as rolling in the "upstream" direction, if the parcel was too high when superimposed on the parcel group already placed. This action apparently enabled greater packing density to be achieved. The analogy to the real world needs testing, since both the packing techniques and the estimation of when the conveyor is full, are models and very crude ones at that, when compared with a complex and sophisticated real world situation. How the conveyor is estimated to be full in the model is discussed later. It can be seen that the simulated rolling action helps to achieve a later cut-off point in loading. It is essential to comment that visual studies would indicate that something of this type does occur in the real world also, but any research required to validate the action is beyond the scope of this research, owing to the need for measurements in the Post Offices.

Movement Towards the Sidewall

The first models had been arranged so that, when overlap in the horizontal plane occurred at the sidewalls, the parcel was moved inwards so that it just lay in contact with the sidewall, maintaining the same angles to the sidewall, as discussed in Chapter 5. (Pages 112 & 113) This gave an excessive bias and so the section of programme was removed. After this section was deleted, the bias was towards not having enough parcels near the sidewall, whereas previously there was an excess of parcels in contact. A compensation was made to the programme to allow parcels to shuffle nearer towards the sidewall when they were within two inches of it. This was the most satisfactory compromise, judging from tests made of shuffling parcels, within one to four inches of the sidewall, until they made contact.

Testing if the Conveyor is Full

The initial trial models were all static, random placement systems. Originally the rules for determining if the conveyor was full were confined to establishing if a parcel showed above the sidewall. This was soon proved to be inadequate, as parcels showed above the sidewall at around 25 parcels for the 40 inch wide by 36 inch high by 72 inch long conveyor at 12 to 15% packing density. When the cut-off point was altered to increase the loading, even when the bottom of the parcel was level with the top of the sidewall, the packing density was still far below observed values. When the model of the conveyor was plotted, parcel by parcel, it was found that due to the large size of the parcels in relation to the conveyor, groups of parcels projected well above the sidewall, while large voids existed elsewhere. This was overcome by allowing that parcel which tried to load in an area where the conveyor was full to be reloaded. Nine more attempts to load seemed to be the optimum number, based upon drawing out the parcel layouts and examining the computer print outs. If more than ten attempts to load a parcel were programmed, there was little advantage, because the parcel was usually too large to load into any of the voids remaining. Tests based upon less than ten attempts to load a parcel showed, when plotted out, that there were voids left in the packing which seemed to be unreasonably large. These problems never occurred with the moving belt model, since the loading was more even as the belt moved along. At the highest rates of dropping, when a parcel could not fit in below the sidewall, the parcel was rolled along the conveyor and resited upstream, while parcels continued to drop at the same point. This meant that large parcels were moved upstream while the smaller ones filled up the conveyor at the dropping point. This enabled higher densities to be achieved.

Comparison with the Packing of Spheres

The packing densities of spheres is a well known study with metallurgists and it had been hoped originally that an analogue model based on this type of model would be feasible. Such writers as Smallman (1963) or Cottrell (1960) would have been a good basic source. The evaluation of typical densities for static models, both hand and mechanically packed, and also dynamic models, had been made by Denton (1953). He found for spheres of diameter D that the packing in a cylinder of diameter equal to 42 times D was 60.5 to 60.9% with very high reproducibility. The standard error was 0.8% and the experimental error was 0.05%. The effect of a hexagonal container was very little and the packing density was 60.7%. It was felt that these values, which were found infrequently with parcels in belt conveyors, were only relevant to very small objects in a very large container. In the parcel conveyor it proved on occasions that parcels were present which were longer than the conveyor width. As the area of these parcels was considerable they could obstruct the loading of other parcels and cause voids which were larger than normal, thus lowering the packing density considerably. Packing densities of a very high order were obtained for parcels in containers packed by hand for shipment in closed boxes and trucks, when compared to random packing. This was common when the parcels were selectively placed to achieve the closest possible packing. Published work in this area seemed limited. Discussions with Post Office engineers and National Freight/B.R.S. Parcels executives had commented on this difference. A Post Office/Metra (1969) report studied the packing of parcel containers. Castellano and Clinch (1969) investigated the wide range of air freight container sizes.

Maximum Loads and Pressures on the Parcels

The parcels are considered as solid bodies which transmit the forces imposed upon them as if they consisted of joined polyhedra, with rigid rods on the edges, with no compliance. Adjustment of the programme to introduce compliance would require considerably higher speed and more core than was available during this research. It would be desirable for this to be done, since the calculation based on a rigid material gave average maximum loads in full conveyors of about 100 lbf on the most loaded parcel. If this were a point loading, then from the validation tests, it is likely that very few parcels could accept this without permanent collapse and possible damage. Plastic hingeing was often shown at around 20 to 25 pounds loading. A typical computer print out isshown in Fig. 7.50. The high values of load
(page 416)
predicted by the model are less likely to occur in the "real world" parcel conveyors. The different behaviour of "real world" parcels

of varying softness would allow the load to be reduced by parcel compliance. This would reduce the effect of higher loads, by the softer parcels deflecting under load, and redistribution of forces would occur. The model avoids this complication to reduce the demands on the computer. The values given by the model for pressure on parcels (see Fig. 7.51) (page 417) are realistic simulations of the actual pressures. The downwards load is regarded as being distributed, over the whole of the parcel surface which is oriented towards the load. The loads were calculated in the orthogonal directions, parallel and perpendicular to the conveyor axes. The vertical load was not always the maximum load in any configuration. Also, the maximum load and maximum pressure in any test loading were not always to be found on the same parcel. This was particularly noticeable with respect to loads across, or horizontally perpendicular to, the conveyor length, which achieved three very high values on parcels 7, 17 and 20 (see Fig. 7.50) (Page 416) which were in contact. This high concentration did not spread across the whole loading, to cause a jam and it would appear that something causative would be necessary to spread this force out to the sidewalls, to create a jam.

The pressure range found was of interest. In 357 loadings, which were examples of full conveyor sections, the maximum pressure was 14.40 lbf/in^2. The distribution of maximum pressures was such that 9.2% of test loadings had a maximum load on one parcel of more than 4.00 lbf/in^2 and 32.7% had a maximum load of 1.70 lbf/in^2 more. These figures were felt to represent probable damage to one parcel in the load, although there was a significance to the value of 1.7 lbf/in^2 in connection with friction behaviour of plastics. This was the figure beyond which the laboratory tests had indicated that plastic wrappings would collapse. Also, these tests had indicated that plastic and rubber materials would give very high values of friction at these pressures. However, when conveyor loadings are heavy, the number of parcels at risk, is not that high. In Table 7.51 the results (Page 417) for a heavy loading are shown. The average is seen to be 0.605 lbf/in^2, which is not severe, although much higher values are given than in the previous Table. Only 9.6% of the parcels have pressures exceeding (Table 7.50, page 416) 1.7 lbf/in^2 and no parcels are loaded above 4.0 lbf/in^2. In this exceptional case then, 6 parcels in 62 were subject to loadings that might cause damage, i.e. were "at risk". In these two selected cases of high pressures under dense packings, only around 10% of the parcels reached a potentially damaging pressure. The alternative approach was taken, which was to find the proportion of parcels "at risk" in a sample of test loadings under conditions where conveyors were subject to large numbers of closely packed parcels, rather than to select cases where high pressures have occurred in one or two selected test loadings. For a sample of 40 test loadings of 3881 parcels under these conditions, the maximum number of parcels which could be damaged by the pressure due to the load was found to be 121. Thus, the percentage of parcels at risk was 3.14%. The number of parcels subjected to a load which was likely to damage them was 32, or 0.82%. If this figure is coupled to the probability of whether the parcel which receives a loading of more than 4.0 lbf/in^2 is fragile enough to be damaged, then the risk of damage in normal circumstances is quite low. It is likely that other accidental risks are just as common as a source of damage.

Sidewall/Base Force Ratio

This evaluator, chosen by the author to assess the effect of friction in causing a jam in a parcels conveyor, is entitled the Sidewall/Base Force Ratio. This is defined as the ratio of the forces dragging the parcels backwards due to the contacts with the sidewalls, compared to the forces pulling along the conveyor due to contact with the belt, expressed as a percentage thus:

$$\text{Sidewall/Base Force Ratio} = \frac{\text{Dragging force due to friction on sidewalls}}{\text{Traction force due to friction on conveyor belt}} \times 100\%$$

The Sidewall/Base Force Ratio is used to assess when a jam is likely, as it is when the ratio rises above 100%. It is, of course, subject to the changes due to the sliding or static friction of the two surfaces of belt and sidewall.

$$\text{Sidewall/Base Force Ratio} = \frac{\text{Dragging force due to friction on sidewalls}}{\text{Traction force due to friction on conveyor belt}} \times 100\%$$

$$= \frac{\text{Normal force on sidewall}}{\text{Perpendicular force on conveyor belt}} \times \frac{\mu s}{\mu B} \times 100\%$$

where μs = sidewall/parcel friction coefficient

and μB = belt/parcel friction coefficient

Before a jam, μs is a coefficient of <u>sliding</u> friction and μB is a coefficient of <u>static</u> friction. After a jam occurs the position reverses. Since the likelihood of a jam is greater before the jam occurs the evaluator, i.e. Sidewall/Base Force Ratio, is always taken in this work as sliding friction on the sidewall and static friction on the base. If a jam occurs, the likelihood of the jam collapsing due to the reversal of the friction conditions, is then examined, to see if the jam is permanent.

The Effect of Loading upon Sidewall/Base Force Ratio

The average number of parcels for a 40 inch wide, 72 inch long, 36 inch high conveyor section, given by 29 test loadings of 1822 parcels from all the offices, was 62.83 for loading by the random placement model. For comparison we may use the figures for the moving belt model, where the nearest feed rate is 59 parcels for the same conveyor section. At this feed rate, there were 39 test loadings of 2301 parcels from all the offices. The average values of Sidewall/Base Force Ratio, for both moving belt and random placement models, are surprisingly close. For moving belt the Sidewall/Base Force Ratio value is 1.84; for random placement loading the value is 1.94. Since the mean number of parcels does not coincide, the moving belt Sidewall/Base Force Ratio could be compensated, by multiplying by the ratio of the two means, as follows, (where the average numbers of parcels in the two types of loading are 62.83 for static and 59 for moving belt)

$$\begin{array}{l}\text{Moving Belt}\\ \text{Sidewall/Base Force Ratio}\\ \text{(after compensating for}\\ \text{ the difference in means)}\end{array} = 1.84 \times \frac{62.83}{59} = 1.96$$

This revision gives a value for moving belt of 1.96 (adjusted to the equivalent of the random placement model loading of 62.83 parcels) compared to 1.94 for the random placement model. This is even closer and there is very little justification in suggesting that there is any change of the Sidewall/Base Force Ratio caused by the two different types of loading.

Effect of Loading upon Contacts with Conveyor

Table 7.52 (Page 418) shows the figures for comparison for the base and sidewall contacts for moving belt and random placement models. The average number of parcels in the smaller sample from the random placement model used for this comparison, was 63.8. The nearest moving belt test, was again the 59 parcels test loading. If we compare these two samples for numbers of parcel contacts on base and sidewall, we can set up the Null Hypothesis:

$H_o: \mu_1 = \mu_2$ where μ_1 = mean of sample tests of random placement model

and $H_1: \mu_1 \neq \mu_2$

μ_2 = mean of sample tests of moving belt model

The values are given in Table 7.52 (Page 418) for both F-test and t-test of the hypothesis.

The F-test shows there is no significant difference in the variance ratios of the two samples and we should accept the Null Hypothesis. The t-test shows a just significant difference in the number of contacts on the base but not on the sidewall. Previously use has been made of a correction factor to adjust the mean of random placement and moving belt models, which is acceptable because of the similarity of variances. If we interpolate a value, between the mean number of contacts for 59 parcels in the moving belt model and the mean number of contacts for another moving belt sample of 69 parcels, we get:

Parcels in Load	Mean (59 parcels)	Mean (69 parcels)	Calculated Mean (63.8 parcels)
Base Contacts	16.89	18.67	17.75
Sidewall Contacts	8.67	14.67	11.55

Since the variances are sufficiently similar to be acceptable we can calculate the t-test again to give t equal to 2.84 for the base contacts and 0.99 for the sidewall. The new tests indicate that there is no significant difference in sidewall contacts. For the number of base contacts there is once more a significant difference between the two means at the 95% level, but not at the 99% level. The higher mean value for the number of parcels in contact with the belt confirms that a closer packing has occurred with the moving belt model. This would infer that the "rolling action" of the moving belt causes a different and somewhat more homogeneous packing than the random placement (static) model, since the conditions of the two models only differ in the method of loading.

Effect of Loading upon Computer Usage

The differences between loadings had far less effect on the computing than on the programming changes. For example, consider the programme Tilt 75, which eventually became Tilt TL 202 after extensive development. Tilt 75 took from 5.35 to 6.56 seconds of mill time to run one parcel through the model. Tilt 202 took about one-tenth of this from 0.528 to 0.720 seconds per parcel. Table 7.53 (Page 418) shows how close values are for the four final programmes. It will be seen that TL 204 has reduced the value to 0.378 to 0.438 seconds, for a similar method of static loading. Any conclusions about the variations in the programmes are not possible on the value so far obtained, as the evidence is inconclusive and trends vary according to the parameter chosen for examination.

These variations between the final four are therefore likely to be due to chance variations in sequence and characteristics of the parcels in a load.

7.5.4.2 Traffic Intensity

Traffic intensity is the rate of parcels entering the chosen conveyor section in a given time. Table 7.54 (Page 419) gives the correlation analysis of the relations between the evaluation parameter and the traffic intensity. The range of traffic intensity was from 9 to 97 parcels per minute when the moving belt was loaded with the Croydon parcel data. The programme used was TL 203.

Packing

The correlation of the packing parameters with the traffic intensity was most marked and better than 0.999 for both packing density and weight. The conveyor section used was 40 inches wide, 36 inches high and a length of 72 inches was traversed. The relationship was therefore strictly linear with packing.

Load/Pressure

The relation of parcel load to traffic intensity was somewhat linear, with a correlation coefficient of r = 0.782. This was not particularly good and it is likely that the variation is evidence of the effect caused by the large size of the parcels compared to the conveyor section, about which Jenike (1970) had warned the author. Investigation showed that the effect seemed to be due mainly to scatter in the size and shape of individual loads (as already discussed in Section 7.5.4.1 (Pages 210 to 213) and values given in Fig. 7.50 (Page 416)). The pressure on the parcels seemed to be completely random and the value of correlation coefficient r = 0.137, with a slope of only m = 0.014, supports this point of view. However, even though there is little evidence of a relationship between traffic intensity and parcel pressure, there is wide variation in the value of pressure. The standard deviation is 3.090, compared with the mean of 2.605, which indicates a wide, skewed distribution of parcel pressure, which must be due to the variations in individual parcels.

Sidewall/Base Force Ratio

This parameter has been defined previously in 7.5.4.1 (Page 213) and is used as an evaluator for the possibility of jamming.

The values for Sidewall/Base Force Ratio against traffic intensity are interesting. The average Sidewall/Base Force Ratio is not strongly related to the traffic intensity. The correlation coefficient is only 0.185 and the slope virtually zero, at 0.005. The mean value of Sidewall/Base Force Ratio is 2.17 and the intercept close to it at 1.895; and the standard deviation is only 0.309. This relation will be discussed further, in the section below on forces. On the other hand, the values for maximum levels of Sidewall/Base Force Ratio are very variable. They have a much greater scatter, with a mean of 4.40 and a standard deviation of 2.56. The slope is almost zero, once again, at 0.056, but the intercept is well away from the mean at 7.385. Although the correlation is marginally better at -0.556 for maximum Sidewall/Base Force Ratio, the experimental scatter is greater than for the average Sidewall/Base Force Ratio. Whether this is an effect due to the loading, or a result of insufficient data, is not apparent. To investigate this would require a study of the distributions of pressures to establish measures of dispersion and this is felt to be beyond the scope of this thesis, but it is possible to conclude that the Sidewall/Base Force Ratio is independent of traffic intensity.

Forces and Contacts

The sidewall and base (or moving belt) forces generate the friction forces which are the components of the Sidewall/Base Force Ratio, as was shown in the previous section, 7.5.4.1. (Page 213)

$$\begin{aligned}\text{Sidewall/Base Force Ratio} &= \frac{\text{Dragging force on sidewall}}{\text{Traction force on moving belt}} \times 100\% \\ &= \frac{\text{Normal sidewall force x constant } (\mu_s)}{\text{Normal base force x constant } (\mu_\beta)} \times 100\%\end{aligned}$$

The normal sidewall and base forces show correlations which indicate a linear relationship with traffic intensity, strongly in the case of the base force, $r = 0.997$ and reasonably in the case of the average sidewall force, $r = 0.694$. When these two forces are coupled in the relationship shown above, for the Sidewall/Base Force Ratio, we get:

Sliding Force = M_1 (traffic intensity) + C_1

Base Force = M_2 (traffic intensity) + C_2

and Sidewall/Base Force Ratio = M_3 (traffic intensity) + C_3

Examination of Table 7.54 (Page 419) shows that there is strong confirmation of a linear relationship between both sliding and base forces against traffic intensity, which suggests that there should be a similar relationship between Sidewall/Base Force Ratio and traffic intensity. The simulation runs do confirm this with only a poor correlation at $r = 0.185$, but the value of Sidewall/Base Force Ratio is practically constant with traffic intensity, since the slope is only 0.005. It would appear that the particular values of slope and intercept of the normal forces, together with the effects of the friction coefficients, cause a considerable reduction in the slope of Sidewall/Base Force Ratio. On the other hand, the variability of the two normal force values are combining to increase the variability of the Sidewall/Base Force Ratio and lowering the correlation coefficient r.

It can be seen that the normal sliding and base forces which form the numerator and denominator are linear functions of the traffic intensity, as shown by the correlation analysis. The Sidewall/Base Force Ratio, owing to the particular juxtaposition of the constants of linearity of the forces, and values of friction coefficients, is virtually independent of traffic intensity.

Computer Usage

Table 7.55 (Page 420) shows the variation of computer usage as the traffic intensity is ranged from 9 to 97. Computer usage is measured by the time in the Central Processor Unit (CPU), known as "mill time". The last column shows the differences in the mill time for an increase in traffic intensity of 10 parcels over the 72 inch section length. The differences are small and fairly regular until, in loading the conveyor, the computer programme begins using the "rolling and shuffling action" at a traffic intensity of 39 parcels. The next increment causes a doubling of the computer time per parcel and more than doubles the time for the computer run. This is clearly due to the extra manipulation required to achieve the rolling and shuffling actions, which fill the conveyor belt section up. This is clearly a discontinuity in computer time. It is then followed by smaller changes of rate, but they increase rapidly, since the relationship is now exponential. Any further steps nearly double the previous difference in computer time, until the last step is reached and the cut-off point terminates the run.

7.5.4.3 Width of the Conveyor

The conveyors that had been observed in the parcel office were of more than one type and the widths varied from over 6 feet at the unloading point to 30 or 40 inches at restricted points. The upper limit which could be modelled sensibly, owing to computer storage limitations, was 72 inches. The model was therefore ranged from 32 inches to 72 inches wide, in steps of 4 inches. With the moving belt model using Croydon parcels, four simulation runs using 49 parcels were carried out at each size of conveyor. In the random placement model only three runs at each size of conveyor were possible, since the average number of parcels per run often exceeded 60. This value is the maximum average number of parcels, which would allow four runs from the 240 parcels in the Croydon sample.

Tables 7.56 to 7.59 show the values obtained for a comparison of (Pages 421 to 424) width of conveyor against the four major evaluators. Table 7.60 shows (Page 425) the analysis of the values in Tables 7.56 to 7.59 by linear regression.

Loading

The scatter was not extreme for all three parameters of number of parcels, packing density and weight, as may be seen in Table 7.56. The linear regression in Table 7.60 (Page 425) gave a correlation coefficient of around 0.5, and it was considered that loading was not strongly dependent upon the conveyor width. The weak correlation given for all three parameters was felt to be due to the simulation of the tumbling and shuffling action which favoured longer parcels tumbling towards the conveyor length.

Load/Pressure

In the same way the parcel loads and pressures, given in Table 7.57 (Page 422), were not shown to have any relation to the conveyor width. With the maximum pressure on parcels, the correlation was -0.556, but then the slope was only -0.023. With the maximum load on a parcel the slope was -0.364, then the correlation dropped to -0.264. Here the effect might be more significant due to a greater slope, but the correlation is so weak that little importance should be placed upon the relationship. Hence, neither load or pressure on parcels can be regarded as affected by the width of the conveyor.

Forces and Contacts

The values for base forces and contacts, given in Tables 7.58 and 7.59 (Pages 423 & 424), show little correlation, since the conveyor section is of constant area in plan with the length reducing as the width increases, as listed in Table 7.58. The actual values in Tables 7.58 (Page 423) and 7.59 (Page 424) are affected by this inverse relationship, but if the values are adjusted to compensate for the variation in length of conveyor, there is virtually no correlation with sidewall forces and number of contacts, as is shown in Table 7.60 (Page 425). With this correction made, and possible trend ignored, then the mean number of contacts is 15.958

for the static model, with a standard deviation of 1.182, compared with 15.977 for the moving belt model, with a standard deviation of 1.719. Hence, the general conclusion may be made that forces and contacts are not affected by changes in width. As a check, the number of times parcels overlapped the sidewall and the top of the conveyor were considered. The overlap of parcels at the top of the conveyor had a correlation of -0.427, which was not considered to be significant. The sidewall overlap had a correlation coefficient $r = -0.952$, which was a strong correlation, except that when the length of the sidewall was allowed for, the correlation dropped and the value was $r = -0.275$. Hence, there was no effect from variation of the width, after compensation for the variation in the length of sidewall inversely with width.

Sidewall/Base Force Ratio

The values for Sidewall/Base Force Ratio, given in Table 7.60, (Page 425) were interesting, in that the slope and intercept were remarkably close. Correlation was low with the random placement model and too much significance should not be placed on the analysis. The rolling action of loading parcels with the moving belt model improves correlation from -0.188 to -0.560 and reduces the range of scatter from 8.8 to just under 2.5. The figures suggest that the lower packing density with random placement is the cause of the low correlation. In moving belt models, the Sidewall/Base Force Ratio will correlate inversely with width of conveyor, due to higher densities and better contact with the sidewalls. To confirm this, the Null Hypothesis was set up. This suggests that there is no effect due to width, which was tested by analysis of variance.

$H_o: \mu_o = \mu_1 = \mu_2 = \ldots\ldots = \mu_{11}$

and $H_1: \mu_o \neq \mu_1 \neq \mu_2 \neq \ldots\ldots \neq \mu_{11}$

where μ_o = population mean of Sidewall/Base Force Ratio for any width of conveyor

and μ_1 to μ_{11} = means of Sidewall/Base Force Ratio for conveyor widths from 32 inches to 72 inches

The F-ratio for the random placement model was 1.036, where the degrees of freedom of the numerator were 10 and those of the denominator were 22. The critical value of F was greater at 2.30 for the 0.95 probability (95% chance). We must, therefore, accept the Null Hypothesis for this model and say for random placement loadings that there is no significance to the effect of varying the width of the conveyor.

On the other hand, for the moving belt model, if we apply the same F-test to the Null Hypothesis, we get an F-ratio of 6.90 for 10 degrees of freedom for the numerator and 33 for the denominator. The critical value of F is less than this at 4.13 for 0.999 probability,(99.9%) so the Null Hypothesis must be rejected for the moving belt model. Clearly the effects of varying the width of the conveyor upon the Sidewall/Base Force Ratio are highly significant with the moving belt model, which typifies normal conveying of parcels.

This analysis shows that the effect of the width of the conveyor upon the Sidewall/Base Force Ratio, and therefore upon the jamming of the conveyor, depends upon how the conveyor is loaded and upon the "shuffling" and "settling" of parcels due to the movement of the belt and the drag of the sidewalls.

Computer Usage

With a constant traffic intensity of 49 parcels, over varying widths of approximately the same area, the computer mill time was from 1.00 minutes to 1.14 minutes, with little scatter. The times for the static loading, were more variable and higher at 1.13 to 1.47, but no trend was discernable. With such close figures for mill time, to draw firm conclusions is risky, because the scatter might be due to the computer job mix, affecting multiprogramming, and thus the variation in mill time figure, would be affected by the job mix, in computer operations. Hence, on the evidence for computer usage, it was decided that width of conveyor had no effect.

7.5.4.4 Materials and Environment

Considerable discussion has been devoted to the effects of plastic parcels and humidity, upon the performance of the conveyor. The graph Figure 7.61 (Page 426) shows the effects of the percentage of plastic wrapped parcels present in the load from 0 to 100% and under humidity variations from 40% to 70% RH. The graphs show that a marked increase occurs in traction force, pulling parcels along the belt, at the instant that a jam occurs. At this instant, the traction force changes from static friction to sliding friction. Thus, the traction force increases from the static value (lower lines) plotted for each relative humidity from 40-70% RH to the sliding value (upper lines), given in Fig. 7.61. (Page 426)

The proportion of plastic covered parcels affects the amount of the increase and when approximately half of the parcels are wrapped in plastic materials, the greatest change occurs in traction force at the instant of jamming. Further increases in the proportion of plastic wrapped parcels, reduce the intensity of the effect. When all the parcels are wrapped in plastic coverings, the change in static/

sliding friction is small, due to other complexing factors, such as different atmospheric contamination, loading, rate of sliding, contact pressures and so forth. The relative humidity (RH) has an intensifying effect and when the atmosphere is relatively dry, at 40% RH and below, the presence of plastic wrappings tends to minimise the change in traction force. As the RH rises the change in the traction force at the instant of jamming becomes intensified and at levels of humidity of 70% RH, close to saturation under Post Office conditions, the maximum effect is noted when about half the parcels are plastic wrapped. The ratio found at this point is about 1.62, for sliding force to static force. If only plastic wrapped parcels are present, and the humidity is high, at or near saturation levels of around 70%, then the ratio drops to values close to the 1.15 given by the laboratory test rig, showing a level of validation with "real world" data. This difference is not important in a straight conveyor, but is relevant in configurations which are likely to jam, such as L-turns and chutes. The sidewall forces are more regular and the results are plotted in graph 7.62. (Page 427) The effects of humidity are predictable and fairly acute in both static and sliding friction. Thus, it may be said that comparatively damp conditions in the U.K. are a cause of difficulties, by producing considerably increased frictional effects. None of the values from the model would suggest a jam, since the highest S/B Force Ratio observed was only 11.0%. If any of the high loads, shown to be present across the conveyor on some of the parcels, had ever been present in an interconnected bridge of parcels that reached across the conveyor completely, then a jam could be created. The frequency of occurrence would be very rare. In this connection, the findings of Denton (1953) concerning dust are very relevant. He found that if dust was present, it became a source of infrequent jamming, whereas clean, dry surfaces jammed frequently. It is possible that the variability in jamming performance in conveyors is more related to local environmental factors such as dust and humidity, than to the nature of the wrappings or conveyor materials.

7.5.4.5 Parcel and Office Attributes

The variation of the parcel attributes from office to office was more than just the wrapping. As had been noted previously, there were some local variations in compliance, for example Liverpool had rather more soft parcels than London N.W.P.O. In a similar way the size and shape varied from office to office, but the difference was never great enough to be significant. In this connection the statistical package SPSS was used on samples of 200 parcels from each office at random, to test attributes for significant differences, but there appeared to be none. Checks made in friction, contacts, parcel loads and pressures, packing and loading, all resulted in there being no evidence to suggest that the various offices produced parcels of different characteristics. It is therefore valid to say that a common parcel distribution exists.

It is, of course, a very variable material.

7.6 THE VALIDATION OF THE MODEL

It is a major source of difficulty to validate the computer models of "real world" complex industrial plant. Any validation tests are limited to exact comparisons. Industrial plant must make production runs and only rarely are these capable of direct comparison,with the results of the oversimplified model. This is true in this case. By courtesy of the Post Office, a validation was performed using some live traffic ("real world" parcels), in the conveyor section nearest to the computer model, at Western District Post Office (W.D.P.O.). The results, obtained by loading the parcels into the static conveyor in a random manner, were compared with the computer programme results. (See Tables 7.63 and 7.64). The conveyor section used, was not exactly the (Page 428) same section as the computer simulation. This was assumed to have vertical sidewalls, which proved to be unavailable in practice, but the order of agreement was not expected to be so good, that errors caused by the difference in section would be large, compared with errors from other sources.

To obtain permission to use the live mail, (i.e. actual customers' parcels) in any validation, is very difficult. This is only right, since it is possible that delays might arise from this cause, coupled with a slight risk from extra handling. Thus only the above validation was carried out, since any validation beyond this, was beyond the scope of this research. The mail was chosen, to be as representative as possible of the sample data to hand, but in actual fact the validation was insufficient to establish whether the sample was truly representative or not. The W.D.P.O. validation used a sample of real parcels, of such sizes, when used as input data for the computer model, as to give values of packing density which look high. On the other hand, the packing density from Birmingham parcel data in the model, is only 4%

(approximately) lower in packing density and the mean number, at 73.5, compares well with the 74 of the validation (see Tables 7.63 and 7.64). (Page 428) If the W.D.P.O. parcel sizes which occur in the validation are fed into the model, it gives a packing density of 49.1%, or just over 1% different from the validation, but the mean number of parcels is low at 68.3 (see Table 7.63). (Page 428) To reproduce the loading of the 74 parcels exactly would mean the programme must load the computer simulation model of the conveyor in exactly the same pattern as the validation and nullify any comparison of model and validation.

There is an effect due to the length of the conveyor. The validations were made on two lengths of conveyor (see Table 7.64). (Page 428) The longer 108 inch section, gave a higher packing density at 54.9%, which compares with 50.51% for the 72 inch validation. We may also compare the number of parcels, by scaling the number of parcels loaded into the 108 inch validation, down to an "equivalent number" for a 72 inch section. The adjustment is made to the 126 parcels packed into the 108 inch section as follows:

$$\text{Equivalent Number} = 126 \times \frac{72}{108} = 84$$

(packed into 72 inch
section, based upon
the 108 inch validation)

Thus we find that this number of 84 is 13.5% higher than the 72 inch validation which loaded 74 parcels. This could be taken as evidence of the "end effects" caused by the short sections used in the model. On the other hand, it could be that the values arising in the validation are different, due to chance variation in parcel sizes, since they are well inside a plus or minus two standard deviation range of the mean, predicted by the computer model. As far as can be ascertained from the computer validation exercise at W.D.P.O., the model reproduces the "real world". Only further application and validation can establish completely how accurate the model is.

7.7 STATISTICAL ANALYSIS PACKAGES

Since the study of the data was such an important part of this research, the statistical packages might be thought to be a fruitful source of analytical results. In actual fact, a considerable amount of time was wasted, in developing skills in using two of these packages, without any great advantage. Like most programme suites, the large statistical packages are unwieldy, because they try to do everything, when compared to a purpose built programme for doing limited analysis. The penalty for this "all-embracing" function, is a very large computer overhead. The three packages tested in this research were ASCOP, GLIM and SPSS. The first two were available on the ICL 1900 and the third on the CDC 7600. The size of these packages restricted turnaround considerably, but fortunately towards the end of the project, the CDC had available 64 Kwds of fast core and 256 Kwds of slow core and this enabled the SPSS programme to be available in two fast versions and one slow version, according to the size of the data to be handled. Even though the computer power was adequate for the problem, there were still difficulties over the programmes. None of these packages were created to cover specifically the type of project which would compare data such as the parcel attribute distributions. Naturally, this was to be expected of the GLIM package, once it was realised that the initials stood for the "Generalised Linear Modelling Package". However, there were similar problems with both SPSS - "Statistical Package for Social Scientists" and with ASCOP - and in this case the manual did not explain the derivation of the initials. The difficulty arises, because the packages are written with attributes which are a collection of dependent and independent variables, so that linear relationships are sought between the elements of a data point. The programme assumes, for example, that length will be linearly related as a function of breadth, height, weight and so forth. Had a good "ranking sort" been available as part of the suite, it would be possible to rank each of the variables from their smallest values upwards, say for a random 200, from the approximately 400, parcels in each office group. The logical basis for this method is dubious. It is quite feasible, however, to write FORTRAN programmes for this, but considerable computing is involved and the project would become computer research in its own right. Trial programmes showed that computer times in excess of three hours were needed for each office.

There is no doubt that some of the features in these packages for data correction are extremely useful and superior to the various text EDIT facilities. Of these the CYBERNET interactive package STAN seemed the best. (See CRC (1973)). Other useful features are ability to compute derived variables such as volume and density. On the whole, however, the large statistical analysis packages were better left to the purpose most of them were developed for, and that is social science research. Table 7.65 (Page 429) gives the results obtained from the SPSS programme, using the CONDESCRIPTIVE, STATISTICS ALL commands. The programme is in Appendix VI. (Page 298) If a statistical study of the parcels was made, considering them as a very variable, but homogeneous material, then a very good approach would be to use the SPSS or other statistical package for the computer available to the investigator. The Table of Means and standard deviations of Table 7.65 (Page 429) were abstracted from the SPSS run shown in Appendix VI (Page 298) for the six parcel offices. This SPSS run also gave details, for each office and parameter, of the standard error of the mean, the skewness and the Kurtosis of the distribution. Kurtosis is the "peakedness" of the distribution, to use the terminology of Chou (1969). Although beyond the scope of this work, owing to the time, this information could well prove a basis for solving this problem. This could greatly affect the design of conveyors for particular applications in specific geographical locations. If the nature of the parcel distribution could be specified more exactly, then the conveyor design could be much more effective.

As an example, the data for the W.D.P.O. sample of packets had been made available by the Post Office. Thus, one SPSS run was carried out for the data for these packets and another for the 2075 parcels from all offices (treated as one batch). The results are added to the SPSS run for the parcel data, to give Table 7.65.
(Page 429)
These results are analysed in Table 7.66 to show the ratio of the parameters of Table 7.65 given by
(Page 429)
the SPSS package. A further step is to use the parameter Mean Volume or $\bar{V}$, which is very simple in SPSS, previously suggested in Section 3.4 for analysis. (See page 68) Hence :

$$\bar{V} = \bar{L} \times \bar{B} \times \bar{H}$$

where $\bar{L}$ = Average Length
$\bar{B}$ = Average Breadth
$\bar{H}$ = Average Height
$\bar{V}$ = Mean Volume

and the comparison between packets and parcels, could be made on a basis of a comparison ratio CR, where:

$$CR = \frac{\text{Parameter of Packet}}{\text{Parameter of Parcel}}$$

The values for CR given in Table 7.66 are interesting.
(Page 429)
If we take the CR for the length (0.677) and also the CR for the breadth (0.622), and to a lesser extent that for the height (0.243), then letter packets are surprisingly large, on average, compared to parcels. On the other hand, the CR for weight shows, at 0.119, that packets are about 12% of parcel weight on average.

The regulations which allowed wide limits on dimensions for packets at the time of the survey (1971), yet restricted weight due to the high costs, would seem to be in accord with this analysis. If, on the other hand, we calculate the mean volume $\overline{V}$ and the associated CR, we get 0.102, which means that letter packets are in fact only about 10% of the volume of parcels. Using this type of analysis would ensure the correct handling for packets. An alternative approach would be to adjust the packet distribution by amending the statutory regulations for size and/or the costing by weight, so that the distribution of packets suited the handling facilities currently available. This would be a suitable area for further study.

8.0 CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The conclusions are grouped into the following headings:

GENERAL CONCLUSIONS

CONCLUSIONS ABOUT COMPUTING

CONCLUSIONS ABOUT THE MODEL

SUGGESTIONS FOR FUTURE WORK

8.1 GENERAL CONCLUSIONS

This section is sub-divided into the following:

Achievement

Parcel Distributions

Loading and Packing

Forces and Pressures

Friction - General Comments

Friction of Conveyor and Wrapping Materials

Jamming of Parcels

8.1.1 Achievement

1. A computer simulation model has been written to demonstrate the operation and to aid in the design of belt conveyors for parcels traffic. It has shown that a computer model can reproduce the random packing of containers and the action of straight conveyors of normal section.

2. A study has been made to establish the nature of parcels on a statistical basis. It has shown that the size, shape and weight of the parcels may be statistically defined and that they are a very variable group of objects. There are significant differences shown by some of the offices as far as some of the above characteristics are concerned. The internal materials of which the parcel is composed and the internal structures of the parcels are too complex and variable to

define. The variation in elastic properties, from orientation to orientation on the same parcel, is so large that one orientation can give values of Modulus of Elasticity which are hundreds of times larger than another orientation on the same parcel. To attempt to average such widely differing values would give meaningless results. Under these circumstances, it is impossible to define an "Ideal Parcel Material". The question remains unanswered of whether different Offices have parcels of different internal material characteristics and whether each one could be represented by a particular (and different) "Ideal Parcel Material" for that Office. Considerable research, beyond the scope of this present project, would be required to answer the question.

3. This study has shown that a computer simulation is the best way to model a parcel conveyor. A belt conveyor is not a particularly complex thing to model, but the use of many normal engineering techniques is denied to the designer and operator, by the unique nature of the parcels traffic. By the use of a large data bank of parcels, the past history of parcels data has served as the input data of discrete parcels. The loading of these into a conveyor section, is done individually with respect to parcels already sited on the belt. The orientation and attitudes of the parcels are partially at random and partially governed by the laws of mechanics and partially governed by the parcels already on the conveyor, or by the sidewall of the conveyor.

4. This model has shown that, even though it is not particularly suited to computer languages, particularly simulation languages based upon time clock or even timings, it is still feasible to use a High Level language and a good operating system to create a complex model in a medium sized computer. To do so requires the use of modular computer programming and multi-file handling.

5. A study has been made of friction. This shows that Coulomb friction does not apply to the materials used in the conveyor and the parcel wrappings. The friction behaviour of a given group of parcels is a function of operational and environmental factors, especially speed of the conveyor, areas of the parcels in contact and also the humidity and atmospheric pollution near to the conveyor.

6. In the computer simulation the behaviour of oversize and irregular parcels has been disruptive. Numbers of these appear in the samples of live mail from the various Offices. This would appear to be due to the somewhat vague and incomplete specifications at present in use. Some standardisation is essential to reduce parcel handling costs. It is doubtful that the adoption of the E.E.C. standards will achieve enough in this direction.

8.1.2 Parcel Distributions

1. When parcels arrive in an Office from a single large source, such as a large mail order company, with a characteristic method of packing and wrapping, the effect upon size and shape is sufficient to distort the parcel traffic significantly from the averages. In particular the wrapping characteristics and the compliance,(i.e. the softness of the parcels) are significantly affected by this distortion. The behaviour in friction is shown to be affected by this distortion, caused by large numbers of similar parcels arriving at one office. To monitor this effect would not require large samples, since the change in parcels which are present in large percentages,is the only important factor.

2. It is not possible to say that parcels from all Offices,are from the same parent population. Tests involving samples of over 2000 sample parcels, from six Offices, showed significant differences.

In wrappings, size, shape, weight, volume and density, there was evidence to suggest that there were significant differences in physical attributes in the samples from different Offices. In the case of the wrappings, considerable further sampling would have to be done to analyse the characteristics of certain wrappings, which were present in very small quantities and which could cause jamming.

3. The SPSS computer based statistical analysis package had advantages for analysis of the parcel characteristics. If an up-to-date sample of parcels was available, rapid evaluation could be made with this package. This would be useful to monitor change, such as the increase in parcels wrapped in plastic materials. The survey by Castellano et al. (1971) showed that, at that time, there was a considerably higher proportion of brown paper and cardboard wrapped parcels, compared to any other form of wrapping.

4. There is no such thing as an "Ideal Parcel Material". A model which used a rationalisation which assumed parcels consist of an "Ideal Solid", in predicting conveyor performance, would result in great inaccuracies.

5. Many parcels are related to thin walled box structures. This gives rise to severe problems in predicting forces and pressures in parcel conveying.

6. Load-deflection values established by testing are remarkably linear for parcels. However, the shear effects are marked and values for the Modulus of Elasticity predicted from the load-deflection values, if it is assumed that parcels are solid, vary enormously, ranging from under 1 to close to 1000 lbf/in^2.

7. The difficulties in predicting elastic behaviour, which affects Poisson's ratio as well as the Modulus of Elasticity, renders the use of finite element techniques difficult in this research. In any case, the complex model would entail very long computer times,if finite element analysis was used to calculate the stresses for one point in a probabilistic analysis. This would be for the force calculation module alone, without considering the loading and packing of parcels into the conveyor, which takes the bulk of the computer time at present.

8.1.3 Loading and Packing

1. There is a marked difference between the computer simulation model results given for parcels dropped randomly into a container, and for those loading onto a moving belt.

2. Loading is 1.37 to 1.78 times greater with the moving belt model, as compared to random placement in a static container. The variation occurs according to whether the number of parcels, the packing density, or the weight of the parcels,is used as an evaluation parameter of the loading.

3. The packing of small spheres in large diameter containers is much more dense and more regular than the loading of parcels into a conveyor.

4. The loading of a moving belt conveyor is not a function of width, irrespective of the evaluation parameter chosen for loading.

5. The number of parcel contacts with a given area of the belt and the sidewall is not affected by the width of the conveyor.

6. The loading of a conveyor is a linear function of the rate at which parcels are being loaded onto the conveyor (the traffic intensity).

This is true for number of parcels, packing density and weight, which all show a correlation coefficient (r) equal to 0.999 or more.

7. The number of sidewall contacts is affected by the loading pattern. Differences are noticeable between randomly dropping parcels into a container and the loading of a moving conveyor.

8.1.4 Forces and Pressures

1. The forces exerted upon the parcels by other parcels in the conveyor are not a function of the loading (i.e. the packing). Conversely some parcels have very high forces, even when the packing of the conveyor is only moderate.

2. The high forces may be transverse, along or vertical with respect to the conveyor.

3. The transverse forces are adequate to cause a jam if bridges formed across the conveyor. While one could occur by chance, the probability must be low, since it has not occurred in the model in 1472 loadings of a 40 inch wide conveyor. It has not occurred in any of the range of other widths from 32 inch to 72 inch either, but the number of loadings in these other widths was very much less. It may be concluded that jams can form by bridges occurring from some cause, as well as from random occurrences.

4. The forces and the pressures on a parcel are not affected by the width of the conveyor, in the range 32 inch to 72 inch, using parcels from the survey sample of Castellano et al. (1971).

5. The traction force on the belt is a linear function of the traffic intensity, that is the number of parcels flowing along the belt.

6. The pressures developed under heavy packing densities are sufficient to damage the polythene wrappings on parcels,when they slide along conveyor belt or sidewall.

8.1.5 Friction - General Conclusions

1. Sliding friction is clearly higher than static friction with parcel and conveyor material surfaces, by a ratio of from 1.26 to 3.04 at lower relative humidities, (40% RH). Coulomb friction does not apply and the friction behaviour relates to a rubber tyre on road.

2. In general, humidity has a great effect upon the coefficient of friction and other friction performance, as measured by the effect on conveyor characteristics. The effect may be to reduce or increase the likelihood of jamming with increase of relative humidity to the saturation point, depending upon the percentage of plastic parcels present in the traffic.

3. Parcel Offices, by the nature of the building and the conveyor construction, coupled to parcel wrapping behaviour, are likely to have higher relative humidities than the surrounding area - for example, the local metereological station. This is because the large amounts of steel in building and conveyor frames, together with large areas of wrapping which absorb water, are a source of water vapour rather like a wick. This could lead to friction and jamming problems.

4. The coefficient of friction is likely to increase by a factor of up to four, as the humidity goes from very low to saturated. This relationship is an exponential form.

5. The Sidewall/Base Force Ratio, that is, the ratio of sidewall drag to belt traction, can be used as a measure of whether jams will occur. It is virtually independent of the packing density and the type of loading.

6. The Sidewall/Base Force Ratio is inversely related to the width of the conveyor when the model simulates the moving belt conveyor loading, which allows subsequent settling of the parcels.

8.1.6 Friction of Conveyor and Wrapping Materials

1. The most important indicator of belt or sidewall performance, as far as friction is concerned, is the ratio of sliding to static friction. The friction coefficient alone is not sufficient. The ratio would be most suitable for selection of materials for conveyor construction.

2. Increasing the percentage of plastic parcels does not affect adversely the jamming and friction behaviour of the conveyor. This would seem to be due to the higher ratio of sliding to static friction with plastic wrappings, which causes a large increase in the traction force and a reduction in sidewall drag as the parcel slides on the belt and halts against the sidewall.

3. Wooden sideplates are more likely to form permanent jams than steel, as shown by the average values of the ratio of sliding to static friction mentioned in paragraph 1. The ratio for steel is 2.82 on average parcel materials and for plain maplewood 1.09. This should be compared to the friction coefficient (static) for steel, which is 0.21 and for maplewood, which is 0.38 .

4. Varnishing wooden sidewalls increases the friction coefficient, but reduces the likelihood of jams forming. This is because the sliding/static friction ratio changes favourably. The improvement in the ratio is from 1.09 to 1.4. The friction coefficient increases from 0.38 to 0.5, but this is of less significance and so the observed effect, which is to reduce the incidence of jamming by varnishing wooden sidewalls, is thus explained.

5. The ratio of sliding to static friction would be a useful estimator for wrapping materials and could be applied to a Materials Standard for Post Office approved wrapping materials.

6. The ratio of sliding to static friction drops to the lowest value found and makes jams most likely, when a loading of 100% plastic parcels is subject to around 70% relative humidity. This is the value for plastic wrapped parcels against the cotton belt. This phenomenon would account for the jamming which occurs at specific Offices at particular times.

7. The sidewall friction increases linearly with the percentage of plastic wrapped parcels present. This is due to the fact that plastic wrapped parcels show static friction coefficients little different from other wrappings. Friction coefficients range from 0.21 to 0.8 for plastic parcels on steel and plain or varnished wooden sidewalls.

8. Laboratory tests of belting in use in parcel offices with rubber facing showed friction coefficients of 0.49 static and 0.62 sliding. A synthetic rubber faced belt, "Scandura", gave values of 0.81 static and 1.1 sliding.

9. Research gives published values for elastomeric rubber for belts and plastic, coefficients of friction from 0.2 to 1.5 or greater. The practical sliding tests in the Parcel Offices gave values that were normally found to be close to 1.0. Testing the friction of these materials is difficult and further research should be carried out to find reproducible and relevant techniques.

10. The values found for Scandura, a synthetic rubber conveyor belt material, were close to unity. If the techniques of measurement are accurate, and providing the forces do not destroy the wrapping materials

and tear them apart, the properties would appear to be superior to other belts and to plastic wrapping materials.

11. Coefficients of friction higher than 1.0 are quite common in laboratory tests of parcel wrapping and conveyor belt materials.

12. The evaluation of friction coefficients is complicated. They are a function of many other parameters than normal pressure. Humidity, area of contact and rubbing speed, are three parameters which were found to be important with plastic wrappings and elastomeric belts, and so were investigated on simple apparatus. Much of the information in published work does not define these variables when giving friction coefficients.

13. The friction performance of most parcel wrappings is affected by humidity. The mix with parcels which have other wrapping materials, affects plastic wrapped parcels, especially if low percentages of plastic wrappings are present, among a high proportion of brown paper and cardboard wrappings, which emit water and other vapours.

14. Although plastic wrappings are no more sensitive to humidity than other wrappings, if the percentage of plastic parcels is between 40 and 60%, a greatly increased tractive force results (see Fig. 7.61). (Page 426) There is a risk of damage to the plastic wrapping in these circumstances, when pressures exceed about 4 lbf/in^2. Schallamach (1968) found similar damage using a pointed slider.

15. This damage is caused by the self-heating effect mentioned by Schallamach (1968), which was found by laboratory tests on parcel wrappings to cause destruction of the surface at around 800 feet/minute, even with flat sliders. It is mentioned by Grosch as causing an effect at speeds as low as 6 feet/minute.

16. Dust from the atmosphere and possible vapours from the rubber belt (organic chlorides, acid chlorides) or the paper/cardboard materials of the parcels (sulphites and acid sulphites), will affect the friction behaviour of the conveyor and parcel materials.

17. Economic factors, such as price increases for scarce resources such as oil for plastics, and timber and natural fibres for paper and cardboard, will affect wrapping materials in the future. Trends are difficult to predict.

8.1.7 Jamming of Parcels

1. This research has confirmed that factors not incorporated into the model, such as compliance and irregular configurations and shapes of parcels, are likely to be the cause of jamming in straight conveyors. It is more frequent to find that jamming, in the Parcels Offices, occurs at changes in the conveyor, such as turns, changes in section or height and so forth.

2. Jams, reported as causing relatively frequent stoppages by the Post Office, appear to occur too frequently to be caused by chance juxtapositions of normal parcels. They are, therefore, probably causative and the likely causes are that groups of parcels, which include one or more awkward parcels, occur - positioned by chance - across the conveyor.

3. The Offices, which are reported by the Post Office Engineers as showing a rather high preponderance of problems, are those which have environmental factors which favour jamming. These would be high levels of humidity and industrial or coastal contamination, and certain temperatures. Naturally adverse human factors, such as an unsettled or unhappy workforce, may also influence the occurrence of problems. Careful research should be carried out before forming any fixed ideas.

4. The importance of jamming is related to the queueing phenomenon. There is a statutory requirement for the Post Office to provide a rapid postal service. Even under moderate parcel flows, queues will form because the arrivals tend to be concentrated into very short periods of time. These queues are very sensitive to the flow rates, both the service rate (traffic flow on the conveyor) and the instantaneous arrival rate of the parcels. The effect is intensified by packing the parcels into discrete bags, containers or trucks and then putting these containers etc. into parcel vans, which causes bunching when they arrive at Parcels Offices. Local queues must then develop. Under these circumstances the interruption of service caused by a jam, causes a queue of parcels out of all proportion to the time of interruption of service.

8.2 CONCLUSIONS ABOUT COMPUTING

1. The use of a good operating system, GEORGE 3, and FORTRAN IV, a relatively sophisiticated high level language, gives more flexibility than simulation languages. This combination was best for this somewhat unusual computer simulation.

2. It is essential to have a good, computer random number generator routine, capable of giving a number of good strings of random numbers of at least a million numbers each. The 24 bit fixed word length of the ICL 1900, is such that the manufacturer's random number generator needs a careful choice of seed, to achieve random strings. Only four were needed, fortunately, since only six good seeds were found. On the other hand, the longer word length of the CDC 7600, which was 60 bits, produced a very random string of great length. However, the CDC 7600 random number generator was inadequate since the software only allowed for the one string. Since the random numbers were not called in equal numbers for the moving belt model, compared to the random packing model, an undesirable variation was introduced. This reduced the comparability of changes in the controlling parameters.

3. A multifile structure was invaluable in the creation of this model, both for the programmes and the data bank. The multifiling was also of great use, in the determination of the relations between controlling and evaluating variables, when many runs were made. In this latter case, the programmes were kept in the compiled binary form.

4. The advantages of multifiling, using a control data file for the exogeneous parameters, and data bank files for Parcel Office data, could not be realised without writing a special user MACRO. The advantages of the GEORGE 3 operating system language in writing these MACRO s is particularly noteworthy.

5. There was a problem with the excessive printout. Some reduction was achieved by not using the "diagnostic" section of the programme, which could be switched on or off through the control data file. It was only when the computer was controlled by user MACRO's for the GEORGE 3 operating system, written by the author, that the computer printout was reduced to reasonable proportions.

6. In the data checking programmes, it was invaluable to have the ability to over-ride the failure caused by incorrect data. This was given by the FORTRAN COMPILER LIBRARIES routine, FTRAP ERRS. By using this routine errors which were fatal normally were located and over-ridden. In this way, instead of many computer runs to locate data errors, one or two checks on each file were adequate.

7. While in theory the graph plotter should have been ideal for this project, much effort was spent in trying to get both manufacturer's and University software operating in a form suitable for this project. Progress was so slow that it was abandoned.

8. The statistical analysis programmes were all aligned towards linear models of point by point relations for dependent and independent variable. These are typical of social science and, to a lesser extent, other research involving cause and effect. The analysis of distributions of groups of parcels, by their respective attributes, was a difficult problem for these programmes. SPSS was the most suited and for this package much preliminary computation was needed to adjust the data presentation.

9. Even if the CDC 7600 computer facility had been available at the commencement of this project, the ICL 1900 computer was a more likely choice, since it had advantages in creation of the simulation, especially in modular programme form. An ideal combination, had an interface been

available, would have been to write the computer programme on the ICL 1900 and then carry out the research evaluation using the CDC 7600, which was much larger and faster. In the event, conversion of the ICL 1900 programme to run on the CDC 7600 was such a major effort, that it would have been simpler to recode the programme.

10. Mini-computers are ideal for small scale, interactive computing. There are distinct disadvantages to some of the software provided by the mini manufacturers, which is often limited. Of the mini-computers, the Hewlett Packard 2100 series was outstanding, followed by DEC (PDP), INTERDATA and MINIC in that order. The hybrid mini-computer and mainframe combinations, such as CYBERNET were even better, but very expensive to operate.

11. With the present computer power (ICL 1903A) it was not feasible to use the COBOL programmes, which were created and tested for the shuffling and organisation of sets of data from the total sample of over 2000 parcels, because the computer time involved would have been excessive. If an updated version of the model were created for the CDC 7600, then it could be run for a greater number of loadings per sample. It would probably be feasible to generate data from the sample to establish probabilistically the chances of jams forming from random causes. It would also be possible to create a model for the "L" turn and other conveyor configurations.

8.3 CONCLUSIONS ABOUT THE COMPUTER SIMULATION MODEL

1. The computer model simulates the real world, as far as the packing of parcels, when dropped in a random manner into a conveyor section, is concerned. There is less difference between the model and the real world, than there was between the random sample of parcels used for the validation, and the sample of parcels from the statistical survey of Castellano, Clinch and Vick (1971).

2. The simulation of parcels, rolling down and shuffling sideways into place on the moving belt, was apparently very realistic. It is not enough, to simply place a parcel randomly on other parcels.

3. In many cases it proved unnecessary to search slavishly for absolute realism in the model, as far as the detail of positioning was concerned. The improvement in packing densities did not justify computer times being increased by factors of up to ten times.

4. Real difficulties in loading the conveyor model were occasioned by parcels which were oversize. Initially, the presence of these was due to mispunched cards, but as the data checking systems became more sophisticated, these were eliminated. This still left a small proportion of the sample of live mail, either just inside or just beyond the girth limitation, but which had been accepted. These were a consistent source of variable loading and lengthy computer runs.

5. The distortion of the regular rectangular shape to a trapezoidal (lozenge) shaped parcel seemed to have no more effect on the simulation than the assumption that the parcel was a rectangular shape.

6. The principle of "unloading" easily calculates the forces by determining the force on the last parcel to be loaded. This has no upper forces. From this start the computer model is able to resolve

the complex structure of forces, always working on the previous parcel which was loaded, without any need for very large core store or the lengthy calculations using large matrices involved in the finite element techniques.

7. The friction behaviour established from the live mail parcel survey was such as to reduce the likelihood of any permanent jams occurring. During the whole of the research programme no jam was ever found.

8. The computer simulation successfully models the discrete nature of the parcels flow. This is extremely variable,since the physical parameters of size (length, breadth, height, weight, wrapping and stringing) and of material (stiffness, compliance and plasticity), are all independent one from another. It has proved extremely difficult to establish a typical parcel "Ideal Material". On the other hand, the size of the parcels can be established fairly well and a statistical description of the parcel population can be established on reasonably small size samples. Hence an "Ideal Shape" is a feasible concept. It seems unlikely that any algebraic queueing mathematics approach,will be successful for the prediction of the probability of jamming of parcels conveyors in the future. Further work will be based upon computer simulation models of greater complexity as faster and bigger computers become available economically to research workers.

9. Inherent in the creation of the computer models of the parcels conveyor,is the collection of recent historical data on parcels traffic. It is likely to become an economic limiting factor in this type of research, since the variability of parcels,is such as to need samples of near to 1000 parcels in every office considered. This is providing the present free choice of wrapping materials is permitted to continue.

10. An essential part of the creation of the model is to allow it to grow over a period of some hundreds of computer runs. To do this economically, it is probably best to write the programme in modules and ensure that these will run as computer programmes in their own right,where possible. This obviates repeated testing of programme sections which have no faults. On assembly of the modules, testing is confined to the interfaces between modules.

8.4 SUGGESTIONS FOR FURTHER WORK

8.4.1 Extensions of the Existing Model

1. An extension could be made to the existing model to simulate conveyor configurations which are more likely to cause problems, as in the right-angled or "L" turn. This is more involved than might be thought, since first a section of the conveyor has to be loaded and then it must be traversed through the "L" turn. Since two loadings are made, much more computer storage is required. It is, however, a feasible project and requires no extra data acquisition as far as parcels are concerned.

2. The existing model could be modified to introduce compliance, even if no further information was forthcoming, since parcels are already subdivided into six grades. These grades distinguish between rectangular, round and irregular and soft and hard parcels. Using this information alone it would be possible to introduce the effects of compliance and variations in shape. Considerably more computing power would be required and the programme would inevitably be considerably longer in both the placement and the force calculation areas. This is again a feasible product based on data already to hand.

3. The existing model and data could be adjusted to run more efficiently on the CDC 7600 to determine the probability of a jam from random causes, as previously discussed. The programme would have to be adjusted to conform to CDC FORTRAN and, if the MNF optimising compiler was used, together with an effort to increase the efficiency of the programming at the same time, then the further reductions obtained would make this feasible.

4. The present model could be extended to give a graphical display of the parcel loading, with the aid of a suitable display terminal.

The ICL 1900 is very limited in the communications capability at the speeds necessary for computer graphics. It is possible that a "front-end" processor with its own buffer stores might be an essential part of such a project. The degree of complexity of this project is quite simply a function of what hardware and software is available and the feasibility again depends on whether the appropriate interfaces can be found to devices which are available.

5. If the computer simulation was altered to bring in the effects of contact area upon the coefficients of friction of plastic parcel wrappings and conveyor belt materials described by Webber (1972), then it may be possible to introduce a more realistic jamming effect. The loading of the parcel into the "PU, LU and PLU" attitudes, lends itself to assigning coefficients of friction with respect to whether the area was low - a corner; or moderate - a line contact; or high - a plane in contact. Also the nature of the contact, whether into the belt or the sidewall, and whether the wrapping was of plastic or paper or cardboard, are all of relevance in assigning a coefficient of friction. This way of predicting the likely coefficient of friction (according to the type of contact), is felt to be more likely to simulate the conveyor belt behaviour, than would taking test friction coefficients for the parcel. These values may typify only what that parcel will do, if it were on an inclined plane, subject to its own weight. If this programme alteration was coupled to the adjustment for compliance and shape irregularity, mentioned in paragraph 2 of this section, it is likely that even more effective simulation will be achieved.

6. The existing model could be modified to introduce causative effects which cause jamming. The data carries information on the stringing and a random percentage of stringed parcels could be regarded as catching on the sidewall and becoming jammed. This would

be achieved by adding a high force at the sidewall, parallel to the conveyor for that parcel. An extension of this would be to introduce configurations of parcel groups which are known to cause jamming. While these alterations may sound simple, they would make the model more complex, because the effects of traction in trying to break up a jam would have to be modelled much more completely than at present. This area has been neglected because there have been no occurrences of the phenomenon.

7. Another approach would take the existing forces and adjust them in such a way as to create jams. One way would be by increasing the coefficients of friction locally to provide the necessary drag. It would give rise to the same sort of complexity as the previous system in paragraph 6.

8. It is feasible to alter the existing model to copy parcel loadings. The Post Office test parcels could then be used to produce some model loadings. These could then be reproduced in the simulation model with the test parcels' sizes to establish how close to reality the loadings were. Having done this over sufficient sample trials to establish parity, and carrying out any programme adjustments to the model to ensure close agreement, then the test parcels could be used in jamming trials. Records could be kept of the configurations which jammed and the parcels could be loaded in a similar way in the computer simulation. The results for forces, contacts and friction could then be tested to establish that jamming predictions were in agreement. The test parcels which can measure stresses, would also be invaluable here, to check the values given by the simulation for parcel load and pressure. This is a big programme, which would be difficult for anyone outside the Post Office organisation to carry out. Even so, it requires

the use of the parcel test set and suitable conveyor and considerable time in defining parcel positions and attitudes. It would also need the services of a large computer.

8.4.2 Suggestions for the Control of Parcels

1. The acceptance of parcels which are outside the size given in Post Office regulations is not uncommon (see Appendix II for details of the regulations affecting the parcels in the sample data). These large parcels in the sample, together with other parcels which were just inside the limits of Post Office regulations, caused problems in packing and loading in the computer simulation. It is probable that the parcels of this type in the normal parcels traffic, cause similar problems in the Parcel Offices when being conveyed.

2. There appears to be confusion over the method of specification of parcels (Post Office 1971b), as far as size limitations are concerned. There is need for a clearer definition of the size limitation.

3. There appears to be a need for regulation of wrappings to a "Post Office Approved" or British Standard Specification for parcels postal traffic. The small percentage of troublesome parcels could thus be reduced. Their effect in disrupting the efficiency of the flow is out of all proportion to the financial return. This is irrespective of whether they cause a jam or not.

4. There needs to be control over stringing. Although the effect of stringing was not incorporated in this report, when a visit to a Parcel Office was made a number of lengths of string were seen trapped in the conveyor between the belt and sidewall and at other vulnerable points. The Post Office regulations should be altered to cover stringing, after research into approved methods.

5. It would be quite feasible to lay down standards for compliance of parcels traffic, using simple tests of deflection. For example, the parcel must not deflect more than one inch for every ten inches of length under gentle hand pressure. While this may not be very scientific, and is open to obvious criticism, it would be a step towards reducing the problems caused by only a few difficult parcels.

6. There is an urgent need for a work systems design approach, such as that of Nadler (1967 and 1970). Consideration should be given as to what relation should exist between National Freight, B.R.S. Parcels and the Post Office. The responsibility should be defined as to who should carry what group of parcels. The difficult parcels might not need to be handled by the Post Office parcels system. There are other nationalised undertakings possibly more suited for that type of freight. If, on the other hand, the decision is made that the Post Office must be responsible for these difficult parcels, then it is possible that the best way of tackling the problem is to isolate "large" and "difficult" parcels. That is, parcels which are likely to cause problems should be treated separately, and the charges should be increased accordingly. Registered mail is already handled separately, but of course for very different reasons.

8.4.3 Further Studies on Parcels

1. There is an urgent need to monitor the changes in parcel traffic, especially the wrappings. There is the need to have knowledge of the "raw material" of the parcels movement industry. Also, before any further modelling is carried out, there is a need for more information on the friction behaviour of parcel wrappings and conveyor materials of construction. Many changes have occurred since the last parcels survey.

2. The structures of parcels are not understood. The simulation of this could be achieved by making physical models, for example in balsa and sheets of paper, card and plastic film, which would give the thin-walled structures typical of parcels traffic. This is an area of study likely to be fruitful. Some data, for values of load against deflection for a group of parcels, already exists. From this data alone there is enough information to carry out a feasibility study.

3. The study of parcels of awkward shapes, and also the groupings which give rise to bridging, will be useful. It should be possible to define those groupings which have the necessary structural stability to give rise to the bridges across the conveyor, as are found in the conveying of other materials. Here the work of Jenike and other co-workers will be useful.

4. In the original parcels survey each parcel was tested for the position of the centroid and also treated as a compound pendulum. The results for this are capable of being handled very easily with the SPSS package, making use of the COMPUTE facility and comparing figures obtained for Centroid and Moment of Inertia from length, breadth, height and weight with those deduced from the compound pendulum data. This data would be invaluable in improving the final force calculation to determine the centroid and the likely attitude. This would replace the empirical rules used at present.

5. Further work should be carried out on the frictional characteristics to find out more about the effects of dust and atmospheric contamination upon conveyor construction and parcel wrapping materials. Apart from collecting the dust from parcel offices, dusts and contaminants could be blended from woodflour, powdered mica, silica, chalk, talc, gypsum, alumina, magnesia, titania and any other easily obtainable

fillers. Soot, charcoal, sulphur and sulphides, plus acid contaminants could also be added to simulate typical industrial contaminants present in parcel offices. If the friction tests were carried out in a humidity chamber with temperature control (particularly the ability to lower the temperature in hot summer conditions), then some useful characteristics could be established. There are many parameters such as area of contact, rubbing speed, normal pressure, humidity, surface condition and so forth. Accordingly the rig needs to be well designed and sensitive, and the results subjected to statistical analysis.

6. A study could be carried out on the nature and the effects of stringing and banding of parcels upon the friction behaviour. This is obviously an area of complexity, expecially with regard to knots. There is a chance that the friction behaviour of stringed parcels is such as to indicate that stringing is undesirable. Certainly, it would not be enough to simply slide a strung and knotted parcel material across the simulated belt. It would be necessary to try to determine the nature of how strings are drawn into crevices, between belt and sidewall, as has been observed in and reported from the parcel offices.

APPENDIX I

THE SIGNIFICANCE OF DIFFERENCE OF TWO MEANS.

Let the standard error of the mean be σ_M ,

where $$\sigma_M = \frac{\sigma}{\sqrt{N}}$$

σ: Standard deviation

N: number in the sample

Thence for the two samples, respectively,

$$\sigma_{M1} = \frac{\sigma_1}{\sqrt{N_1}}$$

and $$\sigma_{M2} = \frac{\sigma_2}{\sqrt{N_2}}$$

Thence if the standard error of the difference between two uncorrelated means is σ_D , where

$$\sigma_D = \sqrt{\sigma_{M1}^2 + \sigma_{M2}^2}$$

$$= \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$$

If the means of the two samples are respectively M_1 and M_2, then

$$\text{Critical Ratio} = \text{CR} = \frac{|M_1 - M_2|}{\sigma_D}$$

Taken from Connolly & Sluckin (1971), page 104 & 105.

APPENDIX II

Extract from the Post Office Specification PE0097

" (PHW 1115.50.3.71.mr) : reference Post Office (1971a)

"The parcels accepted by the Post Office must not exceed the following limits:-

a. The longest dimension shall not exceed 3ft 6ins

b. The length plus girth shall not exceed 6ft.

c. The weight shall not exceed 22 lbs.

However, as it is impossible to give parcels more than a cursory examination on receipt, the dimensional limits specified in the Parcel regulations have been exceeded in some cases in the dummy mail so that all parcels likely to be encountered are represented".

APPENDIX III

THE FILE CREATION PROGRAMME FOR THE DATA FOR THE PSTF PROGRAMME

The PSTF programme will be found in Appendix IX, figure 7.38. It gives the option of creating the data at run time, or of reading the data from a file, which has been created in advance of the run. The programme listed below, creates this data file. Appendix 3.1 lists the programme and appendix 3.2 gives the output from the file creation run. The computer used was the INTERDATA minicomputer.

Appendix 3.1 Listing of the PSTF File Creation Programme in BASIC.

```
*RU BASIC
BASIC
REW 15
LOAD 15
BASIC
LIST
100 REM    PSTF DATA CREATOR
105 DIM U(8)
110 DIM S(3,2),D(3,8),N(4),A$(5),Y$(3),N$(2)
120 Y$="YES"
130 N$="NO"
150 S1=0
160 FOR Z=1 TO 3
170 FOR Z1=1 TO 8
172 D(Z,Z1)=0
174 NEXT Z1
176 FOR Z2=1 TO 2
178 S(Z,Z2)=0
180 NEXT Z2
182 NEXT Z
200 ;"HOW MANY PARCELS ?"
202 INPUT N1
206 ;"STARTING ON WHICH PARCEL ?"
210 INPUT N5
212 ;"ON WHICH CHANNEL IS YOUR DATA FILE /"
214 INPUT X
216 ;
360 ;"INPUT DATA WHEN * IS PRINTED, IN 7 LINES : THUS"
365 ;"       LINE 1 : PCL NO, LENGTH , WIDTH, HEIGHT"
370 ;"       FOR PLANE 1 ; LINE 2 : PLANE 1 CENTRE,NO OF POINTS"
372 ;"       FOR PLANE 1 ; LINE 3 : LOAD,DEFLECTION,  ETC"
374 ;"       FOR PLANE 2 ; LINES 4&5 SIMILAR TO 2&3"
376 ;"       FOR PLANE 3 ; LINES 6&7 SIMILAR TO 2&3"
```

Continued overleaf ....

App. 3.1 PSTF File Creation Programme ..... continued .....

```
380 ;
332 ;"BEGINNING NOW :"
405 FOR N9=N5 TO N5+N1-1
407 F=(N9-1)*7
420 ;"* N,L,W,H PCL ";N9;":-"
430 INPUT N,L,W,H
440 FOR A=1 TO 3
445 ;"* CENTRE,NO OF PTS :-"
450 INPUT S(A,1),S(A,2)
460 FOR A9=1 TO S(A,2)
465 ;"* POINT ";A9;":-"
470 INPUT D(A,1+(A9-1)*2),D(A,2+(A9-1)*2)
480 NEXT A9
490 NEXT A
500 ; ON (X,1+F)N;L;W;H
505 FOR A=1 TO 3
510 G=(A-1)*2
520 ; ON (X,2+F+G)S(A,1);S(A,2)
530 FOR H1=1 TO 8
540 U(H1)=D(A,H1)
550 NEXT H1
560 ; ON (X,3+F+G)U(1);U(2);U(3);U(4);U(5);U(6);U(7);U(8)
570 NEXT A
600 NEXT N9
9990 ;"RUN NOW ENDS"
9999 END
BASIC
PAUSE
  PAUSE
*
```

Appendix 3.2 The Output at run time from the PSTF File Creation Programme

```
RUN
HOW MANY PARCELS ?
3
STARTING ON WHICH PARCEL ?
9
ON WHICH CHANNEL IS YOUR DATA FILE /
11

INPUT DATA WHEN * IS PRINTED, IN 7 LINES : THUS
     LINE 1 : PCL NO, LENGTH , WIDTH, HEIGHT
     FOR PLANE 1 ; LINE 2 : PLANE 1 CENTRE,NO OF POINTS
     FOR PLANE 1 ; LINE 3 : LOAD,DEFLECTION,  ETC
     FOR PLANE 2 ; LINES 4&5 SIMILAR TO 2&3
     FOR PLANE 3 ; LINES 6&7 SIMILAR TO 2&3

BEGINNING NOW :
* N,L,W,H PCL  9 :-
9,14,8.7,2.7,5--
```

Continued overleaf ....

Appendix 3.2 PSTF File Creator Output ..... continued .....

```
* CENTRE,NO OF PTS :-
10,4
* POINT  1 :-
5,.03
* POINT  2 :-
10,.14
* POINT  3 :-
15,.19
* POINT  4 :-
20,.25
* CENTRE,NO OF PTS :-
10,4
* POINT  1 :-
5,.07
* POINT  2 :-
10,.18
* POINT  3 :-
15,.26
* POINT  4 :-
20,.28
* CENTRE,NO OF PTS :-
5-6,4
* POINT  1 :-
5,.01
* POINT  2 :-
10,.03
* POINT  3 :-
15,.09
* POINT  4 :-
20,.15
* N,L,W,H PCL  10 :-
10,12,12,7
* CENTRE,NO OF PTS :-
8,4
* POINT  1 :-
5,.01
* POINT  2 :-
10,.05
* POINT  3 :-
15,.1
* POINT  4 :-
20,.18
* CENTRE,NO OF PTS :-
8,4
* POINT  1 :-
5,.02
* POINT  2 :-
10,.06
* POINT  3 :-
15,.1
* POINT  4 :-
20,.13
```

continued overleaf ....

Appendix 3.2 PSTF File Ctreator Output ..... continued ....

```
* CENTRE,NO OF PTS :-
8,4
* POINT  1 :-
5,.05
* POINT  2 :-
10,.17
* POINT  3 :-
15,.24
* POINT  4 :-
20,.25
* N,L,W,H PCL  11 :-
11,12.2,9.2,6.2
* CENTRE,NO OF PTS :-
10,4
* POINT  1 :-
5,.01
* POINT  2 :-
10,.05
* POINT  3 :-
15,.11
* POINT  4 :-
20,.19
* CENTRE,NO OF PTS :-
10,4
* POINT  1 :-
5,.02
* POINT  2 :-
10,.12
* POINT  3 :-
15,.25
* POINT  4 :-
20,.87
* CENTRE,NO OF PTS :-
6,4
* POINT  1 :-
5,.01
* POINT  2 :-
10,.05
* POINT  3 :-
15,.12
* POINT  4 :-
20,.18
RUN NOW ENDS
BASIC
WFM 11
PAUSE
  PAUSE
*
```

APPENDIX IV

LISTING OF THE TL 302 PROGRAMME WRITTEN IN FORTRAN FOR THE ICL 1900 COMPUTER TO SIMULATE THE PACKING OF PARCELS IN A BELT CONVEYOR

Appendix IV TL 302 Programme Listing.

```
FORTRAN COMPILATION BY #XFIV MK 2B     DATE  31/10/73  TIME  23/49/11


 0000                    LIBRARY(SUBGROUPSCE)
 0001                    PROGRAM(PS02)
 0002                    INPUT 1=CR0
 0003                    OUTPUT 2=LP0
 0004                    COMPRESS INTEGER AND LOGICAL
 0005                    MIXED SEGMENTS
 0006                    COMPACT DATA
 0007                    END
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing   .... continued .....

```
              MASTER TL302
      C THIS IS THE SECOND TYPE FORCE CALCULATION SYSTEM
      C  THIS IS THE PS PROGRAM VERSION 2B - BINARY WITHOUT TRACE
              INTEGER OFF(10)
              DIMENSION PR(3),IREJ(4)
              DIMENSION MST(4),MSL(4),MPST(4),MPSL(4)
              DIMENSION FM(3,3),TM(3,3)
              DIMENSION NODE(3,3)
              DIMENSION SXBSL(4),SXBST(4),SXWSL(4),SXWST(4)
              DIMENSION ICP(1000,3),NODDS(100,10)
              DIMENSION IHUM(3) ,IOPP(2)
              DIMENSION NOD(100,7,10),IPM(100,3,6)
              DIMENSION IUC(3)
              DIMENSION IJKM(3)
              DIMENSION ISP(100,3,6),IWR(100,6)
              DIMENSION ISWR(100,2),IPNU(3)
              DIMENSION IPR(100,3),ICPTO(40,5)
               DIMENSION IGN(6),  ICKOP(3,8),    ITRI(6),      MAT(10), ICKO(6,
             25),NPL(4),IOPR(3),ICOR(6),ICKOD(3,8),INTTLT(6),ICONT(6),ITT(6),ID
             3PR(6),IP(6),IM(6)
              DATA NPL/3HPLU,2HLU,2HPU,4HNONE/
              DATA OFF/4HSTRM,4HBRIT,4HCROY,3HLIV,4HMANC,4HNWPO,3HWDO,4HTEST,
             24HSPCL,4HNONE/
              DATA IREJ/4HGRTH,3HLEN,3HWID,4HHGHT/
              DATA IHUM/3HOFF,2HON/ ,IOPP/4HPRNT,3HOFF/
              DATA MAT/4HSTEL,4HCOTT,4HSCAN,4HRUBB,4HPWOD,4HVWOD,4HSPCL/
              COMMON/RTNE/CHN1,CHN2,CHN3,CHN4
              MPST(1)=25
              MPST(2)=30
              MPST(3)=35
              MPST(4)=40
              MPSL(1)=30
              MPSL(2)=35
              MPSL(3)=40
              MPSL(4)=45
               NN=1
              READ(1,80001)      IPNMAX    ,IOP
              IF(IOP.EQ.0)IOP=2
      80001        FORMAT(I4,I6)
              WRITE(2,80002)IPNMAX
      80002        FORMAT(1H1,24HTOTAL NUMBER OF CARDS IS,I6)
              WRITE(2,80020)IOPP(IOP)
      80020    FORMAT(13H DIAGNOSTICS:,A8)
              IRNK=1
              WRITE(2,40028)
      40028      FORMAT('   THIS IS THE FIRST RUN')
      4001    READ(1,405)IMAX,JMAX,KMAX
      405     FORMAT(3I10)
              CHN1 = 0.1928374656472442
              CHN2 = 0.192773346520140
              CHN3 = 0.9161716149978456
              CHN4 = 0.1892976539975706
              WRITE(2,401)
      401     FORMAT(1X,33HBEGINNING OF LOADING ARRANGEMENT.)
              VM=(FLOAT(IMAX))*(FLOAT(JMAX))*(FLOAT(KMAX))
      4230    READ(1,430)MUSEL1,MUSEL2,IHC,PPLAS,PEXP
      430      FORMAT(3I10,2F10.4 )
              VM=(FLOAT(IMAX))*(FLOAT(JMAX))*(FLOAT(KMAX))
      4186    WRITE(2,80003)IMAX,JMAX,KMAX,VM,MAT(MUSEL1),MAT(MUSEL2)
      80003    FORMAT(24H CONVEYOR DIMENSIONS ARE,I6,5H WIDE,I6,5H LONG,I6,19H H
             2IGH AND VOLUME IS,F16.3,/21H SIDEWALL MATERIAL IS,A6,9H  BASE IS,A6)
             36)
              PLW=PPLAS*100.
              IF(PPLAS.GT.2.0)PLW=0
```

Continued overleaf ....

```
             WRITE(2,49905)PPW,IHUM(IHC), PEXP
49905          FORMAT(29H PLASTIC PARCELS INJECTED ARE,F10.2,23H%.AND HUMIDITY
            2EFFECT   ,A6,3X,12H EXPONENT IS,F10.4)
             IPLAS=3
             IF(PPLAS.EQ.0)GO TO 80021
             IF(PPLAS.LT.1.1)IPLAS=2
             IF(PPLAS.LT.0.95)IPLAS=1
80021        READ(1,400)IOFS
400          FORMAT(I10)
             WRITE(2,416)OFF(IOFS)
416          FORMAT(1X,23HTHE PROJECTED OFFICE IS,A12)
             IF(TEST.EQ.0)GO TO 4000
4500          CONTINUE
C     THE RESETTING OF THE MATRICES FOR A NEW RUN BUT SAME OFFICE BEGINES HERE
             TEST=0.
             WTSUM=0.
             VR=0.
             DO 3001 I=1,IPN
             DO 3101 IA=1,10
             DO 3130  IB=1,7
3130           NOD(I,IB,IA)=0
3101          NODS(I,IA)=0
             DO 3102 IB=1,6
3102          IWR(I,IB)=0
             IBWR(I,1),IBWR(I,2),IPR(I,1),IPR(I,2),IPR(I,3)=0
             DO 3103 J=1,3
             DO 3103 K=1,6
3103           IPM(I,J,K),IBR(I,J,K)=0
3001           CONTINUE
             NR=IPN*10
             DO 3110 NA=1,3
             DO 3110 N=1,NR
3110           ICP(N,NA)=0
             IPNK=0
             IRNK=IRNK+1
             WRITE(2,40027)IRNK
40027          FORMAT(1H1,'  THIS IS RUN NUMBER',I6)
             KO=0
             WRITE(2,80010)IPNREC,IPNTOT
80010          FORMAT('    TOTAL PARCELS NOW',I6,'    TOTAL CARDS NOW',I6)
4000         READ(1,100)IOF,IPNN,ISH,IWRP,IWT,IOZ,IL,IW,IH,MST(1),MSL(1),
            2 MST(2),MSL(2),MST(3),MSL(3),MST(4),MSL(4)
100          FORMAT(I1,I3,2X,2I1,1X,2I2,3(I2,4X),8I2)
             IF (IPNN.EQ.IPNMAX)GO TO 9901
             IPNK=IPNK+1
             IF(IOP.EQ.2)GO TO 80089
             WRITE(2,40026)IPNN,IPNK,IPNREC
40026          FORMAT('    CARD NO IS ',I4,'    SEQUENCE NO IS ',I4,
            2'  NOW LOADED.    NUMBER USED ON PREVIOUS RUNS WAS ',I5)
80089          IGTH= IL + (IW+IH)/2
             IF(IGTH.GT.72)WRITE(2,80043)IPN   ,IGTH
80043          FORMAT('     GIRTJ ILLEGAL ON PCL NO',I4,'    GIRTH IS',I6)
             IF(IGTH.GT.75)GO TO 40070
             IF(IL.GT.45)GO TO 40081
             IF(IW.GT.40)GO TO 40082
             IF(IH.GT.35)GO TO 40083
             IF(IPNN.GE.IPNMAX+1)GO TO 9901
             IF(IPNN.EQ.999)GO TO 9901
             WT=FLOAT(IWT) + FLOAT(IOZ)/16.
             WTSUM=WTSUM+WT
             IWT=IFIX(WT*10.)
             IPN=IPNK
80080          IF(IPN GE.101)GO TO 80081
             GO TO (80031,80032),IHC
80081          IPN=IPN-1
             GO TO 5000
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
40070   IR=1
        IO=IGTH
40072     WRITE(2,40071)IPNN,IO,IREJ(IR)
40071     FORMAT('    PCL NO',I6,'    REJECTED ON OVERSIZE DIMENSION OF',I6,
      2 '     FOR',A8)
        IPNK=IPNK-1
        GO TO 4000
40081     IR=2
        IO=IL
        GO TO 40072
40082     IR=3
        IO=IW
        GO TO 40072
40083     IR=4
        IO=IH
        GO TO 40072
80032     CALL FPMCRV(CHN4)
        IF(CHN4.GT.PPLAS)GO TO 80031
        IWRP=4
80031     CONTINUE
        IF(TEST.EQ.0)WRITE(2,80033)OFF(IOFS)
80033     FORMAT('     OFFICE FOR THIS RUN IS ',A8)
        IFSU2=0
        IARR,IAR=0
        IF(IL.EQ.0)IL=1
        IF(IH.EQ.0)IH=1
        IF(IW.EQ.0)IW=1
        VRO=VR
        VR=VR+((FLOAT(IL))*(FLOAT(IW))*(FLOAT(IH)))
10500   CALL FPMCRV(CHN1)
        NP=(IPN-1)*10
        NN=IPN
        INDU=0
        DO 2100 I=1,3
        DO 2100 J=1,8
2100     ICKOP(I,J),ICKUD(I,J)=0
        DO 2101 I=1,6
        DO 2101 J=1,5
        ICKU(I,J)=0
2101    CONTINUE
        IF(NTO.GE.41)NTO=40
        DO 2102 J=1,5
        DO 2102 I=1,NTO
2102     ICPTO(I,J)=0
        DO 2115 I=1,6
        IGN(I),ITRI(I),ICOR(I),INTILT(I),ITT(6),ICONT(I)=0
2115     IDIRR(I),IP(I),IM(I)=0
        DO 2116 I=1,3
        IPNU(I)=0
        DO 2116 J=1,3
2116     NODF(I,J)=0
        INDIS,IDSPL=0
        INPL=4
        IMA=IMAX+1
        JMA=JMAX+1
        CALL FPMCRV(CHN1)
        CALL LPSET(ILPA,CHN1,IMA)
        CALL FPMCRV (CHN2)
        CALL LPSET(JLPA,CHN2,JMA)
        ILP=ILPA-1
        JLP=JLPA-1
        IF(IH.LT.IL/3) GO TO 6150
4010    CALL FPMCRV(CHN3)
        CALL LPSET(ICS,CHN3,12)
4021    IF(ICS.LE.6)GO TO 4024
        GO TO 4300
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
4024  INDR=1
      THETA=1.5708
      INDCAS=ICS
6100  GO TO (4031,4032,4033,4034,4035,4036),INDCAS
4032  IDIF=IW
      JDIF=IL
      KDIF=IH
       IC =    2
      GO TO 4193
4033  IDIF=IH
      IF(IH.LT.IW/3)GO TO 4032
      JDIF=IL
      KDIF=IW
       IC =    3
      GO TO 4193
4034  IDIF=IH
      IF(IW+IH.LT.(IL*3)/2)GO TO 4031
      JDIF=IW
      KDIF=IL
       IC =    4
      GO TO 4193
4035  IDIF=IL
      IF(IH.LT.IW/3)GO TO 4032
      JDIF=IH
      KDIF=IW
       IC=    5
      GO TO 4193
4036  IDIF=IW
      IF(IW+IH.LT.(IL*3)/2)GO TO 4031
      JDIF=IH
      KDIF=IL
       IC=    6
      GO TO 4193
4031  IDIF=IL
      JDIF=IW
      KDIF=IH
       IC =    1
4193  IF(INDR.EQ.2)GO TO 6101
      IOMIN=ILP
      JOMIN=JLP
      IOMAX=ILP+IDIF
      JOMAX=JLP+JDIF
      IMN=IOMIN
      IMF=IOMAX
      JMN=JOMAX
      JMF=JOMIN
      GO TO 4103
4300  CONTINUE
      CALL FPHCRV(CHN4)
      THETA=CHN4*0.7854+0.7854
      INDR=2
      INDCAS=ICS-6
      GO TO 6100
6150  ICS = 7
      GO TO 4300
6101  CONTINUE
      IOMIN=ILP
      JOMIN=JLP
      CALL FPHCRV(CHN4)
      CALL DIFIX(ISI,ICO,JSI,JCO,THETA,IDIF,JDIF)
      IMN=IOMIN+JCO
      IOMAX=IMN+ISI
      IMF=IOMIN+ISI
      JMN=JOMIN+JSI
      JOMAX=JMN+ICO
      JMF=JOMIN+ICO
```

Continued overleaf ....

```
4103  IF(IOMAX.GT.IMAX)GO TO 4101
4102  IF(IOMIN.LE.1)INDW=1
      IF(IOMAX GE.IMAX-1)INDW=2
4104  IF(TEST.EQ.0)GO TO 4114
      GO TO 9000
4101  IAR=IAR+1
      IF(II.GT.IMAX)WRITE(2,40)IPN
40    FORMAT(1H ,13HPARCEL NUMBER,I6,2X,27HEXCEEDS INTERWALL DISTANCE.)
      WRITE(2,41)  IPN ,IAR
41     FORMAT('  PCL.NO.',I4,'  OUTISIDE SIDEPLATE ON DROPPING  . REFIT
     2ATTEMPT NUMBER',I4)
      IF(IARR.EQ.1)GO TO 41012
      IF(IAR.EQ.9)GO TO 41011
      GO TO 10500
41011 IARR=1
      ILP=0
      INDR=1
      IF(IPN/2.LT.(IPN+1)/2)ILP=IMAX-IH-1
      GO TO 4033
41012   WRITE(2,42)IPNN,IPN
42     FORMAT('   PCL NO.',I4,'  REJECTED AFTER 10 TRIES',
     2 '    SEQUENCE NUMBER IS ',I4)
      IPNK=IPNK-1
      VR= VRO
      GO TO 4000
9000  CONTINUE
      IF(TEST.EQ.0.)GO TO 4114
      ICK=NP+1
      NTO=1
90000 CONTINUE
      IF(ICK.EQ.1)GO TO 90100
      IF(NTO.GE.41)GO TO 90100
      ICK=ICK-1
      ICHK=ICK-((ICK/10)*10)
      IF(ICHK.LE.4)GO TO 90000
      IF(ICHK.EQ.9)GO TO 90000
      IF(ICP(ICK,1).LE.IOMAX)GO TO 90001
      GO TO 90000
90001 IF(ICP(ICK,1).LT.IOMIN)GO TO 90000
      IF(ICP(ICK,2).LE.JOMAX)GO TO 90002
      GO TO 90000
90002 IF(ICP(ICK,2).LT.JOMIN)GO TO 90000
      GO TO 90010
90010 DO 90011 J=1.3
      ICPTO(NTO,J)=ICP(ICK.J)
90011 CONTINUE
      ITCK=((ICK/10)*10)+10
      ICPTO(NTO,4)=ICK
      ICPTO(NTO,5)=ICP(ITCK.3)
      NTO=NTO+1
      GO TO 90000
90100 CONTINUE
      IF(NTO.EQ.1)GO TO 4114
90200 CONTINUE
      IBK,IG=0
      IKK,IGG=1
      IF(ICPTO(1,5).EQ.0)GO TO 4114
90201 CONTINUE
      IBK=IBK+1
      IF(IBK.GE.41)GO TO 90206
      IF(ICPTO(IBK,3).GT.IG)GO TO 90202
      GO TO 90201
90206 IF(IG.EQ.0)GO TO 90800
      DO 90203 J=1.5
      ICKO(IKK,J)=ICPTO(IGG,J)
```

Continued overleaf ....

```
90203 CONTINUE
      IF(IKK.EQ.6)GO TO 90800
      IKK=IKK+1
      DO 90207 J=1,4
      ICPTO(IGG,J)=0
90207 CONTINUE
      IG,IBK=0
      GO TO 90201
90202 IG=ICPTO(IBK,3)
      IGG=IBK
      GO TO 90201
90800 CONTINUE
      IF(ICKO(1,5).EQ.0)GO TO 4114
      IF(ICKO(2,5).EQ.0)GO TO 90801
      IF(ICKO(3,5).EQ.0)GO TO 90802
      INDIS=6
      IF(ICKO(6,5).EQ.0)INDIS=5
      IF(ICKO(5,5).EQ.0)INDIS=4
      IF(ICKO(4,5).EQ.0)INDIS=3
      GO TO 90300
90801 CONTINUE
      INDIS=1
      GO TO 90300
90802 INDIS=2
90205 CONTINUE
90300 CONTINUE
      INLU.IGNO=0
      ID,IKL,I=1
      DO 14014 J=1,INDIS
      INTILT(ID)=1
90301 ITT(ID)=ICKO(IKL,4)
      ICONT(ID)=(ICKO(IKL,4)/10)*10
      IDCO=((ICKO(IKL,4)/10)*10)+10
      IF(ICP(IDCO,2).GT.ITH)INTILT(ID)=INTILT(ID)+1
90302 CONTINUE
90500 IF(INDR.EQ.1)GO TO 90601
      IF(ICKO(IKL,1).GT.IMN)GO TO 90501
90502 IF(ICKO(IKL,2).LT.JMN)GO TO 90503
90504 IF(ICKO(IKL,1).LT.IMF)GO TO 90505
      GO TO 90506
90501 IF(ICKO(IKL,2).LT.JMF)GO TO 90508
90507 IF(ICKO(IKL,1).GT.IMF)GO TO 90506
      GO TO 90505
90601 IMIDI=IOMIN+IDIF/2
      JMIDI=JOMIN+JDIF/2
      IF(ICKO(IKL,1).GT.IMIDI )GO TO 90602
      GO TO 90603
90602 IF(ICKO(IKL,2).GT.JMIDI)GO TO 90506
      GO TO 90508
90603 IF(ICKO(IKL,2).GT.JMIDI)GO TO 90505
      GO TO 90503
90503 ITRI(ID)=1
      GO TO 90303
90505 ITRI(ID)=2
      GO TO 90303
90506 ITRI(ID)=3
      GO TO 90303
90508 ITRI(ID)=4
90303 ITRIS=ITRI(ID)
      IUPN=(ICKO(ID,4)/10+1)
      ITYP=ICKO(IKL,4)-ICONT(ID)
      ICOR(ID)=ITYP
      IKL=IKL+1
      ID=ID+1
14014 CONTINUE
14012 CONTINUE
```

Continued overleaf ....

```
      IF=0
      IKL,ID,I=1
14013 IF=IF+1
      ITRIS=ITRI(IF)
      ITYP=ICOP(IF)
      ICON=ICONT(IF)
      GO TO (90405,90406,90407,90408),ITYP
90405   GO TO (90411,90412,92412,90414),ITRIS
90406 GO TO(90415,90411,90414,92413),ITRIS
90407 GO TO(92414,90417,90411,90415),ITRIS
90408 GO TO(90417,92411,90412,90411),ITRIS
90412 INLU=1
      GO TO 90431
90414 INLU=2
      GO TO 90431
90415 INLU=3
      GO TO 90431
90417 INLU=4
90431 DO 14035 ID=1,2
      DO 14010 J=1,5
      ICKOP(ID,J)=ICKO(ID,J)
14010 CONTINUE
      ICKOP(ID,6)=ICKO(ID,4)/10+1
      ICKOP(ID,7)=ICON(ID)
      ICKOP(ID,8)=ITRI(ID)
      IF(INDIS.EQ.1)GO TO 90810
14035 CONTINUE
      IPNU(1) =ICKOP(1.6)
      IPNU(2),IPNU(3)=ICKOP(2,6)
      GO TO 15600
90810 KOMIN=0
      NDSU=3
      IPNU(1)=ICKOP(1.6)
      ICKOP(2,6),ICKOP(3,6)= 1000000
      IPNU(2),IPNU(3)=1000000
      GO TO 15500
90411 INSPI=1
      INPL=1
      ID=1
      DO 11460 J=1.5
11460   ICKOP(1,J)=ICKO(1,J)
      ICKOP(1.6)=ICKO(1,4)/10+1
      ICKOP(1.7)= ICOR(1)
      ICKOP(1.8)=ITRI(1)
11404  INIPLU=ICKO(1,5)
      IPNU(1),IPNU(2),IPNU(3)=ICKOP(1,6)
      GO TO (11401.11402,11402),INIPLU
11401  KOMIN=ICKO(1,3)
      KOMAY=KOMIN+KDIF
      NDSU=2
      GO TO 11409
11402 INPL=2
      ICKOP(2.6),ICKOP(3,6)=ICKOP(1,6)
11410 IF(ICP(ICON+5,3).EQ.ICP(ICON+6,3))GO TO 11411
      IF(ICP(ICON+5,3).GT.ICP(ICON+6,3))GO TO 11423
      GO TO 11421
11411 IF(ICP(ICON+5,3).GT.ICP(ICON+7,3))GO TO 11424
11421 INLU=1
      KOMIN=ICP(ICON+6.3)
      KINC=ICP(ICON+5.3)
      GO TO 15000
11422 INLU=2
      KOMIN=ICP(ICON+5.3)
      KINC=ICP(ICON+7.3)
      GO TO 15000
11423 INLU=3
```

Continued overleaf ....

```
      KOMIN=ICP(ICON+5.3)
      KINC=ICP(ICON+6,3)
      GO TO 15000
11424 INLU=4
      KOMIN=ICP(ICON+7.3)
      KINC=ICP(ICON+5,3)
15000 CONTINUE
      KOMAX=KINC+KDIF
      INPL=2
      NDSU=4
      IPNU(1)=ICKOP(1,6)
      IPNU(2),IPNU(3)=ICKOP(2,6)
15157 NP=NP+1
      IND1=IND1+1
      IND2=1+IND2
      IND4=IND4+1
      IF(IND4.GE.9)GO TO 15151
      GO TO (151,152,153,154),IND1
151    ICP(NP,1)=IMN
      GO TO 15154
152   ICP(NP,1)=IOMIN
      GO TO 15154
153   ICP(NP,1)=IMF
      GO TO 15154
154   ICP(NP,1)=IOMAX
      GO TO 15154
15154 GO TO (155,156,157,158),IND2
155   ICP(NP,2)=JOMIN
      GO TO 15158
156   ICP(NP,2)= JMN
      GO TO 15158
157   ICP(NP,2)=JOMAX
      GO TO 15158
158   ICP(NP,2)=JMF
15158 IF(IND4.EQ.4)GO TO 15161
      IF(IND4.GT.4)GO TO 15162
      GO TO (101,102,103,104),INLU
101   GO TO (161,162,162),IND4
161   ICP(NP,3)=KOMIN
      GO TO 15157
162   ICP(NP,3)=KINC
      GO TO 15157
15161 GO TO (111,112,112,111),INLU
111   ICP(NP,3)=KOMIN
      IND1,IND2=0
      GO TO 15157
112   ICP(NP,3)=KINC
      IND1,IND2=0
      GO TO 15157
15162 GO TO (171,172,173,174),INLU
171   GO TO (163,164,164,163),IND1
163   ICP(NP,3)=KOMIN+KDIF
      GO TO 15157
164   ICP(NP,3)=KINC+KDIF
      GO TO 15157
15151 GO TO 4151
172   GO TO (163,163,164,164),IND1
173   GO TO (164,163,163,164),IND1
174   GO TO (164,164,163,163),IND1
104   GO TO (162,162,161),IND4
103   GO TO (162,161,161),IND4
102   GO TO (161,161,162),IND4
16000 CONTINUE
      INPL=3
      GO TO 16001
16157 NP=NP+1
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
      IND1=IND1+1
      IND2=IND2+1
      IND4=IND4+1
      IF(IND4.GE.9)GO TO 16151
      GO TO (16101,16102,16103,16104),IND1
16101 ICP(NP,1)=IMN
      GO TO 16154
16102 ICP(NP,1)=IOMIN
      GO TO 16154
16103 ICP(NP,1)=IMF
      GO TO 16154
16104 ICP(NP,1)=IOMAX
      GO TO 16154
16001 IF(ICKOP(1,8).LE.ICKOP(2,8))GO TO 16002
      IF(ICKOP(3,8).LE.ICKOP(2,8))GO TO 16003
      IF(ICKOP(3,8).LE.ICKOP(1,8))GO TO 16004
      ISE=5
      GO TO 16010
16002 IF(ICKOP(2,8).LE.ICKOP(3,8))GO TO 16005
      IF(ICKOP(3,8).LE.ICKOP(1,8))GO TO 16006
      ISE=3
      GO TO 16010
16003 ISE=6
      GO TO 16010
16004 ISE=4
      GO TO 16010
16005 ISE=1
      GO TO 16010
16006 ISE=2
      GO TO 16010
16010 GO TO (16011,16013,16011,16012,16012,16013),ISE
16011 DO 16021 J=1,8
      ICKOD(1,J)=ICKOP(1,J)
16021 CONTINUE
      GO TO 16020
16013 DO 16022 J=1,8
      ICKOD(1,J)=ICKOP(3,J)
16022 CONTINUE
      GO TO 16020
16012 DO 16023 J=1,8
      ICKOD(1,J)=ICKOP(2,J)
16023 CONTINUE
16020 GO TO (16032,16031,16033,16033,16031,16032),ISE
16031 DO 16024 J=1,8
      ICKOD(2,J)=ICKOP(1,J)
16024 CONTINUE
      GO TO 16040
16032 DO 16025 J=1,8
      ICKOD(2,J)=ICKOP(2,J)
16025 CONTINUE
      GO TO 16040
16033 DO 16026 J=1,8
      ICKOD(2,J)=ICKOP(3,J)
16026 CONTINUE
16040 GO TO (16043,16042,16042,16041,16043,16041),ISE
16041 DO 16027 J=1,8
      ICKOD(3,J)=ICKOP(1,J)
16027 CONTINUE
      GO TO 16050
16042 DO 16028 J=1,8
      ICKOD(3,J)=ICKOP(2,J)
16028 CONTINUE
      GO TO 16050
16043 DO 16029 J=1,8
      ICKOD(3,J)=ICKOP(3,J)
16029 CONTINUE
```

Continued overleaf ....

```
16020 IF(ICKOD(1,8).NE.1)GO TO 16054
      IF(ICKOD(2,8).NE.2)GO TO 16053
      IF(ICKOD(3,8).NE.3)GO TO 16052
      ISF=1
      GO TO 16157
16054 ISF=4
      GO TO 16157
16053 ISF=3
      GO TO 16157
16052 ISF=2
      GO TO 16157
16154 GO TO (16105,16106,16107,16108),IND2
16105 ICP(NP,2)=JOMIN
      GO TO 16158
16106 ICP(NP,2)=JMN
      GO TO 16158
16107 ICP(NP,2)=JOMAX
      GO TO 16158
16108 ICP(NP,2)=JMF
16158 IF(IND4.EQ.4)GO TO 16161
      IF(IND4.GT.4)GO TO 16162
      GO TO (16261,16262,16263),IND4
16261 GO TO (16201,16201,16201,16204),ISF
16201 ICP(NP,3)=ICKOD(1,3)
      GO TO 16157
16202 ICP(NP,3)=ICKOD(2,3)
      GO TO 16157
16262 GO TO (16202,16202,16204,16201),ISF
16203 ICP(NP,3)=ICKOD(3,3)
      GO TO 16157
16204 ICP(NP,3)=ICKO(3,3)+ICKO(1,3)-ICKO(2,3)
      GO TO 16157
16263 GO TO (16203,16204,16202,16202),ISF
      GO TO 16157
16161 GO TO (16304,16303,16303,16303),ISF
16304 ICP(NP,3)=ICKO(3,3)+ICKO(1,3)-ICKO(2,3)
      IND1,IND2=0
      GO TO 16157
16303 ICP(NP,3)=ICKOD(3,3)
      IND1,IND2=0
      GO TO 16157
16162 GO TO (16181,16182,16183,16184),ISF
16171 ICP(NP,3)=ICKOD(1,3)+KDIF
      GO TO 16157
16172 ICP(NP,3)=ICKOD(2,3)+KDIF
      GO TO 16157
16173 ICP(NP,3)=ICKOD(3,3)+KDIF
      GO TO 16157
16174 ICP(NP,3)=ICKO(3,3)+ICKO(1,3)-ICKO(2,3)+KDIF
      GO TO 16157
16181 GO TO (16171,16172,16173,16174),IND1
16182 GO TO (16171,16172,16174,16173),IND1
16183 GO TO (16171,16174,16172,16173),IND1
16184 GO TO(16174,16171,16172,16173),IND1
16151 KOMAX=ICKOP(1,3)+KDIF
      KOMIN=ICKOP(3,3)
      GO TO 4151
15600 KOMIN=ICKOP(2,3)
15500 KINC= ICKOP(1,3)
      GO TO 15000
92411 IF(INDIS.EQ.1)GO TO 90412
      IF(INDIS.EQ.2)GO TO 16600
16500 DO 16501 K=1,3
      DO 16502 J=1,5
      ICKOP(K,J)=ICKO(K,J)
16502 CONTINUE
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
      ICKOP(K,7)=ICOR(K)
      ICKOP(K,8)=ITRI(K)
16501 CONTINUE
      DO 16508 J=1,3
16508 IPNU(J)=ICKOP(J,6)
      NDSU=6
      GO TO 16000
92412 IF(INDIS.EQ.1)GO TO 90414
      IF(INDIS.EQ.2)GO TO 16600
      GO TO 16500
92413 IF(INDIS.EQ.1)GO TO 90415
      IF(INDIS.EQ.2)GO TO 16600
      GO TO 16500
92414 IF(INDIS.EQ.1)GO TO 90417
      IF(INDIS.EQ.2)GO TO 16600
      GO TO 16500
16600 DO 16601 K=1,2
      DO 16602 J=1,5
16602 ICKOP(K,J)=ICKO(K,J)
      ICKOP(K,6)=ICKO(K,4)/10+1
      ICKOP(K,7)=ICOR(K)
      ICKOP(K,8)=ITRI(K)
16601 CONTINUE
      DO 16608 J=1,2
16608 IPNU(J)=ICKOP(J,6)
      IPNU(3),ICKOP(3,6)=1000000
      NDSU=5
      GO TO 16000
2000  CONTINUE
      IF(IPN.GE.99)GO TO 5000
      IF(KOMAX.GT.KMAX)GO TO 5300
      GO TO 4000
5300   WRITE(2,5302)IPN,KOMIN,KOMAX
5302   FORMAT('    PCL.NO.',I4,'  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT',
     2I4,'  TOP HEIGHT',I4)
      IF(KOMIN.GE.KMAX)GO TO 5301
      GO TO 4000
5301  CONTINUE
      IFSW2=IFSW2+1
      WRITE(2,5402)IFSW2
5402  FORMAT ( 38H  PARCEL HAS BEEN REFITTED, TRY NO     ,I6)
      NN=NN-1
      NP=NP-10
      IF(IFSW2.GE.10)GO TO 5000
10700  DO 10701  J=1,3
      INOC=IPNU(J)
      IF(INOC.GT.900000)GO TO 10702
      DO 10704  K=1,10
      IF(NOD(INOC,7,K).EQ.IPN)GO TO 10705
      GO TO 10704
10705   DO 10706 L=1,7
10706  NOD(INOC,L,K)=0
10704   CONTINUE
10702  CONTINUE
10701 CONTINUE
      GO TO 10500
91900 WRITE(2,91905)ITRIS
91905 FORMAT(19H FAILED ON ITRIS NO,I6)
      GO TO 91904
91901 WRITE(2,91902)ITYP
91902 FORMAT(18H FAILED ON ITYP NO,I6)
91903 FORMAT(30H FAILED AT COMPUTED GO TO.IPN ,I6,4HITYP,I6,4H ICS,I6,4H
     2 ITH,I6,4HINPL,I6,5HITRIS,I6)
91904 WRITE(2,91903)IPN,ITYP,ICS,ITH,INPL,ITRIS
      GO TO 5301
```

Continued overleaf ....

```
4114  KOMIN=0
      INPL=1
      KOMAX=KOTF
      TEST=1.
      IPNU(1),IPNU(2),IPNU(3)=1000000
      ICKOP(1,6),ICKOP(2,6),ICKOP(3,6)=1000000
      NDSU=1
      GO TO 11000
11010 CONTINUE
11409 CONTINUE
11000 CONTINUE
4157  NP=NP+1
      IND1=IND1+1
      IND4=IND4+1
      IF(IND4.GE.9)GO TO 4151
      GO TO (41521,41522,41523,41524),IND1
41521  ICP(NP,1)=IMN
      ICP(NP,2)=JOMIN
      GO TO 4158
41522   ICP(NP,1)=IOMIN
      ICP(NP,2)=JMN
      GO TO 4158
41523  ICP(NP,1)=IMF
      ICP(NP,2)=JOMAX
      GO TO 4158
41524  ICP(NP,1)=IOMAX
      ICP(NP,2)=JMF
4158  IF(IND4.EQ.4)GO TO 4161
      IF(IND4.GT.4)GO TO 4162
      KOT=KOMIN
4162  ICP(NP,3)=KOT
      GO TO 4157
4161  ICP(NP,3)=KOT
      KOT=KOMAX
      IND1=0
      GO TO 4157
4151  CONTINUE
      IND1=0
      IND2=0
      IND4=0
4165   ICP(NP,1)= IWRP
      ICP(NP,2)=ISH
      NP=NP+1
      ICP(NP,1)=IPN
       ICP(NP,2)= IFIX(THETA*1000.)
      ICP(NP,3)=INPL
4170  CONTINUE
4172  NODDS(NN,1)=IPN
      NODDS(NN,2)=IL
      NODDS(NN,3)=IW
      NODDS(NN,4)=IH
      NODDS(NN,5)=IWT
      GO TO (49901,49902,49903),IPLAS
49901  CALL FPMCRV(CHN4)
      IF(CHN4.GT.PPLAS)GO TO 49903
49902 NODDS(NN,6)=MPST(MUSFL1)
      NODDS(NN,7)=MPSL(MUSFL1)
      NODDS(NN,8)=MPST(MUSFL2)
      NODDS(NN,9)=MPSL(MUSFL2)
      ICP(NP-1,1)=4
      GO TO 49904
49903 NODDS(NN,6)=MST(MUSEL1)
      NODDS(NN,7)=MSL(MUSEL1)
      NODDS(NN,8)=MST(MUSEL2)
      NODDS(NN,9)=MSL(MUSEL2)
49904 NODDS(NN,10)=IC
```

Continued overleaf ....

```
      NN=NN+1
C EXIT TO IPM LOADING
18000 IN=(IPN-1)*10
 8001 IF(INDW.NE.0)GO TO 18010
18021 DO 18014 M=1,3
      NODE(1,M)=ICP(IN+1,M)
      NODE(2,M)=ICP(IN+2,M)
18014 NODE(3,M)=(ICP(IN+3,M)+ICP(IN+4,M))/2
      GO TO 18099
18010 IF(INDW.EQ.1)GO TO 18011
      IPNU(1),ICKOP(1,6)=3000000
      NODE(1,1)=IMAX
      NODE(1,2)=ICP(IN+4,2)
      NODE(1,3)=(ICP(IN+8,3)+ICP(IN+4,3))/2
       DO 18013  M=1,3
      NODE(2,M)=ICP(IN+3,M)
18013 NODE(3,M)=(ICP(IN+1,M)+ICP(IN+2,M))/2
      GO TO 18099
18011  IPNU(1),ICKOP(1,6)=3000000
18015 NODE(1,2)=ICP(IN+2,2)
      NODE(1,1)=0
      NODE(1,3)=(ICP(IN+6,3)+ICP(IN+2,3))/2
      DO 18016  M=1,3
      NODE(2,M)=ICP(IN+1,M)
18016 NODE(3,M)=(ICP(IN+3,M)+ICP(IN+4,M))/2
      GO TO 18099
18999 DO 18900 J=1,3
      IPR(IPN,J)=IPNU(J)
      DO 18900 K=1,3
18900 IPM(IPN,J,K)=NODE(J,K)
C     NODE MATRIX LOADING
19000  DO 19001 I=1,3
      J=1
      INODC=IPNU(I)
      IF(INODC.GT.900000)GO TO 19001
19002  IF(NOD(INODC,7,J).EQ.0)GO TO 19003
      IF(NOD(INODC,7,J).EQ.IPN)GO TO 19903
      IF(NOD(INODC,7,J).EQ.IPN)GO TO 19903
      IF(J.EQ.10)GO TO 19005
      J=J+1
      GO TO 19002
19903   DO 19904 K=1,3
19904   NOD(INODC,K,J) =(NOD(INODC,K,J)  + NODF(I,K))/2
      GO TO 19001
19005  WRITE(2,19006)  INODC
19006 FORMAT(35H SURPLUS NODE ON NOD MATRIX.PCI NO.,I6)
C   LATEST NODE OVERWRITES THE LINE 3 OF MATRIX
19003   DO 19004 K=1,3
19004   NOD(INODC,K,J)=NODF(I,K)
      NOD(INODC,7,J)=IPN
19001  CONTINUE
      IF(IOP.GT.1)GO TO 2000
      WRITE(2,50118)
50118 FORMAT(14H ICKOP MATRIX.)
      WRITE(2,50119)((ICKOP(L,L1),L1=1,8),I=1,3)
50119 FORMAT(1X,8I10)
      WRITE(2,50120)(IPNU(J),J=1,3)
50120 FORMAT(20H UNDERPARCEL IPN ARE,3I8)
11020 GO TO 2000
6157  NP=NP+1
      IN1=IN1+1
      IN2=IN1
      ICP(NP,3)=KOMIN
6106  GO TO (6156,6158,6159,6160),IN2
6103  IF(IN1.GE.9)GO TO 4151
      IF(IN1.GE.4)GO TO 6104
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
      GO TO 6157
6156  ICP(NP,1)=IMN
      ICP(NP,2)=JOMIN
      GO TO 6103
6158  ICP(NP,1)=IOMIN
      ICP(NP,2)=JMN
      GO TO 6103
6159  ICP(NP,1)=IMF
      ICP(NP,2)=JOMAX
      GO TO 6103
6160  ICP(NP,1)=IOMAX
      ICP(NP,2)=JMF
      GO TO 6103
6104  IN1=IN1+1
      NP=NP+1
      IN2=IN1-4
      ICP(NP,3)=KOMAX
      GO TO 6106
5000  CONTINUE
      VPD=VR/VM*100.
      WRITE(2,700)VPD, IPN
700   FORMAT('   THE PACKING DENSITY IS',F10.2,'  FOR',I4,'  PARCELS.')
      WRITE(2,575)WTSUM
575    FORMAT('   THE TOTAL PARCEL WEIGHTS WERE ',F20.2,'   LBS.')
C WRITE OUT ROUTINES FOR CHECKING ONLY FOLLOW
      IF(IOP.GT.1)GO TO 17000
      WRITE(2,501)
      IF(NP.GT.990)NP=990
      WRITE(2,502)((ICP(MA,M),M=1,3),MA=1,NP+10)
501   FORMAT(1X,19HCORNER POST MATRIX.)
502   FORMAT(1X,3I10)
      WRITE(2,505)
505   FORMAT(1H1,25HNODE STORAGE DATA MATRIX.)
      IF(NN.GT.101)NN=100
      WRITE(2,509)((NODDS(MD,ME),ME=1,10),MD=1,NN)
509   FORMAT(10I10)
      WRITE(2.50151)
      WRITE(2,50152)(((NOD(IA,IB,IC),IC=1,10),IB=1,7),IA=1,IPN)
       WRITE(2,50114)
      WRITE(2,50115)((IPR(MN,MO),MO=1,3),MN=1,IPN)
       WRITE(2,521)
      WRITE(2,520)(((IPM(IA,IB,IC),IC=1,6),IB=1,3),IA=1,IPN)
      WRITE(2,522)
      WRITE(2,523)((IBUR(ID,IC),IC=1,2),ID=1,100)
      WRITE(2,527)
      WRITE(2,529)((IPR(IK,IL),IL=1,3),IK=1,100)
17000 CONTINUE
      IEX=0
      WRITE(2,7001)IPN
7001   FORMAT(1H1,24H UNLOADING STARTS AT PCL,I6)
      IPNW=IPN+1
17005 IPNW=IPNW-1
      DO 17090 K=1,3
      DO 17090 J=1,3
17090   FM(J,K),TM(J,K)=0
      IF(IPNW.LE.0)GO TO 5500
      ICA=(IPNW*10)-10
      IJKM(1) = (ICP(ICA+2,1)+ICP(ICA+4,1))/2
      IJKM(2) = (ICP(ICA+1,2)+ICP(ICA+3,2)) /2
      DO 17018 N=1,8
17018  ITOT = ICP(ICA+N,3) + ITOT
      IF(ITOT.LT.8)ITOT=8
      IJKM(3)  = ITOT/8
      XN=FLOAT(NODDS(IPNW,5))
      RK3=XN/2.
      RK2,RK1=XN/4.
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
      XI1=(RK1*ABS(FLOAT(IJKM(1)-IPM(IPNW,1,1))))/RM3
      XJ1=(RK1*ABS(FLOAT(IJKM(2)-IPM(IPNW,1,2))))/RM3
      XI2=(RK1*ABS(FLOAT(IJKM(1)-IPM(IPNW,2,1))))/RM3
      XJ2=(RK2*ABS(FLOAT(IJKM(2)-IPM(IPNW,2,2))))/RM3
      XI3=(RK3*ABS(FLOAT(IJKM(1)-IPM(IPNW,3,1))))/RM3
      XJ3=(RK3*ABS(FLOAT(IJKM(2)-IPM(IPNW,3,2))))/RM3
      FM(1,1)=-XI1
      FM(2,1)=-XI2
      FM(3,1)=XI3
      FM(1,2)=-XJ1
      FM(2,2)=XJ2
      FM(3,2)=-XJ3
      FM(1,3)=RK1
      FM(2,3)=RK2
      FM(3,3)=RK3
      IF(NOD(IPNW,7,1).EQ.0)GO TO 17499
      DO 17400 JA=1,10
      IF(NOD(IPNW,1,JA).LE.IJKM(1))GO TO 17402
      DO 17403 J=1,3
17403   TM(3,J)=FLOAT(NOD(IPNW,J+3,JA))+TM(3,J)
      GO TO 17400
17402   IF(NOD(IPNW,2,JA).LE.IJKM(2))GO TO 17404
      DO 17405 L=1,3
17405 TM(1,L)=TM(1,L)+FLOAT(NOD(IPNW,L+3,JA))
      GO TO 17400
17404  DO 17498 K=1,3
17498   TM(2,K)=TM(2,K) + FLOAT(NOD(IPNW,K+3,JA))
17400   CONTINUE
17499   DO 17410 J=1,3
      DO 17410 K=1,3
      FTRY=FM(J,K)+TM(J,K)
      IF(FTRY.GT.8300000.)FTRY=8300000.
      IF(FTRY.LT.0.5)GO TO 17417
17419 IF(FTRY.LT.-8300000.)FTRY=-8300000.
      ITRY=IFIX(FTRY)
      GO TO 17410
17417  IF(FTRY.GT.-0.5)GO TO 17418
      GO TO 17419
17418       FTRY=0.0
      GO TO 17419
17410   IPM(IPNW,J,K+3)= ITRY
17004 CONTINUE
17006  DO 17103 K=1,3
      IPNSCH=IPR(IPNW,K)
      IF(IPNSCH.EQ.3000000)GO TO 17700
      IF(IPNSCH.EQ.1000000)GO TO 17800
      J=1
17101 IF(NOD(IPNSCH,7,J).EQ.IPNW)GO TO 17102
      J=J+1
      IF(J.EQ.11)GO TO 17104
      GO TO 17101
17102 DO 17108 KQ=4,6
      IF(NOD(IPNSCH,KQ,J).NE.0)GO TO 17105
      NOD(IPNSCH,KQ,J)=IPM(IPNW,K,KQ)
      GO TO 17108
17105   NOD(IPNSCH,KQ,J)=  NOD(IPNSCH,KQ,J) + IPM(IPNW,K,KQ)
      IF(IOP.EQ.2)GO TO 17108
      WRITE(2,17920)IPNSCH,IPNW,J
17920   FORMAT('  FORCES ON PCL.NO.',I4,'  FROM PCL.NO.',I4,
     2'  AT NODE NO',I4,'  HAVE BEEN SUMMED.')
17108 CONTINUE
      GO TO 17103
17700  IWRC=IPNW
      IF(IWRC.GE.101)GO TO 9800
      DO 17701 J=1,6
```

Continued overleaf ....

Appendix IV   TL 302   Programme Listing   .... continued ....

```
17701    IWR(IWRC,J) = IPM(IPNW,1,J)
        IBWR(IWRC,2) = IPNW
        GO TO 17103
17800    IBRC=IPNW
        IF(IBRC.GE.101)GO TO 9802
        DO 17801 J=1,6
17801     IBR(IBRC,K,J) = IPM(IPNW,K,J)
        IBWR(IBRC,1) = IPNW
        GO TO 17103
17104   WRITE(2,17106)IPNSCH,IPNW
17106   FORMAT(4H PCI,I6,21H HAS NO NODE FROM PCI,I6,17H IPR IS IN ERROR.)
17103   CONTINUE
        GO TO 17005
9800     WRITE(2,9801)IPNW
9801     FORMAT('   THE WALL REGISTER IS FULL WITH',I4,'  LEFT')
        GO TO 5500
9802     WRITE(2,9803)IPNW
9803     FORMAT(32H THE BASE REGISTER IS FULL WITH ,I6,15H  PARCELS LEFT.)
5500    CONTINUE
        IF(IOP.GT.1)GO TO 7500
        WRITE(2,50151)
50151   FORMAT(1H1,12HNODE MATRIX.)
        WRITE(2,50152)(((NOD(IA,IB,IC),IC=1,10),IB=1,7),IA=1,IPN)
50152   FORMAT(10I10)
         WRITE(2,50114)
50114   FORMAT(12H IPR MATRIX.)
        WRITE(2,50115)((IPR(MN,MO),MO=1,3),MN=1,IPN)
50115   FORMAT(1X,3I10)
         WRITE(2,521)
521     FORMAT(12H  IPM MATRIX)
        WRITE(2,520)(((IPM(IA,IB,IC),IC=1,6),IB=1,3),IA=1,IPN)
 520    FORMAT(1X,6I10)
        WRITE(2,522)
522     FORMAT(21H  BASE/WALL REGISTERS)
        WRITE(2,523)((IBWR(ID,IC),IC=1,2),ID=1,100)
523     FORMAT(1X,2I10)
        WRITE(2,524)
524     FORMAT(15H  WALL REGISTER)
        WRITE(2,528)((IWR(IE,IF),IF=1,6),IE=1,100)
528     FORMAT(1X,6I10)
        WRITE(2,525)
525     FORMAT(14H BASE REGISTER)
        WRITE(2,526)(((IBR(IG,IH,IJ),IJ=1,6),IH=1,3),IG=1,100)
526     FORMAT(1X,6I10)
        WRITE(2,527)
527     FORMAT(5H  IPR)
        WRITE(2,529)((IPR(IK,IL),IL=1,3),IK=1,100)
529     FORMAT(1X,3I10)
7500    CONTINUE
        IF(IHC.GT.1)NX=4
        DO 7645 M=1,4
7645    SXBSL(M),SXBST(M),SXWSL(M),SXWST(M)=0.
        DO 7601 J=1,100
        NIC=ICP(J*10-1,1)
        UBSL=TAN(FLOAT(NODDS(J,9))/57.29577)
        UBST=TAN(FLOAT(NODDS(J,8))/57.29577)
        UWSL=TAN(FLOAT(NODDS(J,7))/57.29577)
        UWST=TAN(FLOAT(NODDS(J,6))/57.29577)
        DO 7604 N=1,3
        SB=FLOAT(IBR(J,N,6)   )
        IF(NIC.EQ.4)GO TO 7610
        DO 7602 JA=1,NX
        SXBSL(JA)=SB*UBSL/10.+SXBSL(JA)
7602    SXBST(JA)=SB*UBST/10.+SXBST(JA)
        GO TO 7609
7610    UBBSL=UBSL
```

Continued overleaf ....

```
      DO 7603 JB=1,NX
      IF(JB.EQ.1)GO TO 7605
      JE=JB-1
      DO 7606 JD=1,JE
      UBBSL=UBBSL*PEXP
7606  UBBST=UBBST*PEXP
7605  SXBSL(JB)=SB*UBBSL/10.+SXBSL(JB)
      SXBST(JB)=SB*UBBST/10.+SXBST(JB)
7603  CONTINUE
7609  CONTINUE
7604   CONTINUE
      SW=FLOAT(IABS(IWP(J,4)))
      IF(JTC.EQ.4)GO TO 7620
      DO 7621 LA=1,NX
      SXWSL(LA)=SW*UWSL/10.+SXWSL(LA)
7621  SXWST(LA)=SW*UWST/10.+SXWST(LA)
      GO TO 7619
7620  UWWSL=UWSL
      UWWST=UWST
      DO 7623 LB=1,NX
      IF(LB.EQ.1)GO TO 7625
      LE=LB-1
      DO 7626 LD=1,LE
      UWWSL=UWWSL+PEXP
7626  UWWST=UWWST*PEXP
7625  SXWSL(LB)=SW*UWWSL/10.+SXWSL(LB)
      SXWST(LB)=SW*UWWST/10.+SXWST(LB)
7623  CONTINUE
7619  CONTINUE
7601  CONTINUE
      DO 7630 JX=1,NX
      IF(JX.EQ.1)GO TO 7651
      JXX=JX*10+30
      WRITE(2,7650)JXX
7650   FORMAT(////'   HUMIDITY IS',I4,'%')
7651  CONTINUE
      WRITE(2,508)
508   FORMAT('   FRICTION FORCES ARE:')
      WRITE(2,530)
530   FORMAT(40X,5HBASE:,40X,9HSIDE WALL)
      WRITE(2,760)SXBSL(JX),SXBST(JX),SXWSL(JX),SXWST(JX)
760   FORMAT(1X,F10.2,9H SLIDING,,F10.2,8H STATIC.,20X,F10.2,9H SLIDING,
     2,F10.2,8H STATIC.)
      IF(SXWSL(JX).LT.SXBST(JX))GO TO 7520
      IF(SXWST(JX).LT.SXBSL(JX))GO TO 7525
      WRITE(2,761)
761   FORMAT(15H PERMANENT JAM.)
      GO TO 7630
7520  WRITE(2,762)
762   FORMAT(15H NO JAM OCCURS.)
      GO TO 7630
 7525 WRITE(2,763)
763   FORMAT(30H INITIAL JAMMING BUT BREAKS UP & FREES.)
      GO TO 7630
7630  CONTINUE
C  PARCEL INDIVIDUAL PRESSURE CALCULATIONS
      WRITE(2,19107)
19107   FORMAT('  PARCEL LOADS, & PRESSURES (LBF/IN2)')
      WRITE(2,19207)
19207   FORMAT('  NUMBER',5X,10X,'LOAD',14X,'LOAD 2',14X,'LOAD 3',14X,'P
     2RESSURE')
19100 KO=KO+1
      P=0
      IF(KO.GE.IPN)GO TO 19110
      INDCAS=IODDS(KO,7)
```

Continued overleaf ....

```
      DO 19108 J=1,3
      PR(J)= FLOAT(IPN(KO,J,6))/10.
      P=P+PR(J)
19108 CONTINUE
      IL=NODDS(KO,2)
      IW=NODDS(KO,3)
      IH=NODDS(KO,4)
      GO TO (19101,19101,19102,19103,19102,19103),INDCAS
19101 A=FLOAT(IL)
      B=FLOAT(IW)
      GO TO 19104
19102  A=FLOAT(IL)
      B=FLOAT(IH)
      GO TO 19104
19103 A=FLOAT(IW)
      B=FLOAT(IH)
19104   PRES=P/(A+B)
19105   WRITE(2,19106)KO,PR(1),PR(2),PR(3),PRES
19106   FORMAT(1H ,I6,10X,4E20.4)
      GO TO 19100
19110 CONTINUE
      WRITE(2,19302)
19302   FORMAT(1H1,'  PARCEL NUMBERS OF BASE CONTACTS')
      DO 19300 LA=1,IPN
      IF(IBWR(LA,1).NE.0)WRITE(2,19301)IBWR(LA,1)
19301   FORMAT(1H ,I10)
19300   CONTINUE
      WRITE(2,19304)
19304   FORMAT(1H ,////,'   PARCEL NUMBERS OF WALL CONTACTS')
      DO 19305 LB=1,IPN
      IF(IBWR(LB,2).NE.0)WRITE(2,19301)IBWR(LB,2)
19305   CONTINUE
      IPNL=IPNN-IPNK-IPNREC
      IPNREC=IPNREC + IPN
      IPNTL=IPNTL+IPNL
      WRITE(2,9705)IRNK,IPNL
9705   FORMAT('   NO.OF PCLS REJECTED ON RUN',I4,'WAS',I4)
      IPNTOT = IPNN
      IPNC=IPNC+IPN
      GO TO 4500
      GO TO 9999
9901   WRITE(2,9902)
9902   FORMAT(15H NO MORE CARDS.)
      GO TO 9999
9991  WRITE(2,701)
701   FORMAT(37H PACKING IS OVER THE SECTION CAPACITY)
9999  WRITE(2,420)
420    FORMAT(1H1,'  END OF RUN')
      WRITE(2,9706)IPNTL,IPNN,IPNC,OFF(IOFS)
9706   FORMAT('   CARDS REJECTED WERE',I6/'  CARDS USED WERE',I6/
     2' PARCELS USED IN COMPLETED LOADS WERE',I6/' OFFICE WAS',A8)
      STOP
      END

END OF SEGMENT, LENGTH  5115, NAME  TL302
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued ....

```
      SUBROUTINE LPSET(IO,R,I)
      F=FLOAT(I)
      F=F*R
      IO=IFIX(F)
      IO=IO+1
      RETURN
      END

END OF SEGMENT, LENGTH    37, NAME  LPSET
```

```
      SUBROUTINE DIFIX(IS,IC,JS,JC,A,I,J)
      RI=FLOAT(I)
      RJ=FLOAT(J)
      RIS=RI*SIN(A)
      RIC=RI*COS(A)
      RJS=RJ*SIN(A)
      RJC=RJ*COS(A)
      IS=IFIX(RIS)
      IC=IFIX(RIC)
      JS=IFIX(RJS)
       JC=IFIX(RJC)
      IO=IFIX(F)
      IO=IO+1
      RETURN
      END

END OF SEGMENT, LENGTH    89, NAME  DIFIX
```

Continued overleaf ....

Appendix IV TL 302 Programme Listing .... continued .....

```
 1203                      FINISH

 END OF COMPILATION -  NO ERRORS

      S/C SUBFILE  :     96 BUCKETS USED

   FIRST WORKFILE  :    137 BUCKETS USED

  SECOND WORKFILE  :    175 BUCKETS USED

   S/C FILE             EXTENDED TO      160  BUCKETS

   FIRST WORKFILE       EXTENDED TO      160  BUCKETS

  SECOND WORKFILE       EXTENDED TO      240  BUCKETS


CONSOLIDATED BY XPCK 12B   DATE      31/10/73   TIME 23/54/43

PROGRAM PS02
MIXED SEGMENTS.          STARTS IN COMPACT DATA (15AM)
COMPACT PROGRAM (DBM)
CORE                  25536

                    SEG      TL302
                    SEG      IABS
                    SEG      TAN
                    SEG      ABS
                    SEG      IFIX
                    SEG      FLOAT
                    CUV      RTNE
                    SEG      DIFIX
                    SEG      LPSET
                    SEG      FPMCRV
                    SEG      COS
                    SEG      SIN
                    SEG      FPZABS

********************************************************************
```

APPENDIX V

SAMPLE OUTPUT FROM THE TL 302 COMPUTER PROGRAMME

Appendix 5.1 The Listing of the GEORGE 3 Output File.

```
TOTAL NUMBER OF CARDS IS    225
DIAGNOSTICS:     OFF
  THIS IS THE FIRST RUN
BEGINNING OF LOADING ARRANGEMENT.
CONVEYOR DIMENSIONS ARE     40 WIDE     72 LONG     36 HIGH AND VOLUME IS       103680.000
SIDEWALL MATERIAL IS  STEL  BASE IS  COTT
PLASTIC PARCELS INJECTED ARE      50.00%,AND HUMIDITY EFFECT     ON       EXPONENT IS     1.1500
THE PROJECTED OFFICE IS          CROY
   OFFICE FOR THIS RUN IS      CROY
 PCL.NO.    1  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.    2  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.    5  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.    5  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    2
 PCL.NO.    5  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    3
 PCL.NO.    5  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    4
 PCL.NO.    6  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.    7  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.    7  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    2
 PCL.NO.    7  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    3
 PCL.NO.    8  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   10  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   10  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    2
 PCL.NO.   11  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   18  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   22   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   34   TOP HEIGHT   37
 PCL.NO.   24  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   24   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   33   TOP HEIGHT   40
 PCL.NO.   26  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   27  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   27   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   29   TOP HEIGHT   37
  PCL.NO.   28   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   37   TOP HEIGHT   40
 PARCEL HAS BEEN REFITTED, TRY NO           1
  PCL.NO.   28   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   36   TOP HEIGHT   43
 PARCEL HAS BEEN REFITTED, TRY NO           2
 PCL.NO.   28  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   29  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   30   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   29   TOP HEIGHT   43
  PCL.NO.   31   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   35   TOP HEIGHT   40
  PCL.NO.   32   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   29   TOP HEIGHT   41
 PCL.NO.   33  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   33   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   15   TOP HEIGHT   49
  PCL.NO.   36   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   43   TOP HEIGHT   60
 PARCEL HAS BEEN REFITTED, TRY NO           1
 PCL.NO.   36  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   36  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    2
 PCL.NO.   36  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    3
 PCL.NO.   36  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    4
  PCL.NO.   36   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   32   TOP HEIGHT   51
 PCL.NO.   37  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
  PCL.NO.   37   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   33   TOP HEIGHT   45
  PCL.NO.   38   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   35   TOP HEIGHT   47
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    1
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    2
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    3
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    4
  PCL.NO.   40   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   47   TOP HEIGHT   49
 PARCEL HAS BEEN REFITTED, TRY NO           1
  PCL.NO.   40   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   40   TOP HEIGHT   51
 PARCEL HAS BEEN REFITTED, TRY NO           2
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER    5
  PCL.NO.   40   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   47   TOP HEIGHT   49
 PARCEL HAS BEEN REFITTED, TRY NO           3
  PCL.NO.   40   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   42   TOP HEIGHT   43
 PARCEL HAS BEEN REFITTED, TRY NO           4
  PCL.NO.   40   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   40   TOP HEIGHT   43
```

Continued overleaf ....

```
   PARCEL HAS BEEN REFITTED, TRY NO          5
    PCL.NO.  40  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  37  TOP HEIGHT  39
   PARCEL HAS BEEN REFITTED, TRY NO          6
    PCL.NO.  40  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  41  TOP HEIGHT  45
   PARCEL HAS BEEN REFITTED, TRY NO          7
   PCL.NO.  40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   6
   PCL.NO.  40  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   7
    PCL.NO.  40  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  37  TOP HEIGHT  44
   PARCEL HAS BEEN REFITTED, TRY NO          8
    PCL.NO.  40  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  40  TOP HEIGHT  45
   PARCEL HAS BEEN REFITTED, TRY NO          9
    PCL.NO.  40  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  43  TOP HEIGHT  53
   PARCEL HAS BEEN REFITTED, TRY NO         10
    THE PACKING DENSITY IS      26.67  FOR  40  PARCELS.
    THE TOTAL PARCEL WEIGHTS WERE                 176.87   LBS.




 UNLOADING STARTS AT PCL     40



  HUMIDITY IS  40%
  FRICTION FORCES ARE:
                                  BASE:                                      SIDE WALL
    122.76 SLIDING,     86.37 STATIC,                   0.06 SLIDING,     0.05 STATIC.
NO JAM OCCURS.



  HUMIDITY IS  50%
  FRICTION FORCES ARE:
                                  BASE:                                      SIDE WALL
    139.55 SLIDING,     93.34 STATIC,                   0.07 SLIDING,     0.05 STATIC.
NO JAM OCCURS.



  HUMIDITY IS  60%
  FRICTION FORCES ARE:
                                  BASE:                                      SIDE WALL
    181.06 SLIDING,    127.93 STATIC,                   0.09 SLIDING,     0.07 STATIC.
NO JAM OCCURS.



  HUMIDITY IS  70%
  FRICTION FORCES ARE:
                                  BASE:                                      SIDE WALL
    269.73 SLIDING,    191.14 STATIC,                   0.13 SLIDING,     0.11 STATIC.
NO JAM OCCURS.
```

Continued overleaf ....

Appendix 5.1 TL 302 Output Listing .... continued ....

```
PARCEL LOADS, & PRESSURES (LBF/IN2)
NUMBER             LOAD 1              LOAD 2              LOAD 3              PRESSURE
     1                      2.0000              40.0000               6.2000               0.3130
     2                      1.2000              57.0000               2.5000               0.3592
     3                      0.8000              23.0000               1.6000               0.3256
     4                      0.6000               0.6000               1.2000               0.0150
     5                      4.1000               3.7000              10.3000               0.0622
     6                      1.5000              51.2000               3.1000               0.2583
     7                      2.6000               2.6000              44.5000               0.2209
     8                      1.2000              18.0000               0.8000               0.0962
     9                      0.3000               0.3000               0.7000               0.0232
    10                     15.9000               1.8000               3.6000               0.0657
    11                      0.8000              11.5000               1.7000               0.2222
    12                      0.5000               0.5000               1.7000               0.0300
    13                      0.7000               0.7000               1.4000               0.0311
    14                      0.5000               9.5000               1.1000               0.1233
    15                      2.2000               2.2000              13.0000               0.0888
    16                      1.1000               1.1000               3.2000               0.0491
    17                      0.6000               0.6000              10.1000               0.1009
    18                      0.6000               0.6000               1.3000               0.0595
    19                      0.2000               0.2000               0.5000               0.0141
    20                      0.9000               4.0000               5.0000               0.1125
    21                      3.5000              14.1000               6.0000               0.1430
    22                      0.5000               7.8000               1.0000               0.3100
    23                      0.5000               5.2000              17.8000               0.4608
    24                      3.5000               0.5000               1.0000               0.0397
    25                      3.2000               0.7000               1.4000               0.0757
    26                      0.8000               0.8000               1.6000               0.0208
    27                      0.8000               4.6000               1.7000               0.1109
    28                      0.8000               0.8000               1.7000               0.0393
    29                      0.5000               0.5000               1.1000               0.0168
    30                      3.8000               2.1000               2.6000               0.0344
    31                      1.8000               0.8000               4.7000               0.0579
    32                      3.2000               3.2000               6.5000               0.0763
    33                      1.0000               1.0000               2.1000               0.0427
    34                      4.9000               1.0000               2.1000               0.1481
    35                      0.3000               0.3000               0.6000               0.1000
    36                      1.3000               1.3000               2.6000               0.0153
    37                      3.0000               3.0000               6.1000               0.0846
    38                      0.2000               0.2000               0.5000               0.0321
    39                      0.0000               0.0000               0.0000               0.0000


PARCEL NUMBERS OF BASE CONTACTS
         1
         2
         3
         4
         9
        10
        12
        14
        16
        18
        35
        39


PARCEL NUMBERS OF WALL CONTACTS
         4
        12
        13
        15
        32
        40
NO.OF PCLS REJECTED ON RUN   1WAS    0
```

Continued overleaf ....

Appendix 5.1 TL 302 Output Listing .... continued ....

```
  THIS IS RUN NUMBER       2
  TOTAL PARCELS NOW     40    TOTAL CARDS NOW     40
   OFFICE FOR THIS RUN IS       CROY
 PCL.NO.    1  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.    2  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.    2  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.    6  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.    7  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.    7  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   14  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   14  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   14  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
 PCL.NO.   16  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   16  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   16  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
 PCL.NO.   18  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   19  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   19  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   19  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
 PCL.NO.   22  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   23  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   23  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   24  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   24  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   24  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
 PCL.NO.   26  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   27  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   27  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   32  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   33  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   37  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   37  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   40  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   41  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   41  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
  PCL.NO.   41   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   23   TOP HEIGHT   42
 PCL.NO.   42  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   42  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
 PCL.NO.   42  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
 PCL.NO.   42  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    4
  PCL.NO.   44   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT    0   TOP HEIGHT   43
  PCL.NO.   47   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   36   TOP HEIGHT   46
 PARCEL HAS BEEN REFITTED, TRY NO              1
 PCL.NO.   47  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   48  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
 PCL.NO.   50  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
  PCL.NO.   50   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   24   TOP HEIGHT   38
  PCL.NO.   51   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   28   TOP HEIGHT   38
  PCL.NO.   52   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   26   TOP HEIGHT   43
  PCL.NO.   53   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   34   TOP HEIGHT   41
 PCL.NO.   54  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    1
  PCL.NO.   54   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   43   TOP HEIGHT   46
 PARCEL HAS BEEN REFITTED, TRY NO              1
 PCL.NO.   54  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    2
  PCL.NO.   54   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   38   TOP HEIGHT   42
 PARCEL HAS BEEN REFITTED, TRY NO              2
 PCL.NO.   54  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    3
  PCL.NO.   54   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   38   TOP HEIGHT   39
 PARCEL HAS BEEN REFITTED, TRY NO              3
  PCL.NO.   54   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   38   TOP HEIGHT   39
 PARCEL HAS BEEN REFITTED, TRY NO              4
  PCL.NO.   56   SHOWS ABOVE SIDEPLATE.   BOTTOM HEIGHT   35   TOP HEIGHT   42
 PARCEL HAS BEEN REFITTED, TRY NO              5
 PCL.NO.   54  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    4
 PCL.NO.   54  OUTSIDE SIDEPLATE ON DROPPING   . REFIT   ATTEMPT NUMBER    5
```

Continued overleaf ....

Appendix 5.1 TL 302 Output Listing .... continued ....

```
 PCL.NO.  54  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  43  TOP HEIGHT  44
PARCEL HAS BEEN REFITTED, TRY NO           6
 PCL.NO.  54  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  38  TOP HEIGHT  42
PARCEL HAS BEEN REFITTED, TRY NO           7
PCL.NO.  54  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   6
 PCL.NO.  54  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  41  TOP HEIGHT  42
PARCEL HAS BEEN REFITTED, TRY NO           8
 PCL.NO.  54  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  43  TOP HEIGHT  44
PARCEL HAS BEEN REFITTED, TRY NO           9
 PCL.NO.  54  SHOWS ABOVE SIDEPLATE.  BOTTOM HEIGHT  43  TOP HEIGHT  44
PARCEL HAS BEEN REFITTED, TRY NO          10
 THE PACKING DENSITY IS     21.60  FOR  54  PARCELS.
 THE TOTAL PARCEL WEIGHTS WERE               278.19   LBS.





 UNLOADING STARTS AT PCL    54



   HUMIDITY IS  40%
   FRICTION FORCES ARE:
                                             BASE:                                               SIDE WALL
     206.85 SLIDING,    134.59 STATIC,                              0.00 SLIDING,     0.00 STATIC.
 NO JAM OCCURS.



   HUMIDITY IS  50%
   FRICTION FORCES ARE:
                                             BASE:                                               SIDE WALL
     232.24 SLIDING,    151.67 STATIC,                              0.00 SLIDING,     0.00 STATIC.
 NO JAM OCCURS.



   HUMIDITY IS  60%
   FRICTION FORCES ARE:
                                             BASE:                                               SIDE WALL
     295.02 SLIDING,    193.89 STATIC,                              0.00 SLIDING,     0.00 STATIC.
 NO JAM OCCURS.



   HUMIDITY IS  70%
   FRICTION FORCES ARE:
                                             BASE:                                               SIDE WALL
     429.10 SLIDING,    284.07 STATIC,                              0.00 SLIDING,     0.00 STATIC.
 NO JAM OCCURS.
```

Continued overleaf ....

Appendix 5.1 TL 302 Output Listing .... continued ....

```
PARCEL LOADS, & PRESSURES (LBF/IN2)
NUMBER           LOAD            LOAD 2                 LOAD 3               PRESSURE
   1                   1.0000              3.9000              27.5000              0.3682
   2                   1.2000             48.1000               2.5000              0.4111
   3                   0.7000              0.7000               1.5000              0.0279
   4                   0.4000              0.4000               3.9000              0.0839
   5                   0.4000              0.4000              43.2000              0.4000
   6                   2.3000              2.3000               4.6000              0.0885
   7                  83.8000              6.9000               5.2000              1.0656
   8                   0.6000              2.7000              11.8000              0.4194
   9                   0.3000              0.3000              14.9000              0.5536
  10                   0.8000              0.8000               1.6000              0.0653
  11                   0.3000              0.3000               0.7000              0.1083
  12                   0.4000              7.2000               6.7000              0.1702
  13                   1.1000              5.9000               2.3000              0.0775
  14                   1.9000              1.3000               2.7000              0.0615
  15                   4.3000              4.3000              21.1000              0.1757
  16                   1.8000              1.8000               5.0000              0.0672
  17                  75.0000              0.9000               5.3000              0.3904
  18                   7.6000             22.3000               2.9000              0.1941
  19                   2.1000              2.1000              29.7000              0.4708
  20                  54.1000              4.0000              16.0000              0.7125
  21                   0.5000              0.5000               1.1000              0.0875
  22                   0.8000              0.8000               1.6000              0.1600
  23                   0.5000              2.1000               7.9000              0.0868
  24                  10.9000              5.3000               1.6000              0.1187
  25                   2.0000              5.6000               4.6000              0.1556
  26                  10.1000              1.5000               3.0000              0.1604
  27                   0.9000              3.6000               4.1000              0.0269
  28                   1.6000              2.1000              19.7000              0.1125
  29                   0.6000             15.5000               5.4000              0.7679
  30                   1.1000              1.1000               2.3000              0.0714
  31                   0.5000              0.5000               1.1000              0.0389
  32                   0.5000             43.2000               9.0000              0.3660
  33                   0.5000              0.5000               1.0000              0.0303
  34                   0.7000              0.7000               1.4000              0.0259
  35                   1.8000             13.1000               6.2000              0.1279
  36                   0.5000              0.5000               1.1000              0.0350
  37                   1.0000              1.0000               2.1000              0.0325
  38                   4.0000              4.0000              33.0000              0.4271
  39                   1.8000              4.4000               1.8000              0.0606
  40                   1.0000              1.4000               2.0000              0.0458
  41                   3.5000              3.5000               7.8000              0.1265
  42                   0.8000              6.8000              14.6000              0.0822
  43                   1.5000              1.0000               2.0000              0.0433
  44                   0.9000              0.9000               3.9000              0.1163
  45                   0.9000              0.9000               1.8000              0.0735
  46                   0.4000              0.4000               0.8000              0.0205
  47                   0.4000              0.4000               0.8000              0.0229
  48                   0.5000              0.5000               2.2000              0.0296
  49                   1.4000              1.4000               3.2000              0.0513
  50                   0.4000              0.4000               0.8000              0.0348
  51                   4.1000              4.1000               8.3000              0.1269
  52                   0.8000              0.8000               1.7000              0.0317
  53                   4.3000              4.3000               8.7000              0.1331
```

Continued overleaf ....

Appendix 5.1 TL 302 Output Listing .... continued ....

```
 PARCEL NUMBERS OF BASE CONTACTS
          1
          2
          4
          5
          6
          7
          9
         10
         11
         21
         22
         31

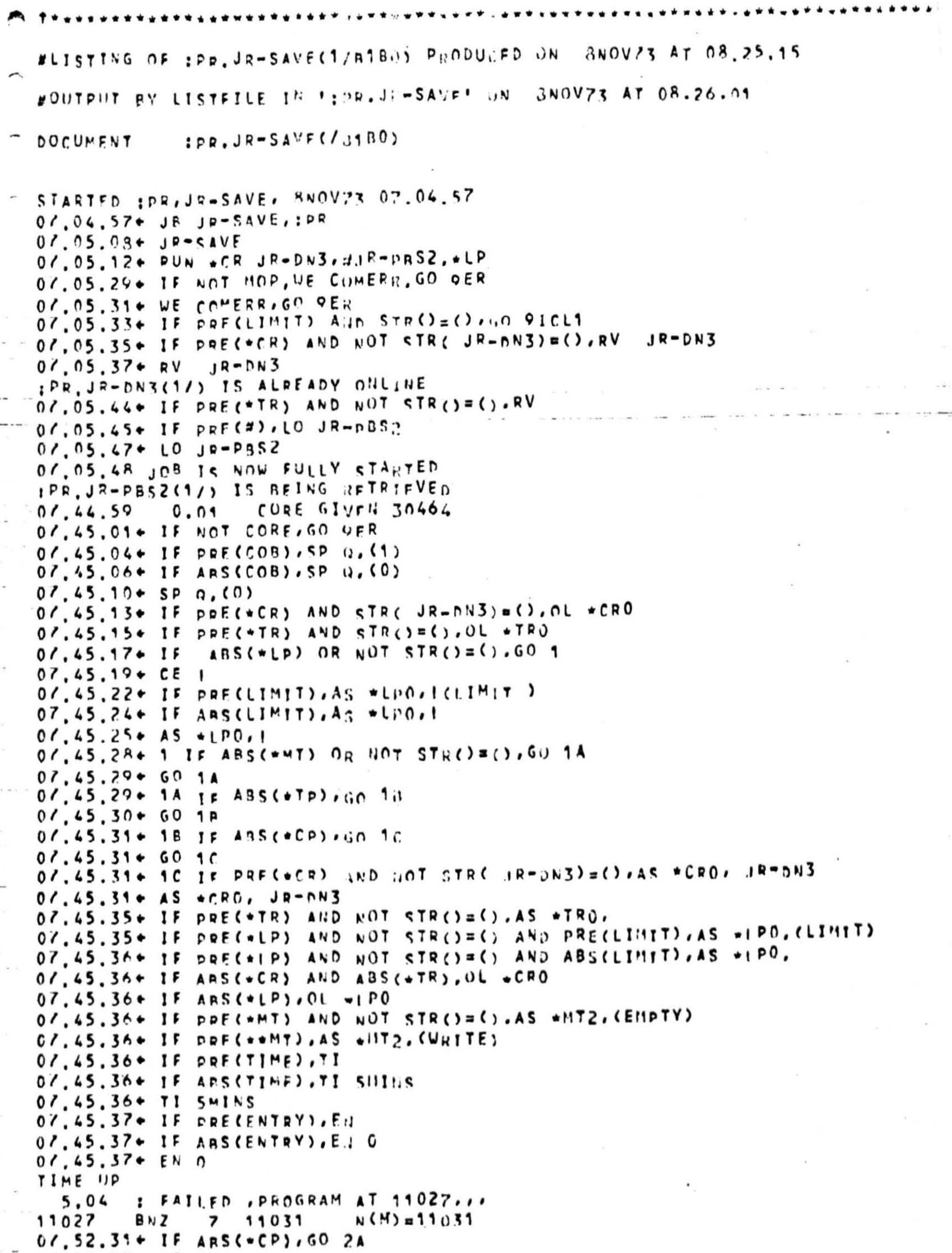

 PARCEL NUMBERS OF WALL CONTACTS
          4
         16
         22
         42
         47
         53
 NO.OF PCLS REJECTED ON RUN    2WAS  - 1



  THIS IS RUN NUMBER        3
  TOTAL PARCELS NOW     94    TOTAL CARDS NOW     93
   OFFICE FOR THIS RUN IS      CROY
 PCL,NO.    1  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   1
 PCL,NO.    3  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   1
 PCL,NO.    3  OUTSIDE SIDEPLATE ON DROPPING  . REFIT  ATTEMPT NUMBER   2

*********************************************************************************
```

Appendix 5.2 The Listing of the GEORGE 3 Monitor Log for the TL 302 Computer Programme run.



```
†*****************************************************************************

#LISTING OF :PR.JR-SAVE(1/B1B0) PRODUCED ON  8NOV73 AT 08.25.15

#OUTPUT BY LISTFILE IN ':PR.JR-SAVE' ON  8NOV73 AT 08.26.01

DOCUMENT     :PR.JR-SAVE(/31B0)


STARTED :PR,JR-SAVE, 8NOV73 07.04.57
07,04.57+ JB JR-SAVE,:PR
07.05.08+ JR-SAVE
07,05.12+ RUN *CR JR-DN3,#JR-PBS2,*LP
07,05.29+ IF NOT MOP,WE COMERR,GO 9ER
07,05.31+ WE COMERR,GO 9ER
07,05.33+ IF PRF(LIMIT) AND STR()=(),GO 91CL1
07,05.35+ IF PRE(*CR) AND NOT STR( JR-DN3)=(),RV  JR-DN3
07,05.37+ RV  JR-DN3
;PR,JR-DN3(1/) IS ALREADY ONLINE
07,05.44+ IF PRE(*TR) AND NOT STR()=().RV
07,05.45+ IF PRF(#),LO JR-PBS2
07,05.47+ LO JR-PBS2
07,05.48 JOB IS NOW FULLY STARTED
:PR,JR-PBS2(1/) IS BEING RETRIEVED
07,44.59   0.01   CORE GIVEN 30464
07,45.01+ IF NOT CORE,GO 9ER
07,45.04+ IF PRE(COB),SP Q,(1)
07,45.06+ IF ABS(COB),SP Q,(0)
07,45.10+ SP Q,(0)
07,45.13+ IF PRE(*CR) AND STR( JR-DN3)=(),OL *CRO
07,45.15+ IF PRE(*TR) AND STR()=(),OL *TRO
07,45.17+ IF  ABS(*LP) OR NOT STR()=(),GO 1
07,45.19+ CE 1
07,45.22+ IF PRF(LIMIT),AS *LPO,1(LIMIT )
07,45.24+ IF ABS(LIMIT),AS *LPO,1
07,45.25+ AS *LPO,1
07,45.28+ 1 IF ABS(*MT) OR NOT STR()=(),GO 1A
07,45.29+ GO 1A
07,45.29+ 1A IF ABS(*TP),GO 1B
07,45.30+ GO 1B
07,45.31+ 1B IF ABS(*CP),GO 1C
07,45.31+ GO 1C
07,45.31+ 1C IF PRF(*CR) AND NOT STR( JR-DN3)=(),AS *CRO, JR-DN3
07,45.31+ AS *CRO, JR-DN3
07,45.35+ IF PRE(*TR) AND NOT STR()=().AS *TRO,
07,45.35+ IF PRE(*LP) AND NOT STR()=() AND PRE(LIMIT),AS *LPO,(LIMIT)
07,45.36+ IF PRE(*LP) AND NOT STR()=() AND ABS(LIMIT),AS *LPO,
07,45.36+ IF ABS(*CR) AND ABS(*TR),OL *CRO
07,45.36+ IF ABS(*LP),OL *LPO
07,45.36+ IF PRF(*MT) AND NOT STR()=().AS *MT2,(EMPTY)
07,45.36+ IF PRF(**MT),AS *MT2,(WRITE)
07,45.36+ IF PRF(TIME),TI
07,45.36+ IF ABS(TIME),TI 5MINS
07,45.36+ TI 5MINS
07,45.37+ IF PRE(ENTRY),EN
07,45.37+ IF ABS(ENTRY),EN 0
07,45.37+ EN 0
TIME UP
  5,04  : FAILED ,PROGRAM AT 11027,,,
11027    BNZ   7  11031     N(M)=11031
07,52.31+ IF ABS(*CP),GO 2A
07,52.33+ GO 2A
```

Continued overleaf ....

```
07.52.35+ 2A IF ABS(*TP),GO 2B
07.52.37+ GO 2B
07.52.39+ 2B IF ABS(*LP) OR NOT STR()=(),GO 2
07.52.41+ IF ABS(*MT) OR NOT STR()=(),GO 2C
07.52.43+ GO 2C
07.52.45+ 2C SP 0,(0)
07.52.47+ 2CC IF 10,*LP
07.52.52+ FR 10
07.52.55+ 2 IF PRE(END) AND HAL() OR DEL(),GO 9RUNOK
07.52.56+ IF ABS(END),GO 9RUNOK
07.52.58+ GO 9RUNOK
07.53.00+ 9RUNOK
END OF MACRO
07.53.02+ ****
ERROR  IN VERB : VERB FORMAT ERROR
END OF MACRO
WAITING FOR DUMPER TO FINISH INCREMENT
08.04.55 FREE *LP0, 384 TRANSFERS
08.04.57 FREE *CR0, 105 TRANSFERS
08.05.00    5.05    DELETED,CLOCKED 00.04.59
08.05.02    5.05    FINISHED



           NNN         NNN   EEEEEEEEEEE   WWW                     WWW     SSSSSSSS
           NNNN        NNN   EEEEEEEEEEE   WWW                     WWW   SSSSSSSSSSSS
           NNNNN       NNN   EEE           WWW                     WWW   SSS      SSS
           NNNNNN      NNN   EEE           WWW                     WWW   SSS
           NNN NNN     NNN   EEE           WWW                     WWW   SSS
           NNN  NNN    NNN   EEEEEEE       WWW                     WWW    SSSSSSSSS
           NNN    NNN  NNN   EEEEEEE        WWW        WWW        WWW      SSSSSSSSS
           NNN     NNN NNN   EEE             WWW      WWWWW      WWW              SSS
           NNN      NNNNNN   EEE              WWW    WWW WWW    WWW               SSS
           NNN       NNNNN   EEE               WWW WWW     WWW WWW       SSS      SSS
           NNN        NNNN   EEEEEEEEEEE        WWWWW       WWWWW        SSSSSSSSSSSS
           NNN         NNN   EEEEEEEEEEE          WWW       WWW            SSSSSSSS



15-10-73   DEBUGGING OR RUNNING A FORTRAN PROGRAM?
           MAYBE FLAIR WILL IMPROVE YOUR TURNROUND.

FLAIR-     FLAIR SESSIONS ARE NOW HELD EVERY DAY:
           SEE MAIN NOTICE BOARD FOR SCHEDULE AND
           DETAILS. HANDOUTS AND FURTHER INFORMATION
           AVAILABLE FROM LIAISON OFFICE.

16-10-73   GEORGE 3 MK6.6 WILL REMAIN IN USE FOR THE REST OF THIS TERM
           THE POSSIBLE USE OF MARK 7 WILL BE RE-EXAMINED AT CHRISTMAS
           AFTER FURTHER PERFORMANCE TESTS.

↑****************************************************************************************************
```

APPENDIX VI

OUTPUT FROM THE SPSS PROGRAMME RUN ON THE CDC & CTL COMPUTERS, THE CDC 7600 ACTING AS A LARGE 64K FASTCORE PLUS 256K SLOWCORE & THE CTL MODULA I ACTING AS A LINK REMOTE JOB ENTRY (RJE) TERMINAL.

Appendix VI Output from the SPSS programme, run on the CDC & CTL computers, the CDC 7600 acting as a large 64K fastcore plus 256K slowcore, and the CTL Modula I acting as a link Remote Job Entry (RJE) terminal.

```
**** 7600 SCOPE 2.0 ****        CYCLE 171-E           10/12/75        75344

**** UNIV. OF LONDON COMPUTER CENTRE ****

HH.MM.SS CPU SECOND ORIGIN
            11.35.49APFS.IBX.   LONDON UNIV.  3.4.0.2M L355   6 OCT 75  CYBER72
11.36.28 00000.006 LOD.       -JOB(GRHC022J,J6,M7600)ROURKE
11.36.32 00000.025 JOB.       -ATTACH(SPSS,SPSS,ID=PUBLIC)
11.36.34 00000.034 SYS.          PF673 - CYCLE     5 ATTACHED
11.36.34 00000.031 LOD.       -SPSS.
11.36.35 00000.041 USR.         FORTRAN LIBRARY 177/377        18/07/74
11.36.36 00000.298 USR.              END  SPSS
11.36.36 00000.298 USR.               .256 CP SECONDS EXECUTION TIME
11.36.36 00000.300 SYS.          RM770 - MAXIMUM ACTIVE FILES                         3
11.36.36 00000.300 SYS.          RM771 - OPEN/CLOSE CALLS                            11
11.36.36 00000.300 SYS.          RM772 - DATA TRANSFER CALLS                        737
11.36.36 00000.300 SYS.          RM773 - CONTROL/POSITIONING CALLS                    9
11.36.36 00000.301 SYS.          RM774 - BM DATA TRANSFER CALLS                     109
11.36.36 00000.301 SYS.          RM775 - BM CONTROL/POSITIONING CALLS                24
11.36.36 00000.301 SYS.          RM776 - QUEUE MANAGER CALLS                         22
11.36.36 00000.301 SYS.          RM777 - RECALL CALLS                                24
11.36.36 00000.302 SYS.          SCM                        4.693  KWS
11.36.36 00000.302 SYS.          I/O                        0.012  MW
11.36.36 00000.302 SYS.          RMS                        0.006  MWS
11.36.36 00000.302 SYS.          USER                       0.297  SEC
11.36.36 00000.302 SYS.          JOB                        0.304  SEC
11.36.36 00000.303 SYS.          USAGE                      0.138  7600 UNITS
11.36.36 00000.303 SYS.          SC250 - 000005 SC/LC SWAPS
11.36.36 00000.303 SYS.          ULCC02-MAX. SCM USED                  040600B
```

```
VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY                                        10/12/75      PAGE    1

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 5.0 -- SPSS100 -- DECEMBER 1972
SMALL VERSION FOR CDC 7600  AT ULCC - AUGUST 73.

                                              NB. SAVE FILES FROM SCOPE 3.2 WILL HAVE TO BE
                                                 CONVERTED USING  FTBCOPY(TAPE,GTFILE,1)
MINIMUM SCM = 043000B ( 17920D )


          RUN NAME          CG OF SAMPLES OF 200 FROM 6 OFFICES
          VARIABLE LIST       WBM LBM BBM HBM WBR LBR BBR HBR WCR LCR BCR HCR WLI LLI BLI
                              HLI WMT LMT BMT HMT WNW LNW BNW HNW
          INPUT MEDIUM        CARD
          # OF CASES          200
          INPUT FORMAT        FIXED(24F3.1)
          CONDESCRIPTIVE     ALL
          STATISTICS          ALL
          READ INPUT DATA
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                          10/12/75     PAGE   2
FILE   NONAME   (CREATION DATE =  10/12/75 )


VARIABLE  WBM
MEAN                 5.844           STD ERROR            .314           STD DEV              4.438
VARIANCE            19.698           KURTOSIS            1.131           SKEWNESS             1.288
RANGE               20.400           MINIMUM              .800           MAXIMUM             21.200
VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  LBM
MEAN                 7.350           STD ERROR            .206           STD DEV              2.907
VARIANCE             8.448           KURTOSIS            1.494           SKEWNESS             1.132
RANGE               15.100           MINIMUM             2.400           MAXIMUM             17.500
VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  HBM
MEAN                 4.488           STD ERROR            .129           STD DEV              1.830
VARIANCE             3.348           KURTOSIS            -.072           SKEWNESS              .549
RANGE                8.600           MINIMUM              .600           MAXIMUM              9.200
VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                      10/12/75     PAGE    3

FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE   HBM

MEAN                 2.340          STD ERROR            .094          STD DEV              1.333

VARIANCE             1.778          KURTOSIS            1.130          SKEWNESS             1.076

RANGE                7.300          MINIMUM              .400          MAXIMUM              7.700

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   WBR

MEAN                 5.339          STD ERROR            .267          STD DEV              3.779

VARIANCE            14.280          KURTOSIS            1.114          SKEWNESS             1.252

RANGE               17.400          MINIMUM              .800          MAXIMUM             18.200

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   LBR

MEAN                 8.042          STD ERROR            .194          STD DEV              2.740

VARIANCE             7.510          KURTOSIS            3.211          SKEWNESS             1.336

RANGE               17.600          MINIMUM             2.400          MAXIMUM             20.000

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                     10/12/75     PAGE    4

FILE   NONAME   (CREATION DATE =  10/12/75 )


VARIABLE  B6R

MEAN                5.272        STD ERROR           .129        STD DEV            1.818

VARIANCE            3.306        KURTOSIS           1.107        SKEWNESS            .537

RANGE              11.400        MINIMUM            1.100        MAXIMUM           12.500

VALID   OBSERVATIONS -     200
MISSING OBSERVATIONS -       0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  H6R

MEAN                2.578        STD ERROR           .113        STD DEV            1.593

VARIANCE            2.538        KURTOSIS           -.206        SKEWNESS            .871

RANGE               6.600        MINIMUM             .400        MAXIMUM            7.000

VALID   OBSERVATIONS -     200
MISSING OBSERVATIONS -       0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  KCR

MEAN                4.518        STD ERROR           .279        STD DEV            3.946

VARIANCE           15.571        KURTOSIS           4.099        SKEWNESS           2.008

RANGE              21.600        MINIMUM             .100        MAXIMUM           21.700

VALID   OBSERVATIONS -     200
MISSING OBSERVATIONS -       0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                        10/12/75      PAGE     5

FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE  LCR

MEAN                   7.499          STD ERROR              .349          STD DEV                 4.941

VARIANCE              24.416          KURTOSIS             65.168          SKEWNESS                6.533

RANGE                 59.300          MINIMUM               1.300          MAXIMUM                60.600

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  HCR

MEAN                   4.730          STD ERROR              .306          STD DEV                 4.331

VARIANCE              18.754          KURTOSIS            136.988          SKEWNESS               10.810

RANGE                 59.800          MINIMUM                .800          MAXIMUM                60.600

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  HCR

MEAN                   2.345          STD ERROR              .209          STD DEV                 2.958

VARIANCE               8.749          KURTOSIS            138.435          SKEWNESS               10.951

RANGE                 40.200          MINIMUM                .400          MAXIMUM                40.600

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                              10/12/75      PAGE    6

FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE   WLI

MEAN                  4.707          STD ERROR            .278          STD DEV             3.936

VARIANCE             15.495          KURTOSIS            4.167          SKEWNESS            1.953

RANGE                21.000          MINIMUM              .500          MAXIMUM            21.500

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   LLI

MEAN                  7.601          STD ERROR            .226          STD DEV             3.192

VARIANCE             10.192          KURTOSIS            3.635          SKEWNESS            1.560

RANGE                18.900          MINIMUM             2.500          MAXIMUM            21.400

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   BLI

MEAN                  5.234          STD ERROR            .350          STD DEV             4.945

VARIANCE             24.450          KURTOSIS          148.478          SKEWNESS           11.478

RANGE                69.000          MINIMUM             1.300          MAXIMUM            70.300

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                   10/12/75       PAGE      7

FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE  HLI

MEAN                  2.355            STD ERROR            .356           STD DEV             5.037

VARIANCE             25.374            KURTOSIS          172.204           SKEWNESS           12.810

RANGE                70.800            MINIMUM              .300           MAXIMUM            71.100

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  KMT

MEAN                  4.808            STD ERROR            .255           STD DEV             3.610

VARIANCE             13.031            KURTOSIS            3.822           SKEWNESS            1.855

RANGE                21.200            MINIMUM              .100           MAXIMUM            21.300

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE  LMT

MEAN                  7.752            STD ERROR            .217           STD DEV             3.066

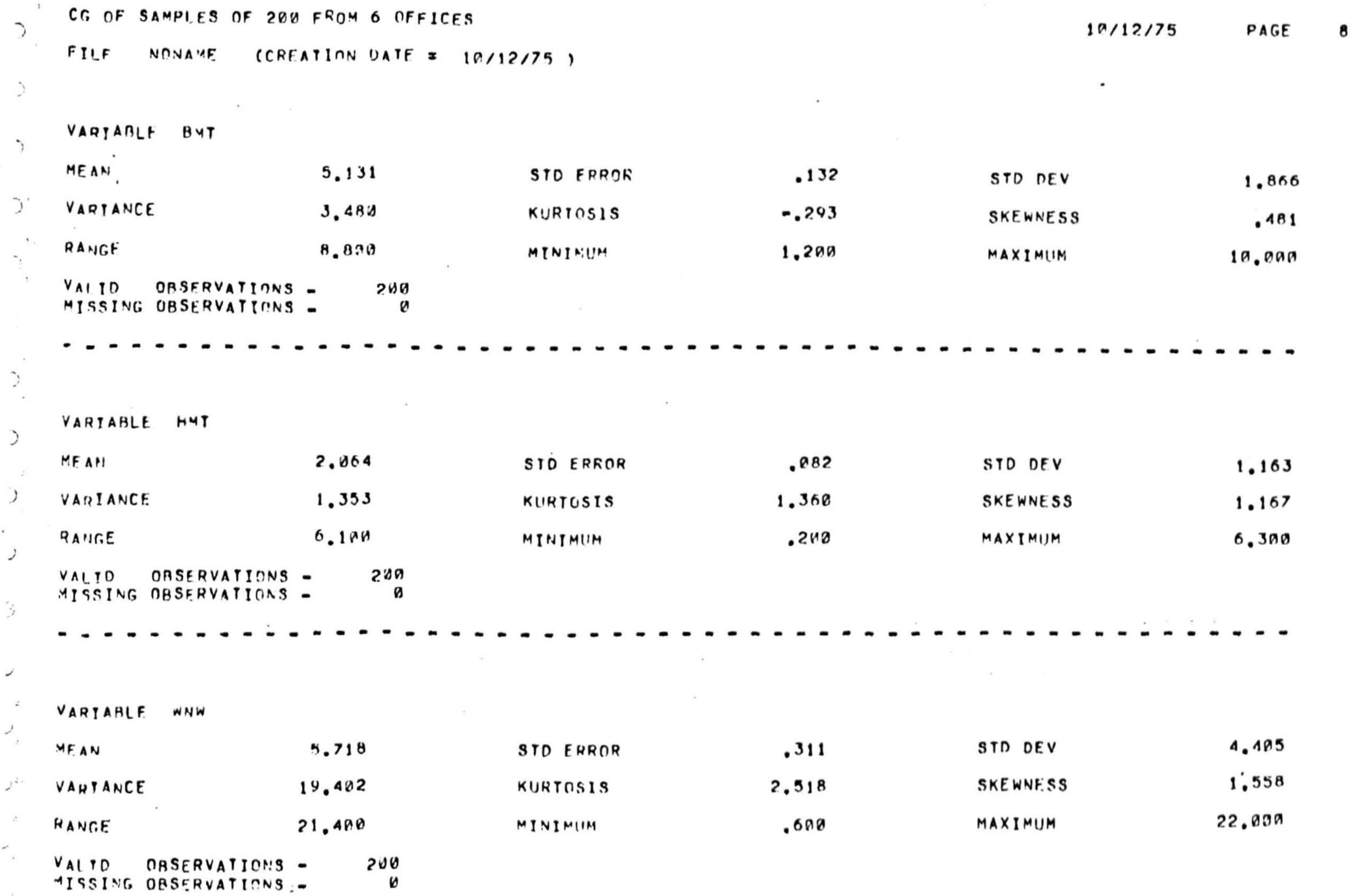
VARIANCE              9.400            KURTOSIS            2.661           SKEWNESS            1.432

RANGE                18.200            MINIMUM             2.300           MAXIMUM            20.500

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....



```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                        10/12/75     PAGE    8
FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE   BMT
MEAN                    5.131          STD ERROR                .132          STD DEV                  1.866
VARIANCE                3.480          KURTOSIS                -.293          SKEWNESS                  .481
RANGE                   8.800          MINIMUM                 1.200          MAXIMUM                 10.000

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   HMT
MEAN                    2.064          STD ERROR                .082          STD DEV                  1.163
VARIANCE                1.353          KURTOSIS                1.360          SKEWNESS                 1.167
RANGE                   6.100          MINIMUM                  .200          MAXIMUM                  6.300

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   WNW
MEAN                    5.718          STD ERROR                .311          STD DEV                  4.405
VARIANCE               19.402          KURTOSIS                2.518          SKEWNESS                 1.558
RANGE                  21.400          MINIMUM                  .600          MAXIMUM                 22.000

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                          10/12/75      PAGE     9
FILE    NONAME    (CREATION DATE =  10/12/75 )


VARIABLE   LNW

MEAN                   7,784          STD ERROR              ,233         STD DEV                3,290

VARIANCE              10,821          KURTOSIS              1,612         SKEWNESS               1,216

RANGE                 17,000          MINIMUM               2,000         MAXIMUM               19,000

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   BNW

MEAN                   4,702          STD ERROR              ,133         STD DEV                1,876

VARIANCE               3,518          KURTOSIS               ,036         SKEWNESS                ,371

RANGE                 10,100          MINIMUM                ,900         MAXIMUM               11,000

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


VARIABLE   HNW

MEAN                   2,916          STD ERROR              ,242         STD DEV                3,416

VARIANCE              11,671          KURTOSIS             90,761         SKEWNESS               8,493

RANGE                 41,900          MINIMUM                ,500         MAXIMUM               42,400

VALID   OBSERVATIONS -      200
MISSING OBSERVATIONS -        0
```

Continued overleaf ....

Appendix VI SPSS Programme Output .... continued ....

```
CG OF SAMPLES OF 200 FROM 6 OFFICES                                                   10/12/75      PAGE   10

                   FINISH



CG OF SAMPLES OF 200 FROM 6 OFFICES                                                   10/12/75      PAGE   11


RUN COMPLETED

NUMBER OF CONTROL CARDS READ  10
NUMBER OF ERRORS DETECTED    0
```

APPENDIX VII

THE DATA CHECKING AND HISTOGRAM PLOTTING PROGRAMME FOR TESTING PARCEL PARAMETERS

This programme is written in FORTRAN for the ICL 1903 computer.

Appendix VII The Data Checking and Histogram Plotting Programme for testing Parcel Parameters, written by the author for the ICL 1900 computer.

```
              MASTER PCLANAL
              INTEGER BLANK,AST,OH,END
              DIMENSION LINE(101),OFF(10),VAR(4),PV(10)
              DIMENSION C(500),TYPE(6),SIG(14),SD(4),AX(4),CLASS(14)
              DIMENSION RI(500),RJ(500),RK(500),WT(500)
              DIMENSION WRAP(6),MT(4),ML(4),CT(6),RM(4),FCT(6,4),FCL(6,4)
              COMMON/OMC/OMAX
              COMMON/IBLOCK/LINE,BLANK,AST,OH
              DATA OFF/8HBIRMIHAM,8HBRIGHTON,7HCROYDON,8HLIVERP'L,8HMANCH'TR,4HN
             2WPO,3HWDO,7HSPECIAL,4HNONE/
              DATA END/3HEND/
              DATA TYPE/6HWEIGHT,6HLENGTH,5HWIDTH,6HHEIGHT/
              DATA WRAP/5HPAPER,6HCARDBD,7HSACKING,7HPLASTIC,4HWOOD,5HSPARE/
              DATA RM/5HSTEEL,6HCOTTON,6HRUBBER,8HSCANDURA/
              WRITE(2,92)
     92        FORMAT(1H1,17H PARCEL ANALYSIS.)
              READ(1,52)MX
     52         FORMAT(1X,I3)
              DO 5 L=1,2
     50       FORMAT(I4)
              READ(1,50)N
     5         CONTINUE
              READ(1,400)IOFS
     400      FORMAT(I10)
              IF(IOFS.EQ.0)IOFS=9
     450      FORMAT('  THIS OFFICE IS ',A8,'  NUMBER ',I3)
              WRITE(2,450)OFF(IOFS) ,IOFS
     501      FORMAT(' OFF NO SW LB OZ LEN  WID  HT  STEEL COTTON RUBB SCAND'//)
              WRITE(2,501)
              DO 70 M=1,MX
     4000      READ(1,100)IOF,IPNN,ISH,IWRP,ILB,IOZ,IL,IW,IH,
             2  MT,ML
     100      FORMAT(I1,I3,2X,2I1,1X,2I2,3(I3,3X),8I2)
              RI(M)=FLOAT(IL)/10.
              RJ(M)=FLOAT(IW)/10.
              RK(M)=FLOAT(IH)/10.
              WT(M)=FLOAT(ILB)+FLOAT(IOZ)/16.
              WRITE(2,500)IOF,IPNN,ISH,IWRP,ILB,IOZ,RI(M),RJ(M),RK(M),
             2  MT,ML
     500       FORMAT(1H ,I1,I4,2I2,I2,I3,3F5.1,8I3)
              CT(IWRP)=CT(IWRP)+1.
              DO 150 LX=1,4
              FCT(IWRP,LX)= FLOAT(MT(LX)) + FCT(IWRP,LX)
     150      FCL(IWRP,LX)= FLOAT(ML(LX)) + FCL(IWRP,LX)
              WTSUM=WTSUM+WT(M)
              RIS=RI(M)+RIS
              RJS=RJ(M)+RJS
     70       RKS=RK(M)+RKS
              XM=FLOAT(MX)
              WTM=WTSUM/XM
              RIM=RIS/XM
              RJM=RJS/XM
              RKM=RKS/XM
              DO 80 MA=1,MX
              WV=(WT(MA)-WTM)**2+WV
              RIV=(RI(MA)-RIM)**2  +RIV
              RJV=(RJ(MA)-RJM)**2   +RJV
     80       RKV=(RK(MA)-RKM)**2   +RKV
              SW=SQRT(WV/XM)
              SI=SQRT(RIV/XM)
              SJ=SQRT(RJV/XM)
              SK=SQRT(RKV/XM)
              WRITE(2,90)
     90        FORMAT(26X,4HMEAN,16X,18HSTANDARD DEVIATION)
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Programme .. continued ..

```
       [illegible]
 91     FORMAT(8H  WEIGHT,10X,F10.2,28X,F10.2)
       WRITE(2,93)RIM,SI
 93     FORMAT(8H  LENGTH,10X,F10.2,28X,F10.2)
       WRITE(2,94)RJM,SJ
 94     FORMAT(7H  WIDTH,11X,F10.2,28X,F10.2)
       WRITE(2,95)RKM,SK
 95     FORMAT(8H  HEIGHT,10X,F10.2,28X,F10.2)
       WRITE(2,532)
 532    FORMAT(///' FRICTION MEAN VALUES.'//)
       DO 530 JU=1,6
       WRITE(2,531)WRAP(JU),CT(JU)
 531    FORMAT(//'   FOR WRAP MATERIAL CONSISTING OF ',A8,' & ',F6.1,
      2 ' PARCELS IN GROUP.'/)
       IF(CT(JU).EQ.0.)WRITE(2,580)
 580    FORMAT('   THERE ARE NO PARCELS IN THIS GROUP')
       IF(CT(JU).EQ.0.)GO TO 530
       DO 533 JV=1,4
       FCT(JU,JV)=FCT(JU,JV)/CT(JU)
       FCL(JU,JV)=FCL(JU,JV)/CT(JU)
       XT=TAN(FCT(JU,JV)/57.29577)
       XL=TAN(FCL(JU,JV)/57.29577)
       WRITE(2,510)FCT(JU,JV),XT,FCL(JU,JV),XL,RM(JV)
 510   FORMAT('  FRICTION IS ',F6.2,' DEGREES ',F6.4,' COEFFICIENT STATIC, '
      2. ',F6.2,' DEGREES ',F6.4,' COEFFICIENT SLIDING FOR ',A8)
 533   CONTINUE
 530    CONTINUE
       WRITE(2,751)
       RX(1)=WTM
       RX(2)=RIM
       RX(3)=RJM
       RX(4)=RKM
       SD(1)=SW
       SD(2)=SI
       SD(3)=SJ
       SD(4)=SK
       VAR(1)=SW*SW
       VAR(2)=SI*SI
       VAR(3)=SJ*SJ
       VAR(4)=SK*SK
       IND=0
 730    J,NC=0
       IP=1
       IF(IND.GE.4)GO TO 9999
       IND=IND+1
       IF(IND.EQ.1)GO TO 781
       DO 870 JX=1,14
 870   CLASS(JX)=0
 781   CS=SD(IND)
 710   SIDB=RX(IND)-3.0*CS
 720    J=J+1
       IF(J.GE.15)GO TO 730
       SID(J)=SIDB+FLOAT(J-1)*CS/2.
       IF(SID(J).LT.0.)GO TO 721
       GO TO 720
 730    GO TO (731,732,733,734),IND
 791    WRITE (2,792)
 792    FORMAT(////'   PROGRAM FAILED BY EXCEEDING RANGE OFSD WITH ALL
      2NEGATIVE VALUES')
        GO TO 9999
 721     IR=J
        IF(J.EQ.14)GO TO 791
       GO TO 720
 731    DO 735 I=1,MX
 735    C(I)=WT(I)
        GO TO 740
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Programme .. continued ..

```
732       DO 736 I=1,MX
736      C(I)=RI(I)
         GO TO 740
733       DO 737  I=1,MX
737      C(I)=PJ(I)
         GO TO 740
734       DO 738  I=1,MX
738      C(I)=PK(I)
740       DO 741 J=1,MX
          DO 742 K=IR,13
         IF(C(J).GE.SID(K)) GO TO 743
         CLASS (K)= CLASS(K) + 1
         MC=MC+1
         GO TO 744
743       CONTINUE
742       CONTINUE
         CLASS(14)=CLASS(14)+1
         MC=MC+1
744       CONTINUE
741       CONTINUE
         IF(MC.NE.MX)WRITE (2,905)MC,MX
905       FORMAT('   ERROR IN NUMBER OF CLASS AT ',I4,'  COMPARED WITH ',
        2  I4,'  IN TOTAL')
         SID(14)=999.
         WRITE(2,750)TYPE(IND)
750        FORMAT(//'  HISTOGRAM POINTS FOR ',A8,'.  DIMENSION & NUMBER IN
        2CLASS')
751        FORMAT(1H1,'   HISTOGRAM DATA.')
         WRITE(2,753)
         WRITE(2,752)(SID(L),L=1,7)
         WRITE(2,752)(CLASS(L),L=1,7)
752       FORMAT(1X,7(6 X,F10.4))
753      FORMAT(6X,'< -3.0',10X,'< -2.5',10X,'< -2.0',10X,'< -1.5',10X,
        2'< -1.0',10X,'< -0.5',10X,'< MEAN')
754      FORMAT(6X,'< +0.5',10X,'< +1.0',10X,'< 1.5 ',10X,'< +2.0',10X,
        2'< +2.5',10X,'< +3.0',10X,'> +3.0')
         WRITE(2,754)
         WRITE(2,752)(SID(L),L=8,14)
         WRITE(2,752)(CLASS(L),L=8,14)
         WRITE(2,755)TYPE(IND)
755       FORMAT(/'  DIMENSION WAS ',A8)
         WRITE(2,756)RX(IND),SD(IND),VAR(IND),TYPE(IND)
756      FORMAT('  MEAN ',F10.2,'  STANDARD DEVIATION ',F10.4,
        2'  VARIANCE ',F10.4/'   ALL FOR DATA ON ',A8)
          WRITE(2,6000)TYPE(IND)
6000       FORMAT(1H1,'  FREQUENCY DISTRIBUTION FOR ',A8)
         CL=CS/2.0
         SIDT=RX(IND)+6.0*CS /2.0
         OMAX=CLASS(1)
         DO 6001 J=IR,14
         IF(OMAX.GE.CLASS(J))GO TO 6002
         OMAX=CLASS(J)
6002     CONTINUE
6001     CONTINUE
         WRITE(2,6003)TYPE(IND),SIDB,SIDT,CL,OMAX
6003       FORMAT(6X,' RANGE OF ',A8,' IS FROM ',F10.3,' TO ',F10.3/
        2 6X,' UNIT OF CLASS INTERVAL IS ',F10.3/
        3 6X,' MAXIMUM ORDINATE HEIGHT IS ',F10.1////)
         WRITE(2,6005)
6005      FORMAT(50X,'   NUMBER IN CLASS.'//)
         IPF=0
         DO 6407 NX=1,10
6407      PY(NX)=OMAX/10.*FLOAT(NX)
         WRITE(2,6408)IPF,PY
6408      FORMAT(10X,I1,2X,10(4X,F6.2))
         DO 6322 LY=1,101
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Programme .. continued ..

```
6322     LINE(LY)=BLANK
        LINE(1)=0H
        DO 6323 LZ=1,10
        L=LZ*10+1
6323     LINE(L)=0H
        WRITE(2,6324)LINE
6324     FORMAT(11X,101A1)
        DO 6300  LX=1,101
6300     LINE(LX)=0H
        LP=0
        WRITE(2,6301)LP,0H,LINE
6301    FORMAT(3X,I2,5X,A1,101A1)
        OT=0.
        DO 6310 LP=IR,14
        OL=OT
        OT=CLASS(LP)
        VAL=SID(LP)
        CALL HSGRPH(OT,OL,LP,VAL)
6310     CONTINUE
        OL=OT
        OT=0.
        LP=LP+1
        WRITE(2,6301)LP,0H,LINE
        DO 6302 LF=1,101
6302     LINE(LF)=0H
        WRITE(2,6303)END,0H,LINE
6303     FORMAT(3X,A3,4X,A1,101A1)
        WRITE(2,6304)
6304      FORMAT(///'  HISTOGRAM IS COMPLETED.              **********')
        GO TO 730
9099      WRITE(2,97)
97        FORMAT(/'    RUN ENDS.'/' ********     ********     ********')
        WRITE(2,540)MX
540      FORMAT(///'  THE TOTAL NUMBER OF CARDS WERE ',I4)
        WRITE (2,96)
96       FORMAT(6H *****,5X,5H*****)
        STOP
        END

END OF SEGMENT, LENGTH  1531, NAME  PCLANAL
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Programme .. continued ..

```
            SUBROUTINE HSGRPH(RT,RL,N,V)
            INTEGER BLANK,AST,OH,END
            DIMENSION LINE(101)
            COMMON/OHC/OMAX
            COMMON/IBLOCK/LINE,BLANK,AST,OH
             IRT=IFIX((RT*100.)/OMAX+0.1)
            IRL=IFIX((RL*100.)/OMAX+0.1)
            IF(IRL.EQ.0)IRL=1
            IF(IRT.EQ.0)IRT=1
            DO 640 J=1,101
  640        LINE(J)=BLANK
            IF(IRT-IRL)650,651,652
  650        DO 655 J=IRT,IRL
  655        LINE (J)=AST
            WRITE(2,642)V,OH.LINE
  642       FORMAT(1X,F8.3,1X,A1.101A1)
            JX=IRT+1
            DO 657 J=JX,IRL
  657        LINE(J)=BLANK
            GO TO 660
  651        LINE(IRT)=AST
            WRITE(2,642)V,OH,LINE
            GO TO 660
  652        DO 656 J=IRL,IRT
  656        LINE (J)=AST
            WRITE(2,642)V,OH.LINE
            JX=IRT-1
            DO 658 J=IRL,JX
  658        LINE(J)=BLANK
  660        WRITE(2,641)OH,LINE
  641       FORMAT(10X,A1,101A1)
            WRITE(2,641)OH,LINE
            WRITE(2,661)N,OH.LINE
  661       FORMAT(3X,I3,4X,A1,101A1)
            WRITE(2,641)OH,LINE
            WRITE(2,641)OH,LINE
            RETURN
            END

END OF SEGMENT, LENGTH   296, NAME  HSGRPH
```

```
            BLOCK DATA
            INTEGER BLANK,AST,OH
             DIMENSION LINE(101)
            COMMON/IBLOCK/LINE,BLANK,AST,OH
            DATA AST/1H*/,BLANK/1H /,OH/1H-/
          . END
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Programme .. continued ..

```
 0283                     FINISH
 END OF COMPILATION -   NO ERRORS

       S/C SUBFILE  : .    40 BUCKETS USED
    FIRST WORKFILE  :      56 BUCKETS USED
   SECOND WORKFILE  :      39 BUCKETS USED


 CONSOLIDATED BY XPCK 12B   DATE      17/01/74    TIME 04/33/04

 PROGRAM TEST
 EXTENDED DATA (22AM)
 COMPACT PROGRAM (DBM)
 CORE                  11776

                        SEG       PCLANAL
                        SEG       TAN
                        SEG       SQRT
                        SEG       FLOAT
                        CUP       IBLOCK
                        CUV       OUC
                        SEG       HSGRPH
                        SEG       IFIX
                        SEG       IBLOCK*
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output

```
    PARCEL ANALYSIS.
    THIS OFFICE IS BIRMINHAM  NUMBER    1
   OFF NO SW LB OZ LEN  WID   HT  STEEL COTTON RUBB SCAND

   1    1 1 2 4   6 20.2 16.0   3.4 11 25 27 40 27 40 35 55
   1    2 1 1 3   5 11.0  3.0   4.8  9 25 23 40 29 40 46 55
   1    3 1 2 9  10 16.2 14.6   8.6 10 25 24 40 27 40 34 55
   1    4 2 1 5  14 18.0  4.6   4.6  9 25 24 40 28 40 40 55
   1    5 1 1 2  12 17.0 10.0   6.0  9 25 25 40 29 40 37 55
   1    6 3 1 2   1 26.0 13.4   4.8 11 25 33 40 29 40 30 55
   1    7 1 1 2   1  5.4  4.4   4.4  9 25 24 40 29 40 44 55
   1    8 3 111   8 17.6 14.0   8.4 10 25 23 40 30 40 43 55
   1    9 1 1 5  14 16.0  8.2   7.6  9 25 23 40 30 40 41 55
   1   10 1 1 5   5 20.0 16.0   6.0 11 25 25 40 28 40 41 55
   1   11 1 218   6 14.6 13.2  11.2 10 25 23 40 28 40 41 55
   1   12 3 1 2   8  9.4  7.0   2.4 11 25 27 40 29 40 40 55
   1   13 3 1 9   2 17.0 11.0   6.6 10 25 23 40 30 40 36 55
   1   14 1 1 4  10  6.4  6.0   6.0 12 25 23 40 28 40 33 55
   1   15 1 1 5   5 15.0  3.6   9.0 10 25 25 40 33 40 46 55
   1   16 1 2 5  10  7.2  5.2   4.0 10 25 23 40 27 40 42 55
   1   17 1 1 3   8 16.4  5.0   2.6 11 25 23 40 27 40 38 55
   1   18 1 2 4   0 12.4  9.4   8.6 12 25 22 40 28 40 37 55
   1   19 1 1 3   6  9.0  9.0   3.4 12 25 28 40 29 40 30 55
   1   20 1 1 3   4 16.4 10.6   1.6 50 21 30 16 30 18 50 16
   1   21 1 116  12 12.4 10.2   4.0 11 25 23 40 32 40 36 55
   1   22 1 1 4   9 13.4  2.6   2.4 10 25 22 40 31 40 42 55
   1   23 2 1 1  10 31.2  2.8   2.8 11 25 23 40 30 40 41 55
   1   24 3 1 4  14 12.4  7.4   2.8 11 25 25 40 27 40 37 55
   1   25 1 1 4  14 14.6 11.6   5.0 10 25 24 40 30 40 46 55
   1   26 1 1 4   4 12.4  9.4   5.4 10 25 24 40 30 40 42 55
   1   27 1 2 8   3 23.2 12.0   8.0  9 25 26 40 30 40 47 55
   1   28 1 1 7   2 14.4 12.0  11.0 10 25 25 40 26 40 41 55
   1   29 1 221   4 20.2 31.0  21.2 11 25 92 34 52 04 74 15
   1   30 1 120  13 22.0 13.0   6.4 11 25 24 40 32 40 41 55
   1   31 1 1 2   5 13.6 11.4   1.6 10 25 23 40 27 40 35 55
   1   32 1 4 3  12 20.2 16.8   2.8 11 25 23 40 32 40 38 55
   1   33 1 2 2  14 12.4  9.8   1.6  9 25 24 40 31 40 40 55
   1   34 1 1 1  14 14.0  8.2   1.4 10 25 25 40 29 40 43 55
   1   35 1 1 3   1 10.4  7.0   6.0 10 25 23 40 31 40 45 55
   1   36 1 111  12 15.0  6.8   5.0 00 92 82 34 43 14 54 25
   1   37 3 1 2   0 13.0  6.4   4.2 12 25 28 40 29 40 41 55
   1   38 1 211  14 13.5  9.4   2.6 10 25 23 40 27 40 47 55
   1   39 1 1 2   8  9.0  6.0   3.0 11 25 26 40 30 40 44 55
   1   40 3 1 3   6 13.0  5.4   3.4 12 25 27 40 28 40 37 55
   1   41 3 1 3   8 26.2  9.0   4.0 11 25 24 40 29 40 43 55
   1   42 1 1 4   0 11.0  9.0   2.4 12 25 26 40 27 40 34 55
   1   43 1 1 1   9 14.6  7.8   2.0 11 25 26 40 29 40 45 55
   1   44 3 1 1  10 11.0  8.4   3.4 13 25 28 40 28 40 42 55
   1   45 1 211   0 18.2 13.2   8.6 10 25 23 40 31 40 30 55
   1   46 1 218  10 13.4  7.4   6.0 10 25 23 40 30 40 56 55
   1   47 1 1 2   0  9.4  6.6   7.2 11 25 23 40 29 40 44 55
   1   48 1 1 1   6  9.6  8.8   0.8 11 25 23 40 26 40 38 55
   1   49 1 1 2  14  5.8  5.2   3.6 10 25 22 40 32 40 43 55
   1   50 3 1 1  12 10.0  8.0   2.6 11 25 24 40 29 40 43 55
   1   51 1 2 6   2  9.0  7.0   8.6 10 25 23 40 28 40 42 55
   1   52 1 1 2   0  9.0  4.4   4.4 11 25 24 40 31 40 46 55
   1   53 1 110  14 14.0  5.4   3.0 10 25 24 40 30 40 43 55
   1   54 1 1 2  12 28.0  5.0   4.2 11 25 25 40 29 40 43 55
   1   55 1 1 2   5  9.4  6.6   5.2 11 25 25 40 27 40 30 55
   1   56 1 2 5   1  8.6  7.2   3.4 12 25 26 40 33 40 46 55
   1   57 1 1 8  13  8.0  7.2   4.0 10 25 23 40 29 40 30 55
   1   58 1 111   3  9.0  3.2   2.6 11 25 23 40 32 40 44 55
   1   59 1 2 2   4  7.6  7.4   7.6 11 25 24 40 29 40 40 55
   1   60 1 2 6  12 14.0 12.0   7.0  2 50 44 40 94 40 25 50
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output .. continued ..

```
1  61 1 2 2 12 13.6  5.4  4.4 11 25 23 40 28 40 30 55
1  62 1 1 5 12 10.0  9.6  9.0 11 25 25 40 27 40 35 55
1  63 1 1 1 11 15.6  7.0  2.8 12 25 29 40 27 40 35 55
1  64 1 111  1 16.0 11.4  7.8 10 25 23 40 29 40 30 55
1  65 1 1 4  4 18.2 11.6  6.6 11 25 23 40 31 40 30 55
1  66 1 111 12 15.0  9.4  4.8 10 25 22 40 31 40 41 55
1  67 1 111 10 13.0  9.4  7.4 10 25 22 40 31 40 40 55
1  68 1 2 3 14 10.0 10.0  6.4 11 25 22 40 28 40 40 55
1  69 1 2 3  0 12.6  9.4  1.6 12 25 26 40 31 40 50 55
1  70 3 1 1  8 12.6  4.0  2.6 12 25 26 40 28 40 30 55
1  71 1 1 1 12 18.0  6.6  3.2 12 25 23 40 32 40 41 55
1  72 1 1 8  8 15.6 11.4  6.6 11 25 24 40 32 40 44 55
1  73 3 1 2  0 35.0  3.2  3.2 12 25 24 40 31 40 38 55
1  74 3 1 3 12 20.4 13.0  6.0 12 25 26 40 30 40 30 55
1  75 1 2 2 14 22.2 10.0  1.6 11 25 30 40 30 40 42 55
1  76 1 213  4 15.6 10.8  3.2 12 25 23 40 29 40 46 55
1  77 1 1 6  0 16.0  9.0  3.0 11 25 23 40 31 40 42 55
1  78 1 2 4  0 15.0 10.6  4.6 11 25 22 40 28 40 41 55
1  79 1 1 1 14 10.4  7.2  2.4 10 25 24 40 31 40 48 55
1  80 1 2 7 10 18.2 13.2  1.6 11 25 27 40 32 40 41 55
1  81 2 1 1  3 12.0  4.6  4.6 13 25 22 40 27 40 40 55
1  82 1 2 5  6 12.0  4.8  5.6 11 25 23 40 30 40 47 55
1  83 1 1 3 12 14.6 11.2  4.8 11 25 29 40 29 40 43 55
1  84 1 2 7  2 10.4  3.6  6.8 12 25 23 40 29 40 43 55
1  85 3 1 5  4 19.0 17.0  5.8 11 25 27 40 28 40 45 55
1  86 1 2 2 12 28.8  5.0  3.2 12 25 23 40 31 40 46 55
1  87 1 115  0 12.6  9.0  4.6 11 25 23 40 30 40 44 55
1  88 3 1 3  8 14.0 11.6  7.0 10 25 24 40 28 40 42 55
1  89 2 112  4 29.0  6.0  6.0 12 25 23 40 31 40 51 55
1  90 1 2 8 11 16.4 12.4 12.4 11 25 22 40 32 40 36 55
1  91 6 1 5  0  5.0  6.0  5.6 11 25 23 40 27 40 40 55
1  92 1 1 1  6  7.4  5.2  2.0 11 25 24 40 27 40 37 55
1  93 1 2 9 12  7.4  6.8  5.6 11 25 22 40 28 40 41 55
1  94 1 1 4  8 10.0  7.0  6.2 12 25 22 40 27 40 38 55
1  95 1 111  0  8.6  6.6  3.6 11 25 23 40 34 40 46 55
1  96 1 1 4  8 10.2  7.6  2.6 13 25 27 40 29 40 42 55
1  97 1 1 2  0 10.6  8.4  2.6 11 25 26 40 30 40 45 55
1  98 3 1 3  3 18.8 13.8  2.0 11 25 27 40 30 40 41 55
1  99 1 1 9 12  7.6  5.4  3.6 12 25 23 40 29 40 30 55
1 100 1 2 8  0  7.6  5.4  4.6 12 25 23 40 28 40 35 55
1 101 1 2 2 10  7.0  4.0  6.4 13 25 23 40 27 40 37 55
1 102 1 2 2  6  9.4  7.6  2.0 12 25 22 40 28 40 34 55
1 103 3 1 8  2  9.4  6.2  4.6 13 25 22 40 31 40 35 55
1 104 1 1 8  0 12.6  6.6  3.6 12 25 24 40 32 40 44 55
1 105 1 1 6  2 15.2  6.6  2.6 10 25 23 40 31 40 47 55
1 106 3 1 2  4 12.0  7.0  5.0 11 25 25 40 29 40 46 55
1 107 1 2 7  4 10.4 10.6  9.6 11 25 23 40 30 40 44 55
1 108 1 1 2  4 14.4  9.4  1.0 12 25 29 40 27 40 40 55
1 109 3 1 3 10 14.0 11.6  2.4 12 25 26 40 28 40 41 55
1 110 1 1 6  4 16.0  6.6  3.0 11 25 23 40 32 40 48 55
1 111 1 114  2 10.6  8.0  5.0  9 25 22 40 33 40 42 55
1 112 1 1 2  8  9.4  6.8  2.4 12 25 24 40 26 40 38 55
1 113 1 1 3  0  7.0  4.0  3.0 11 25 23 40 32 40 47 55
1 114 1 1 4 12 11.0  8.0  2.2 10 25 25 40 32 40 47 55
1 115 1 2 2  5  7.6  5.6  2.2 11 25 24 40 31 40 41 55
1 116 1 1 2 10  7.4  4.6  4.0 12 25 23 40 26 40 40 55
1 117 3 1 2  4 13.0  9.2  1.2 12 25 30 40 26 40 36 55
1 118 1 210  0 12.8 11.6  8.6 11 25 23 40 29 40 44 55
1 119 1 2 7 14  9.6  7.6  7.2  9 25 22 40 33 40 43 55
1 120 1 1 5  8 19.0  7.6  5.0 12 25 28 40 28 40 43 55
1 121 1 2 1  8  5.0  5.0  5.2 12 25 23 40 29 40 32 55
1 122 1 2 5 12 10.6  6.2  5.6 10 25 25 40 31 40 47 55
1 123 1 2 2  4 16.2 10.6  5.0 11 25 27 40 32 40 40 55
1 124 2 1 1  2 24.4  3.0  1.0 12 25 23 40 28 40 41 55
1 125 1 112  3 14.2  5.8  5.2 12 25 23 40 30 40 38 55
1 126 3 1 2  3 12.6  7.6  2.0 12 25 31 40 28 40 41 55
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Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output .. continued ..

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1 127 1 1 3 13 20.4  9.4  5.0 10 25 26 40 31 40 51 55
1 128 1 1 7  4 17.8 12.0  5.2 11 25 23 40 32 40 43 55
1 129 1 2 6 12 14.0  7.8  4.2 11 25 15 40 35 40 36 55
1 130 1 2 2 10 12.6 12.4 11.8 12 25 22 40 27 40 34 55
1 131 3 1 1 10 17.4 11.6  6.0 11 25 30 40 30 40 44 55
1 132 1 1 5  0 13.0  9.8  3.0 12 25 33 40 23 40 30 55
1 133 1 112  6 16.6 11.6  3.6 10 25 23 40 32 40 47 55
1 134 1 2 9  4 20.2 15.6  3.4 12 25 23 40 28 40 36 55
1 135 3 1 3  0 26.4 13.0 11.6 11 25 27 40 29 40 45 55
1 136 1 2 3  2 13.2  5.8  4.6 12 25 23 40 31 40 44 55
1 137 1 1 1  0 13.2  3.4  2.4 12 25 27 40 26 40 40 55
1 138 1 1 1 10  8.0  6.6  2.4 12 25 24 40 23 40 42 55
1 139 1 2 5  4 11.0  8.6  1.3 12 25 24 40 29 40 41 55
1 140 1 2 9  8 12.0 11.6  3.4 12 25 23 40 30 40 47 55
1 141 1 1 1 14  9.8  8.0  3.0 13 25 27 40 26 40 39 55
1 142 1 2 7 14 13.2 13.0  8.2 11 25 23 40 33 40 46 55
1 143 1 217  6 15.2 12.4  7.2 12 25 22 40 34 40 45 55
1 144 2 114  0 31.0  5.2  5.2 13 25 23 40 33 40 47 55
1 145 3 1 1 10 15.4  7.4  5.4 13 25 28 40 29 40 42 55
1 146 1 1 1  4 13.0 12.0  2.2 12 25 24 40 32 40 51 55
1 147 1 118  2 18.0  8.0  6.6 11 25 23 40 31 40 40 55
1 148 1 112  8 15.0  9.0  8.0 12 25 23 40 33 40 45 55
1 149 1 2 4  4 11.2  9.0  1.4 42 50 44 40 14 40 35 50
1 150 1 1 7  8 15.6  8.6  7.0 13 25 24 40 20 40 36 55
1 151 1 218  7 19.0  6.6  6.6 11 25 23 40 28 40 36 55
1 152 1 1 3  8 30.4  7.2  1.4 11 25 24 40 29 40 42 55
1 153 1 1 4  0 21.0 12.0  4.6 12 25 28 40 30 40 43 55
1 154 1 116  0  8.6  7.0  4.0 12 25 23 40 29 40 36 55
1 155 1 2 7  4 11.0  8.6  2.8 11 25 22 40 31 40 45 55
1 156 1 1 2  4  6.6  4.4  3.2 11 25 25 40 32 40 40 55
1 157 1 2 5  4 11.0  8.4  2.0 11 25 23 40 28 40 38 55
1 158 1 2 2 10 13.0  6.4  5.6  9 25 23 40 29 40 44 55
1 159 1 2 1 13 10.2  9.2  3.4 11 25 26 40 29 40 30 55
1 160 1 1 3  4  7.6  7.0  4.4 12 25 24 40 27 40 35 55
1 161 1 113  6 12.0  8.6  9.2 10 25 25 40 31 40 44 55
1 162 1 1 6 12 12.0  7.4  6.6 11 25 23 40 29 40 37 55
1 163 1 1 6  8 17.0 17.0  1.6 11 25 25 40 27 40 36 55
1 164 1 112  4 19.0 16.0 10.2 10 25 23 40 33 40 44 55
1 165 1 1 4  0 20.0  7.2  3.0 12 25 27 40 31 40 45 55
1 166 1 2 4 13  9.0  5.0  5.4 10 25 13 40 33 40 37 55
1 167 1 2 4  5 13.4  5.4  3.0 11 25 23 40 29 40 48 55
1 168 1 4 4  4 12.6  9.8  2.0 13 25 23 40 29 40 31 55
1 169 1 1 2  9  8.8  7.6  3.2 10 25 24 40 28 40 40 55
1 170 1 110 14 11.2 11.0  1.8 12 25 20 40 30 40 35 55
1 171 1 110  0 14.0 10.0  9.2 10 25 25 40 31 40 46 55
1 172 1 1 1  9 14.4  3.0  2.0 12 25 23 40 30 40 44 55
1 173 1 1 8  4 10.0 10.0  7.0 11 25 23 40 32 40 43 55
1 174 1 2 4 12 14.6 11.0  9.2 12 25 23 40 29 40 47 55
1 175 2 1 2  0 12.0  3.2  3.2 11 25 22 40 28 40 48 55
1 176 1 114  5 15.2  7.0  7.4  9 25 26 40 32 40 47 55
1 177 1 1 1  8  6.2  6.2  3.0 12 25 23 40 26 40 30 55
1 178 3 1 1 13 14.0 14.0  5.4 12 25 24 40 27 40 37 55
1 179 3 1 6  5 26.0 15.6  4.0 10 25 26 40 30 40 52 55
1 180 3 1 5  2 14.0 12.0  9.2 10 25 23 40 30 40 40 55
1 181 3 1 1  8 12.0 10.0  6.6 11 25 27 40 30 40 40 55
1 182 1 212  5 16.8 15.2 10.3 11 25 23 40 29 40 31 55
1 183 1 1 3 14 12.6  2.2  2.4 11 25 23 40 31 40 40 55
1 184 1 2 7  4 13.0 10.0  6.0 12 25 23 40 30 40 44 55
1 185 3 1 3 13 11.2  7.0  4.0 12 25 25 40 23 40 40 55
1 186 1 2 3  9 14.2  4.8  5.2 12 25 24 40 31 40 40 55
1 187 1 1 1 11 12.2  6.6  4.0 10 25 26 40 32 40 40 55
1 188 1 211 14 13.8 12.8  6.4 13 25 23 40 35 40 41 55
1 189 1 1 8 14 14.0 11.4  2.2 12 25 22 40 29 40 36 55
1 190 1 2 0 13 15.2 10.6  2.4 11 25 28 40 31 40 43 55
1 191 4 110  8 27.4  4.0  4.0 12 25 23 40 31 40 42 55
1 192 1 1 2 10 13.2 12.6  2.0 12 25 27 40 27 40 36 55
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Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output .. continued ..

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 1 193 1 1 3 14 15.4 12.4  3.2 11 25 23 40 27 40 41 55
 1 194 1 1 7  0 12.4  9.0  4.0 11 25 22 40 33 40 46 55
 1 195 1 213 14 15.4 14.6 13.4 11 25 23 40 30 40 31 55
 1 196 1 1 2  5  4.8  3.6  2.2 11 25 23 40 31 40 37 55
 1 197 1 2 2  8  7.8  6.4  5.6 10 25 23 40 29 40 41 55
 1 198 1 1 5  3 12.0  9.6  5.2 11 25 23 40 29 40 43 55
 1 199 6 1 1  6  8.4  4.0  3.2 12 25 22 40 31 40 48 55
 1 200 2 1 2  0 12.2  3.0  3.0 10 25 23 40 29 40 45 55
 1 201 1 2 1 10 13.2  6.4  4.6 11 25 24 40 29 40 43 55
 1 202 1 2 1  2 19.2 13.0  0.8 12 25 23 40 32 40 45 55
 1 203 1 2 1  5 11.8 11.8  1.0 11 25 26 40 29 40 30 55
 1 204 1 1 2  3 10.8  9.2  1.8 12 25 25 40 26 40 30 55
 1 205 3 1 6  0 18.0 10.6  7.4 11 25 24 40 23 40 42 55
 1 206 1 1 2  9 17.0 15.0  5.4 11 25 23 40 30 40 44 55
 1 207 1 1 7  8 13.6 13.0  2.6 11 25 29 40 31 40 43 55
 1 208 1 110  0 11.2 11.4  8.2  9 25 24 40 33 40 43 55
 1 209 1 111 10 17.0  9.0  3.2 10 25 22 40 30 40 46 55
 1 210 1 210 14 12.4 12.4  6.4 13 25 23 40 32 40 45 55
 1 211 1 2 1 10  6.4  3.4  2.2 11 25 24 40 29 40 31 55
 1 212 1 2 7  4  8.4  6.4  6.6 12 25 22 40 29 40 42 55
 1 213 1 2 1 12 19.2 13.0  0.8 12 25 26 40 32 40 30 55
 1 214 1 2 1  5  9.6  4.8  3.2 11 25 22 40 32 40 37 55
 1 215 3 1 2 11 11.0  7.4  7.0 11 25 23 40 28 40 38 55
 1 216 1 1 7  0  9.0  7.0  5.6 11 25 23 40 27 40 36 55
 1 217 1 1 7  4 14.6 13.0  7.6 12 25 24 40 23 40 38 55
 1 218 1 2 9  3 17.0 12.0  8.8 12 25 23 40 35 40 40 55
 1 219 1 1 3  2 15.0  6.8  7.0 12 25 26 40 32 40 45 55
 1 220 1 211  2 11.6  9.0  3.4 10 25 24 40 35 40 40 55
 1 221 1 2 5  8 11.0  7.4  4.2 10 25 24 40 31 40 45 55
 1 222 1 116  8 23.2 13.0  5.4 10 25 24 40 31 40 46 55
 1 223 1 2 9 10 14.2  9.8  6.0 11 25 23 40 28 40 44 55
 1 224 3 1 3 14 16.6 10.0  5.6 12 25 25 40 29 40 42 55
 1 225 3 1 2  8 23.0 11.0  6.4 12 25 30 40 30 40 41 55
 1 226 1 1 5  2 12.0  9.2  5.4 12 25 24 40 29 40 41 55
 1 227 2 1 2 10 21.0  3.6  3.6 12 25 23 40 27 40 43 55
 1 228 1 1 3  3  7.2  5.4  2.8 11 25 23 40 28 40 36 55
 1 229 1 1 1 12  9.2  8.6  1.6 11 25 24 40 33 40 51 55
 1 230 1 1 2  4 15.8  5.2  2.0 11 25 25 40 29 40 43 55
 1 231 1 1 3 14  8.4  8.2  7.8 11 25 21 40 29 40 40 55
 1 232 1 1 2  3 14.4  9.8  1.8 13 25 27 40 29 40 42 55
 1 233 1 116 12 18.0 12.0  7.0 11 25 24 40 30 40 46 55
 1 234 1 2 1 10  9.2  6.2  2.8 11 25 23 40 29 40 44 55
 1 235 1 1 9  6 18.0 17.4  9.0 10 25 25 40 31 40 47 55
 1 236 1 1 3  1  9.0  6.2  2.4 12 25 28 40 30 40 45 55
 1 237 1 1 3 14  7.0  5.0  5.4 12 25 23 40 29 40 35 55
 1 238 3 1 9  6 21.6 14.6  2.6 10 25 23 40 32 40 44 55
 1 239 3 1 2 12 16.6 11.6  3.6 12 25 23 40 29 40 30 55
 1 240 6 3 2  6 10.6  5.6  4.0 10 25 31 40 30 40 40 55
 1 241 1 2 3  4 16.2  9.2  6.4 12 25 24 40 29 40 41 55
 1 242 1 2 2  1  8.6  5.4  5.4  8 25 23 40 30 40 38 55
 1 243 3 1 1 14  9.8  6.0  1.0 11 25 29 40 29 40 42 55
 1 244 1 2 4 11 10.6  7.8  3.8 10 25 22 40 30 40 36 55
 1 245 1 1 4 14 10.6  9.6  3.8 11 25 23 40 28 40 35 55
 1 246 1 1 4  6  8.4  4.2  3.2 11 25 26 40 30 40 47 55
 1 247 1 210  6 12.0  7.6  6.0 12 25 23 40 26 40 35 55
 1 248 1 221  3 21.6  5.0  2.6 12 25 22 40 28 40 40 55
 1 249 1 2 1  8 28.0 20.8  3.6 12 25 24 40 30 40 38 55
 1 250 1 2 7  0 24.0 12.4  6.4 12 25 23 40 32 40 36 55
 1 251 1 1 4 12 17.4 15.6  4.2 12 25 23 40 28 40 38 55
 1 252 1 210  8 15.4 12.0  8.6 11 25 23 40 30 40 44 55
 1 253 2 1 1 12 11.2  1.6  1.6 14 25 25 40 31 40 44 55
 1 254 1 1 3  4 13.6  9.4  1.6 13 25 24 40 33 40 44 55
 1 255 3 1 4  0 10.2  6.2  4.0 10 25 25 40 32 40 48 55
 1 256 3 111  6 17.4 14.0  8.4 10 25 23 40 30 40 43 55
 1 257 1 2 8  4 23.2 12.0  8.0  9 25 26 40 30 40 47 55
 1 258 1 111 14 15.0  6.3  5.0  9 25 23 40 31 40 42 55
 1 259 1 2 6  2  9.0  7.0  3.0 10 25 23 40 28 40 42 55
 1 260 3 1 1  8 12.6  4.0  2.6 12 25 26 40 28 40 36 55
 1 261 3 1 5  4 19.0 17.0  5.8 11 25 27 40 23 40 45 55
 1 262 1 1 9 12  7.6  5.4  3.6 12 25 23 40 29 40 30 55
 1 263 1 112  6 16.6 11.6  3.6 10 25 23 40 32 40 47 55
 1 264 3 1 3 14 11.2  7.0  4.0 11 25 25 40 23 40 40 55
 1 265 1 1 5  4 12.0  9.6  5.2 11 25 23 40 29 40 45 55
 1 266 1 1 7  0  9.0  7.0  5.6 11 25 23 40 27 40 36 55
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Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output .. continued ..

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1 267 2 1 2 10 21.0  3.8  3.8 12 25 24 40 27 40 43 55
1 268 1 2 8  2 16.0 13.0  9.4 11 25 24 40 32 40 44 55
1 269 1 211 14 21.6 15.2 10.0 11 25 23 40 30 40 44 55
1 270 1 1 2 12  0.6  3.8  3.8 10 25 27 40 31 40 40 55
1 271 1 121  5 13.6 10.0  6.4 12 25 24 40 28 40 36 55
1 272 2 3 9  8  4.2  5.6  5.6 11 25 23 40 31 40 44 55
1 273 1 1 4  0 20.8  3.4  2.8 13 25 27 40 29 40 41 55
1 274 1 1 4  5 19.2  7.2  3.6 13 25 27 40 27 40 43 55
1 275 1 1 2  0 10.0  7.4  1.2 12 25 23 40 27 40 35 55
1 276 1 2 6 12 13.6 10.6  4.6 12 25 23 40 28 40 37 55
1 277 1 1 3 12 11.2  5.6  5.4 12 25 -27 40 30 40 33 55
1 278 1 1 6  0 15.2 11.6  7.2 12 25 29 40 28 40 41 55
1 279 1 2 7  0 15.2 10.4 12.4 12 25 23 40 30 40 40 55
1 280 3 1 6  5 25.0 18.0  8.2 13 25 29 40 28 40 41 55
1 281 1 1 3  8  9.6  7.2  3.0 11 25 23 40 31 40 46 55
1 282 1 1 1  2 11.4  5.6  4.2 12 25 25 40 29 40 38 55
1 283 1 2 8  2 16.0 13.0  9.4 11 25 24 40 32 40 44 55
1 284 1 214  4 16.6 11.6  0.0 11 25 25 40 30 40 45 55
1 285 1 1 9 13 10.2  8.2  4.2  9 25 27 40 29 40 42 55
1 286 1 2 2  4  9.6  5.0  3.0 11 25 24 40 28 40 40 55
1 287 1 1 4  2 21.4  5.8  2.8 11 25 26 40 32 40 40 55
1 288 1 2 6 10 11.8  7.6  4.0 11 25 23 40 28 40 38 55
1 289 1 2 3  5 16.4  9.0  6.2 11 25 23 40 27 40 41 55
1 290 1 113  7 16.4 15.0  6.4 12 25 23 40 27 40 37 55
1 291 1 1 5  5 15.0  3.6  0.0 10 25 25 40 33 40 46 55
1 292 1 2 4  0 12.4  9.4  8.6 12 25 22 40 28 40 37 55
1 293 1 120 13 22.0 13.0  6.4 11 25 24 40 32 40 41 55
1 294 1 4 3 12 20.2 16.8  2.8 11 25 23 40 32 40 38 55
1 295 3 1 2  0 13.0  6.4  4.2 12 25 23 40 29 40 41 55
1 296 3 1 1 10 11.0  8.4  3.4 13 25 23 40 28 40 42 55
1 297 1 1 4  8 10.2  7.6  2.6 13 25 27 40 29 40 42 55
1 298 3 1 2  4 13.0  9.2  1.2 12 25 30 40 26 40 36 55
1 299 1 2 5  0 10.4  9.2  3.4 11 25 23 40 29 40 42 55
1 300 1 1 2  8 15.4 13.4  3.0 12 25 23 40 27 40 36 55
1 301 1 213  2 14.0  9.4  8.0 12 25 22 40 29 40 34 55
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1 303 1 1 2  2 14.4 11.4  4.0 12 25 23 40 29 40 40 55
1 304 1 1 6  0 13.0  9.0  3.0 12 25 23 40 28 40 36 55
1 305 3 1 1 14 12.0  8.0  2.0 13 25 33 40 29 40 41 55
1 306 3 1 4  2 18.0 11.0  7.0 12 25 29 40 29 40 42 55
1 307 3 1 2  0 13.0 10.4  2.4 12 25 26 40 27 40 36 55
1 308 1 1 5  8 10.4  7.6  5.2 10 25 25 40 32 40 45 55
1 309 1 2 2  4  8.0  8.0  3.8 11 25 24 40 30 40 46 55
1 310 1 1 1 14  8.6  7.4  4.0 12 25 25 40 29 40 35 55
1 311 1 2 2 13 19.4 16.6  3.6 12 25 23 40 27 40 30 55
1 312 1 2 4 14 12.6 12.4  4.8 10 25 20 40 30 40 30 55
1 313 1 2 1  8 40.4  3.4  3.4 17 25 23 40 30 40 43 55
1 314 1 2 2 12 24.0 13.2  0.4 12 25 30 40 29 40 30 55
1 315 1 211 14 21.6 15.2 10.0 11 25 23 40 30 40 44 55
1 316 1 1 8  6 27.4 17.2  1.4 12 25 27 40 28 40 38 55
1 317 1 2 2 12 22.2 16.2  2.0 11 25 29 40 30 40 30 55
1 318 1 2 3 10  6.8  5.0  2.6 12 25 24 40 28 40 30 55
1 319 1 2 3 14 16.0 12.4  6.0 12 25 24 40 31 40 40 55
1 320 1 1 3  0  8.0  3.0  2.2 12 25 18 40 28 40 33 55
1 321 1 1 2  2  7.6  5.8  4.0 12 25 23 40 27 40 34 55
1 322 1 2 2  8 12.6 12.6  6.4 11 25 27 40 32 40 45 55
1 323 1 1 5  2 12.4 10.8  3.0 12 25 24 40 27 40 35 55
1 324 1 1 1  4 10.6  8.4  1.0 13 25 31 40 29 40 43 55

1 325 1 214  0 17.4 13.2 10.4 11 25 23 40 30 40 42 55
1 326 6 1 3  4 15.0  6.6  4.6 11 25 24 40 31 40 45 55
1 327 1 2 5 12 11.0  7.6  3.4 12 25 23 40 31 40 42 55
1 328 1 1 5  0 20.0 16.2  2.6 12 25 23 40 27 40 34 55
1 329 1 1 4 14 20.2 16.4  4.6 11 25 27 40 28 40 38 55
1 330 3 1 0 14 17.0  9.0  2.8 12 25 26 40 27 40 35 55
                         MEAN                   STANDARD DEVIATION
  WEIGHT                 5.79                                 6.39
  LENGTH                14.20                                 5.40
  WIDTH                  9.07                                 3.78
  HEIGHT                 4.78                                 2.64
```

Continued overleaf ....

Appendix VII Data Checking & Histogram Plotting Output .. continued ..
showing Friction Angles & Coefficients.

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FRICTION MEAN VALUES.


 FOR WRAP MATERIAL CONSISTING OF PAPER    &  216.0 PARCELS IN GROUP.

FRICTION IS  11.79 DEGREES 0.2087 COEFFICIENT STATIC.    29.20 DEGREES 0.5610 COEFFICIENT SLIDING FOR STEEL
FRICTION IS  25.29 DEGREES 0.4725 COEFFICIENT STATIC.    39.78 DEGREES 0.8325 COEFF'CIENT SLIDING FOR COTTON
FRICTION IS  25.08 DEGREES 0.4681 COEFFICIENT STATIC.    40.49 DEGREES 0.8537 COEFFICIENT SLIDING FOR RUBBER
FRICTION IS  39.86 DEGREES 0.8350 COEFFICIENT STATIC.    54.68 DEGREES 1.4113 COEFFICIENT SLIDING FOR SCANDURA

 FOR WRAP MATERIAL CONSISTING OF CARDBD   &  108.0 PARCELS IN GROUP.

FRICTION IS  11.34 DEGREES 0.2006 COEFFICIENT STATIC.    30.48 DEGREES 0.5886 COEFFICIENT SLIDING FOR STEEL
FRICTION IS  25.25 DEGREES 0.4716 COEFFICIENT STATIC.    39.76 DEGREES 0.8320 COEFFICIENT SLIDING FOR COTTON
FRICTION IS  24.72 DEGREES 0.4604 COEFFICIENT STATIC.    40.96 DEGREES 0.8682 COEFFICIENT SLIDING FOR RUBBER
FRICTION IS  39.20 DEGREES 0.8157 COEFFICIENT STATIC.    54.34 DEGREES 1.4039 COEFFICIENT SLIDING FOR SCANDURA

 FOR WRAP MATERIAL CONSISTING OF SACKING  &    2.0 PARCELS IN GROUP.

FRICTION IS  10.50 DEGREES 0.1853 COEFFICIENT STATIC.    30.50 DEGREES 0.5890 COEFFICIENT SLIDING FOR STEEL
FRICTION IS  25.00 DEGREES 0.4663 COEFFICIENT STATIC.    40.00 DEGREES 0.8391 COEFFICIENT SLIDING FOR COTTON
FRICTION IS  27.00 DEGREES 0.5095 COEFFICIENT STATIC.    22.00 DEGREES 0.4040 COEFFICIENT SLIDING FOR RUBBER
FRICTION IS  40.00 DEGREES 0.8391 COEFFICIENT STATIC.    55.00 DEGREES 1.4281 COEFFICIENT SLIDING FOR SCANDURA

 FOR WRAP MATERIAL CONSISTING OF PLASTIC  &    4.0 PARCELS IN GROUP.

FRICTION IS  11.50 DEGREES 0.2035 COEFFICIENT STATIC.    31.00 DEGREES 0.6009 COEFFICIENT SLIDING FOR STEEL
FRICTION IS  25.00 DEGREES 0.4663 COEFFICIENT STATIC.    40.00 DEGREES 0.8391 COEFFICIENT SLIDING FOR COTTON
FRICTION IS  23.00 DEGREES 0.4245 COEFFICIENT STATIC.    35.25 DEGREES 0.7067 COEFFICIENT SLIDING FOR RUBBER
FRICTION IS  40.00 DEGREES 0.8391 COEFFICIENT STATIC.    55.00 DEGREES 1.4281 COEFFICIENT SLIDING FOR SCANDURA

 FOR WRAP MATERIAL CONSISTING OF WOOD     &    0.0 PARCELS IN GROUP.

 THERE ARE NO PARCELS IN THIS GROUP

 FOR WRAP MATERIAL CONSISTING OF SPARE    &    0.0 PARCELS IN GROUP.

 THERE ARE NO PARCELS IN THIS GROUP


  HISTOGRAM DATA.

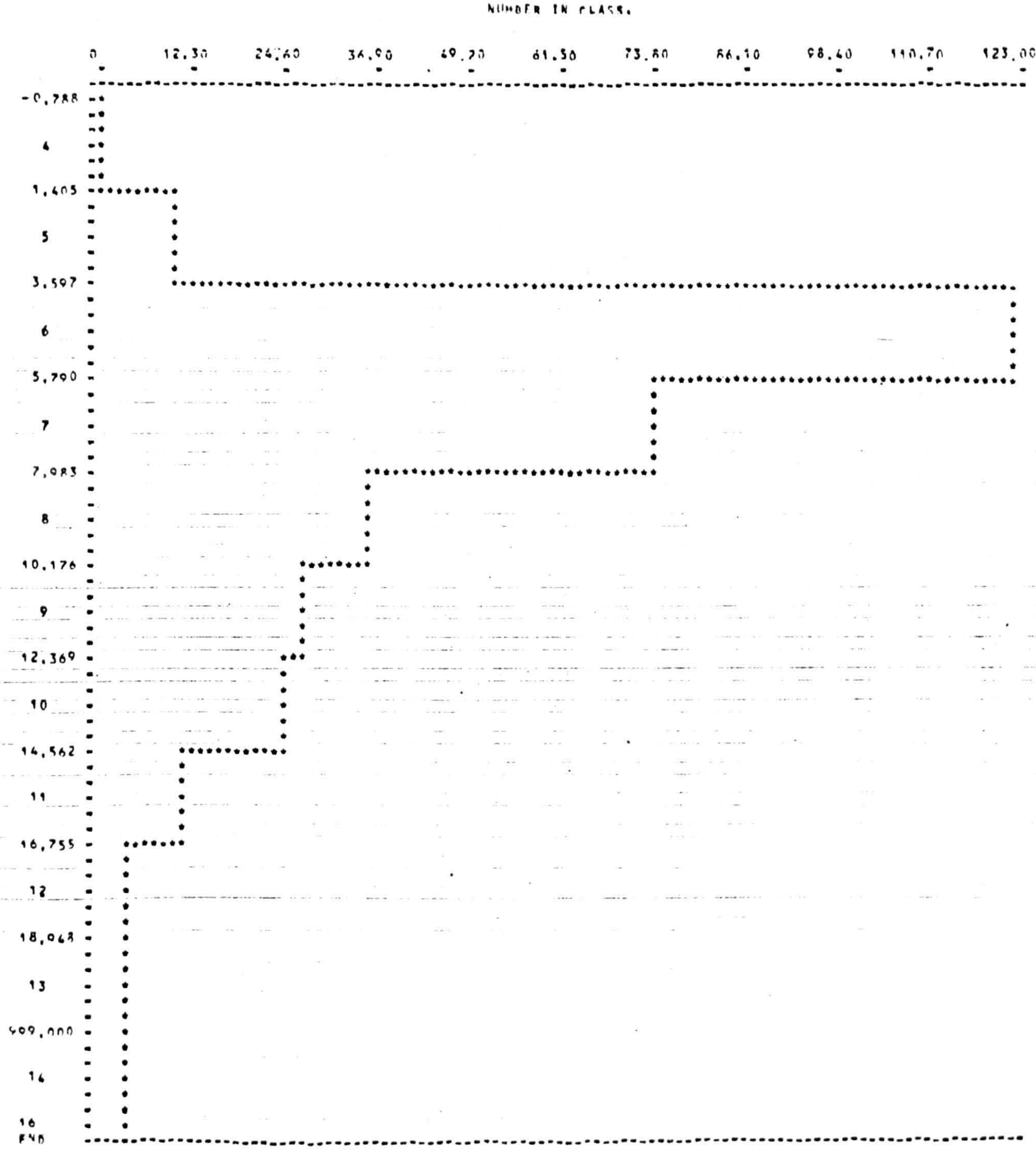
HISTOGRAM POINTS FOR WEIGHT      DIMENSION & NUMBER IN CLASS
    < -3.0         < -2.5         < -2.0         < -1.5         < -1.0         < -0.5         < MEAN
       -7.3672        -5.1742        -2.9613        -0.7384         1.4045         3.5974         5.7903
        0.0000         0.0000         0.0000         0.0000        12.0000       123.0000        75.0000
    < +0.5         < +1.0         < 1.5          < +2.0         < +2.5         < +3.0         > +3.0
        7.9833        10.1762        12.3691        14.5620        16.7549        18.9478       999.0000
       37.0000        29.0000        26.0000        13.0000         5.0000         5.0000         5.0000

DIMENSION WAS WEIGHT
MEAN        5.79  STANDARD DEVIATION      4.3858   VARIANCE     19.2355
 ALL FOR DATA ON WEIGHT
```

Continued overleaf ....

Appendix VII Histogram Plotting Output. The Histogram for Weight.

```
FREQUENCY DISTRIBUTION FOR WEIGHT
    RANGE OF WEIGHT    IS FROM      -2.362 TO       18.948
    UNIT OF CLASS INTERVAL IS        2.193
    MAXIMUM ORDINATE HEIGHT IS     123.000
```



```
HISTOGRAM IS COMPLETED.          *********
```

Continued overleaf ....

Appendix VII Histogram Plotting Output .... continued ....

```
HISTOGRAM POINTS FOR LENGTH  .   DIMENSION & NUMBER IN CLASS
   < -3.0          < -2.5          < -2.0          < -1.5          < -1.0          < -0.5          < MEAN
      -2.0132          0.5303          3.3047          6.0942          8.7046         11.4091         14.2135
       0.0000          0.0000          0.0000          6.0000         15.0000         72.0000         78.0000
   < +0.5          < +1.0          < 1.5           < +2.0          < +2.5          < +3.0          > +3.0
      16.9060         19.5064         22.3049         25.0113         27.7137         30.4162        999.0000
      57.0000         35.0000         24.0000          8.0000          6.0000          5.0000          6.0000

DIMENSION WAS LENGTH
MEAN        14.29  STANDARD DEVIATION        5.4049  VARIANCE      29.2129
 ALL FOR DATA ON LENGTH

      [illegible]
          RANGE OF LENGTH [illegible]           [illegible] TO        [illegible]
          UNIT OF CLASS INTERVAL IS         2.702
          MAXIMUM ORDINATE HEIGHT IS       78.000
```

The Histogram for Length of Parcels is shown on page 324 for ease of presentation.

```
HISTOGRAM IS COMPLETED.                  ..........

HISTOGRAM POINTS FOR WIDTH          DIMENSION & NUMBER IN CLASS
   < -3.0          < -2.5          < -2.0          < -1.5          < -1.0          < -0.5          < MEAN
      -2.2668         -0.3756         [illegible]     [illegible]     [illegible]     [illegible]     [illegible]

      FREQUENCY DISTRIBUTION FOR WIDTH
          RANGE OF WIDTH    IS FROM       -2.265 TO        20.411
          UNIT OF CLASS INTERVAL IS         1.890
          MAXIMUM ORDINATE HEIGHT IS       71.000
```

The Histogram for Width of parcels is shown on page 325 for ease of presentation.

```
HISTOGRAM IS COMPLETED.                  ..........

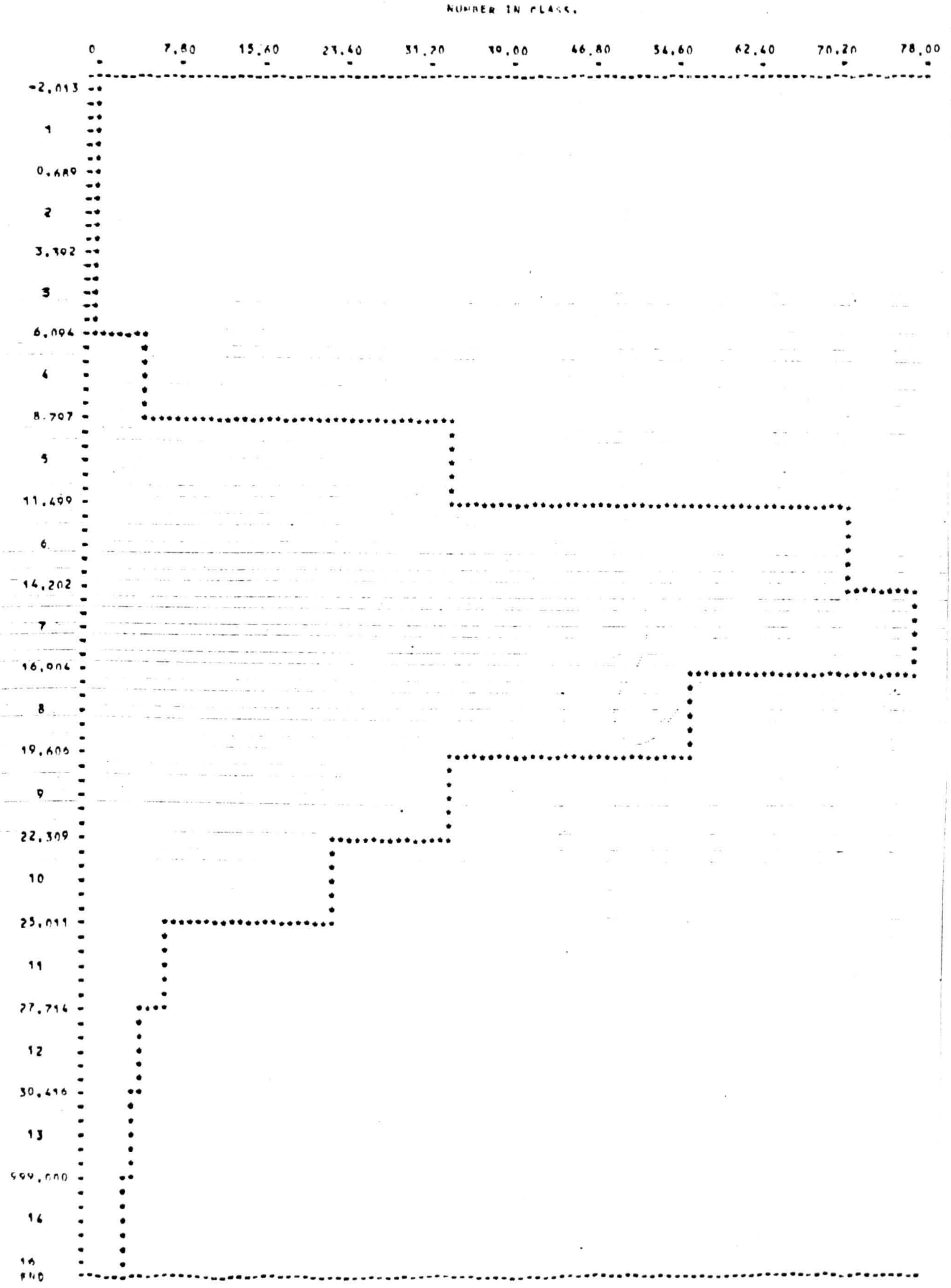
HISTOGRAM POINTS FOR HEIGHT         DIMENSION & NUMBER IN CLASS
   < -3.0          < -2.5          < -2.0          < -1.5          < -1.0          < -0.5          < MEAN
      -5.1139         -1.8149         -0.4152          0.8288          2.1427          3.6617          6.7106
       0.0000          0.0000          0.0000          6.0000         37.0000         84.0000         60.0000
   < +0.5          < +1.0          < 1.5           < +2.0          < +2.5          < +3.0          > +3.0
       6.0723          7.6155          8.7174         10.0966         11.3783         12.6542        999.0000
      56.0000         17.0000         24.0000         15.0000          5.0000          6.0000          2.0000
[illegible]
MEAN        [illegible]

      FREQUENCY DISTRIBUTION FOR HEIGHT
          [illegible]
          [illegible]
          MAXIMUM ORDINATE HEIGHT IS       36.000
```

The Histogram for Height of parcels is shown on page 326 for ease of presentation.

Continued overleaf ....

Appendix VII The Histogram for Length of Parcels.



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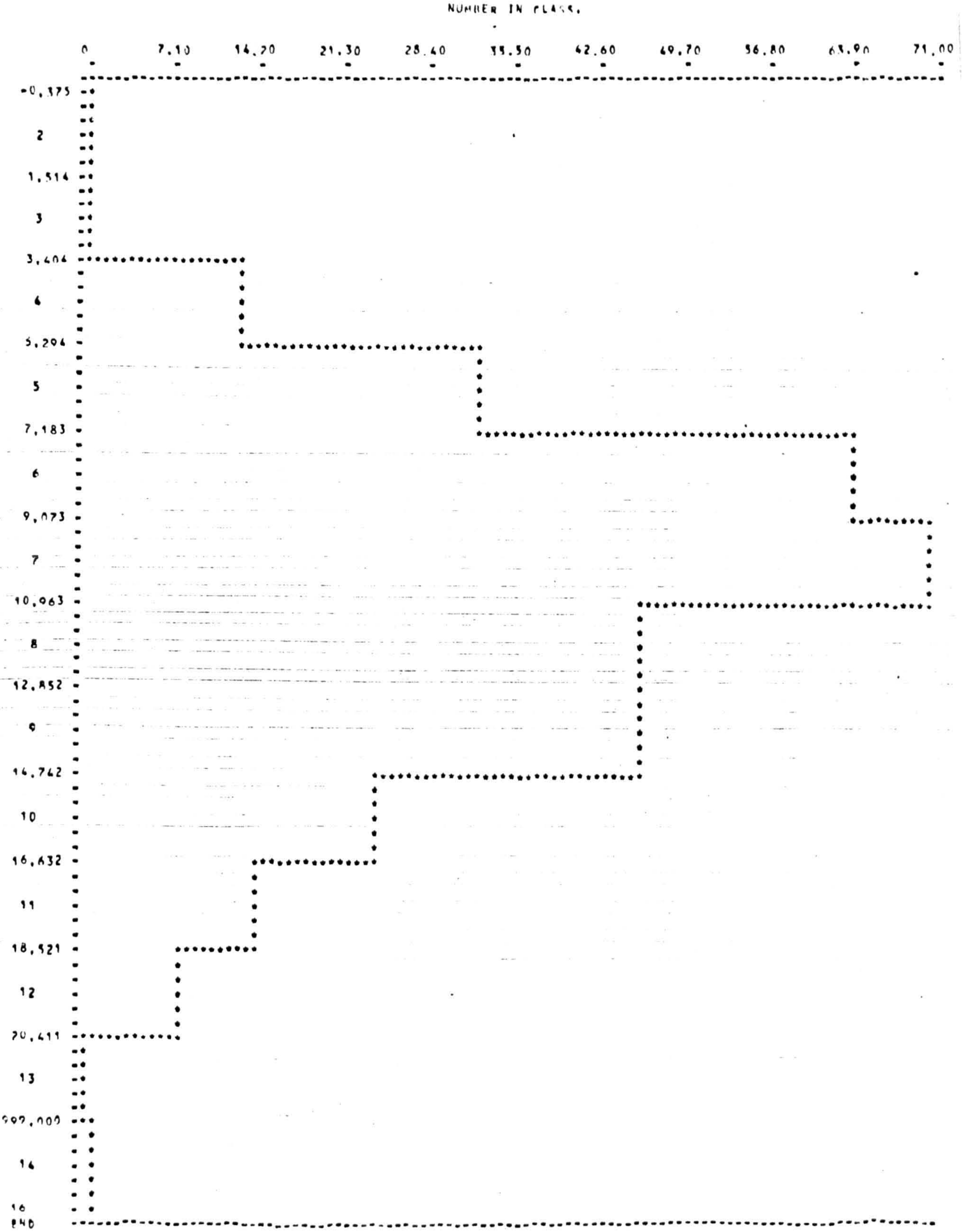
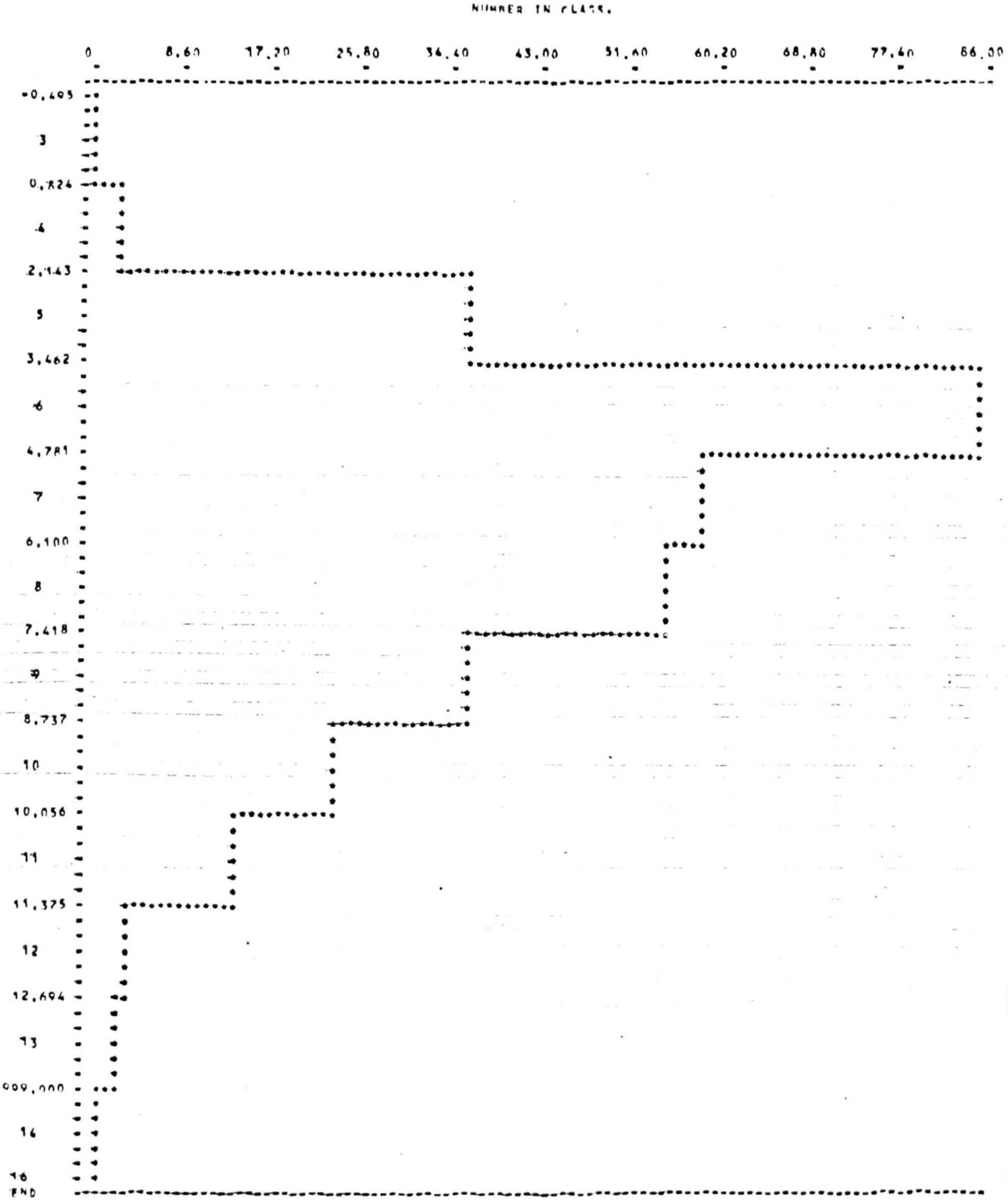
Appendix VII The Histogram for Width of Parcels.



Continued overleaf ....

Appendix VII The Histogram for Height of Parcels & conclusion of the Data Checking & Histogram Plotting Programme.



```
HISTOGRAM IS COMPLETED.        *********

 RUN ENDS.
********   ********   ********


THE TOTAL NUMBER OF CARDS WERE  330
*****   *****
```

APPENDIX VIII

RELATIVE HUMIDITY

APPENDIX VIII RELATIVE HUMIDITY

Relative Humidity is the ratio of the amount of water vapour in a sample of air to the amount of water vapour that the sample of air could hold at the temperature of measurement.

The Relative Humidity (RH) of the ambient conditions may be measured by means of a Wet and Dry Bulb thermometer. A diagram (Fig 8.1) is overleaf. If the air is saturated with respect to its surroundings, then both the wet bulb and dry bulb thermometers read the same temperature. If the ambient air is not saturated, however, the wet bulb thermometer gives a lower reading, because the bulb is cooled by evaporation, which removes the latent heat of vaporisation.

Tables are necessary to find the Relative Humidity. They will also give the Dew Point, which is the temperature at which condensation will occur in a given ambient condition, and also the Specific Humidity.

$$\underset{\text{at any temperature}}{\text{RELATIVE HUMIDITY}} = \frac{\text{Amount of Water Vapour in sample of air}}{\text{Amount of water the air could hold}} \times 100\%$$

$$\text{SPECIFIC HUMIDITY} = \frac{\text{Grammes of Water Vapour}}{\text{Grammes of Dry Air}}$$

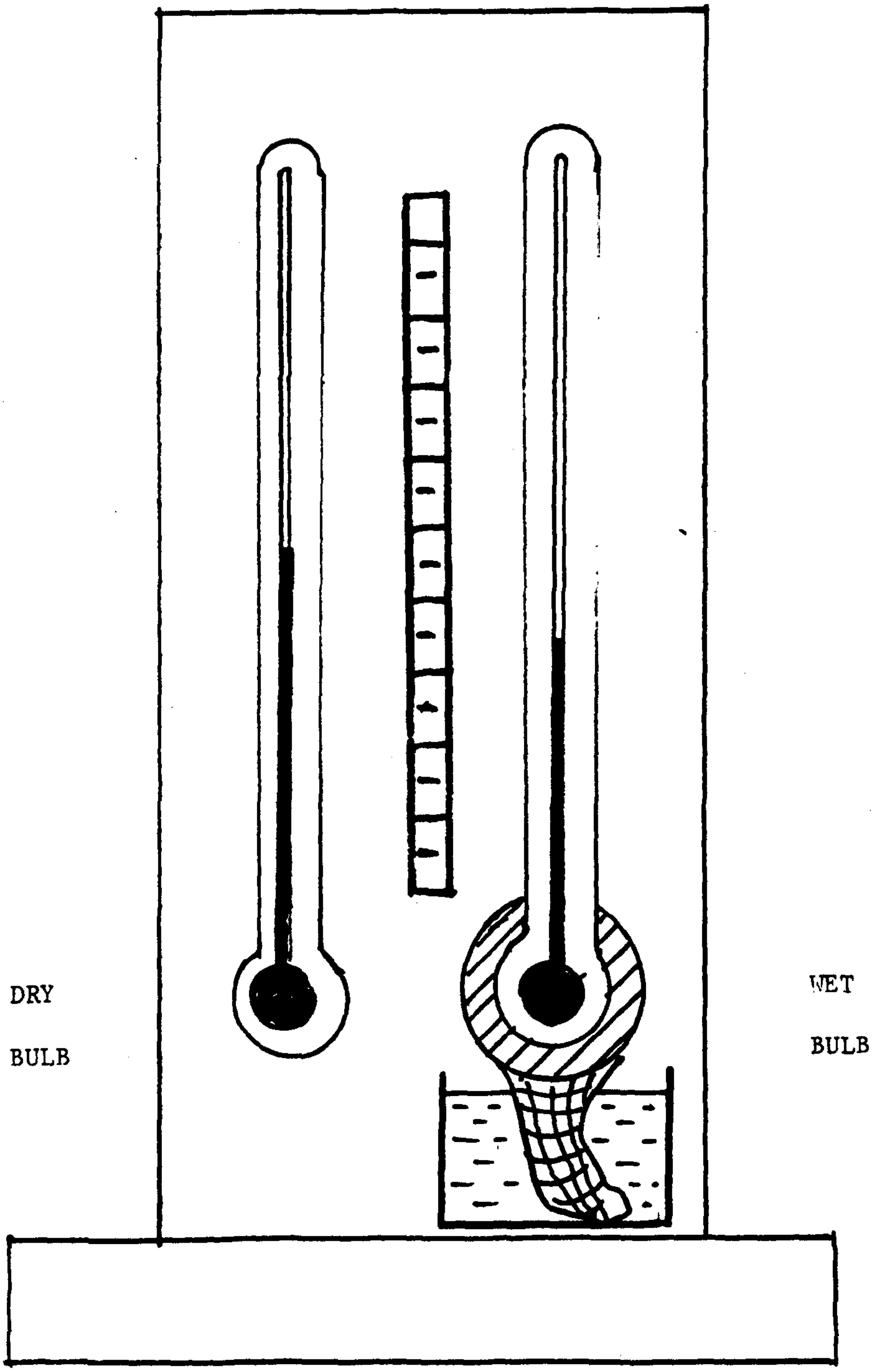


Figure 8.1 The Wet & Dry Bulb Thermometer for determining Relative Humidity.

APPENDIX IX

ILLUSTRATIONS, FIGURES & TABLES

Generally throughout the appendix, the dimensions of the parcel & conveyor length,width & height are in inches. The weights are in pounds.

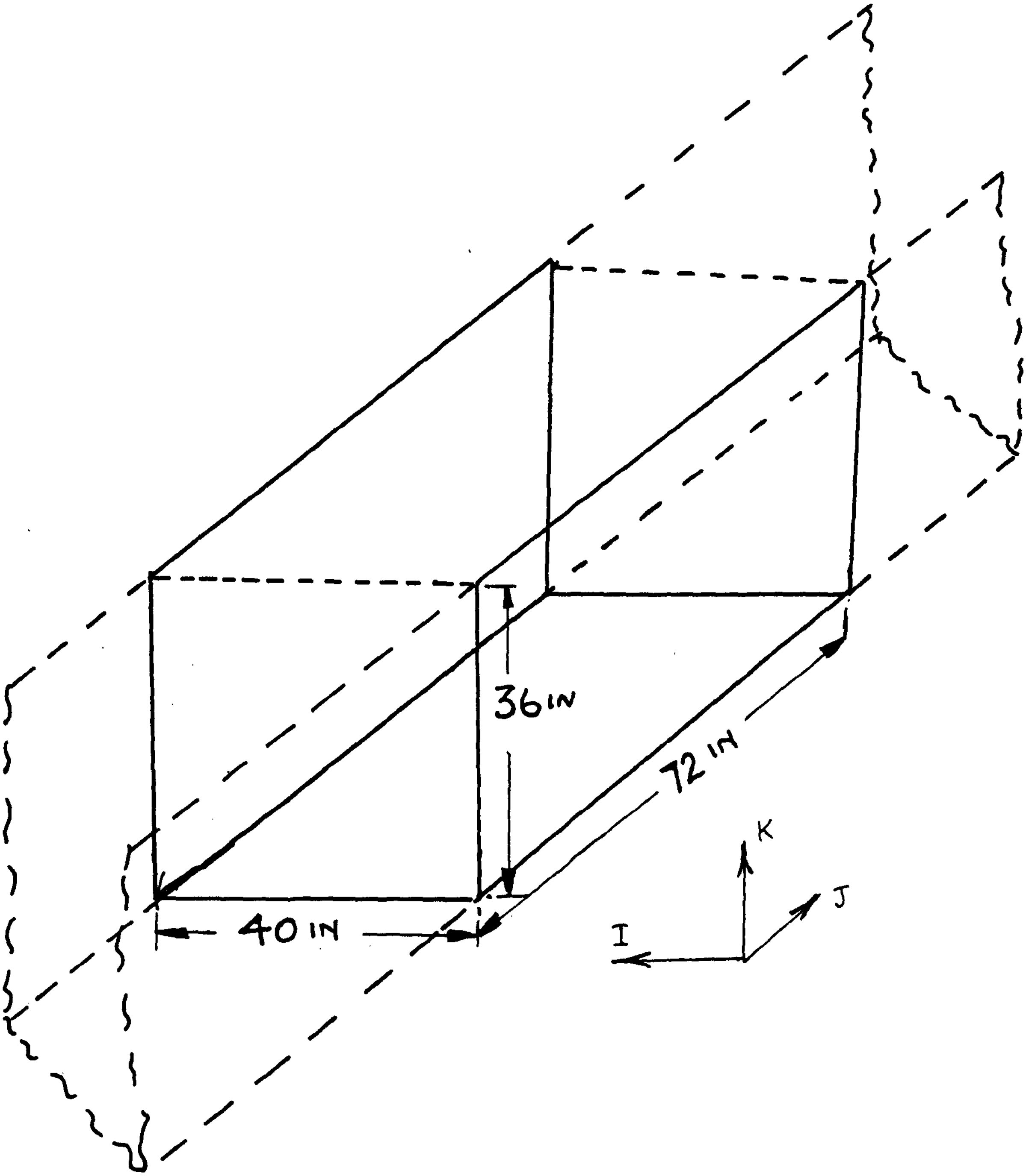


Figure 1.1 Sketch of the conveyor section which was modelled.

TABLE 1.2

Aspect Ratios of Simulated Belt Conveyor (See section 1.4.4.)

Computer	Ratio with Standard 40 inch section	Ratio on Transfer Conveyor section	Acceptable range of widths (inches)
ICL 1903A	1.8	0.25	32 - 53
CDC 7600	7.2	1.0	32 - 108

TABLE 1.3

Sample Parcel Data, obtained from Parcel and Packet Statistical Report. (Castellano, Clinch and Vick 1971) See section 1.5.

Office Number	Office	Number of Parcels
1	Birmingham	330
2	Brighton	381
3	Croydon	315
4	Liverpool	402
5	Manchester	419
6	North West P O	240
	Total	2087

VALUES OF MEAN (M) AND STANDARD DEVIATION (SD) OBTAINED FROM SAMPLES OF PARCELS

OFFICE	NO IN SAMPLE	WEIGHT LBS	LENGTH IN	WIDTH IN	HEIGHT IN	VALUE IN
1	330	5.79 4.39	14.2 5.40	9.07 3.78	4.78 2.64	M SD
2	381	5.71 4.17	15.2 5.17	9.82 3.22	4.99 2.69	M SD
3	315	4.51 3.81	14.45 6.37	8.69 3.51	4.53 2.71	M SD
4	402	5.03 4.25	14.78 6.09	9.65 3.33	4.26 3.04	M SD
5	419	4.90 3.38	15.04 5.64	9.79 3.66	4.51 2.35	M SD
6	240	5.50 4.23	15.21 6.41	8.95 3.46	4.73 2.59	M SD

Table 1.4 Values extracted from the results of the author's parcels data checking programmes. (See chapter 7) The data bank was created from the details of raw data used by Castellano, Clinch & Vick (1971)

Office	VALUE OF CRITICAL RATIO Z					
Office	1	2	3	4	5	6
1	▨	0.25	3.90	2.36	3.04	0.79
2	0.25	▨	3.96	2.26	3.00	0.60
3	3.90	3.96	▨	1.70	1.44	2.85
4	2.36	2.26	1.70	▨	0.48	1.36
5	3.04	3.00	1.44	0.48	▨	1.88
6	0.79	0.60	2.85	1.36	1.88	▨

Table 1.5 Matrix of Critical Ratios for comparison of standard error of the mean for any two samples. (Using the method of Conolly & Sluckin 1971) The results shown are for the mean weight of parcels, using table 1.4 as a basis. One Office is read from the columns, and one from the rows.

Office	1	2	3	4	5	6
1	▨	None	H.S.	J.S.	S.	None
2	None	▨	H.S.	J.S.	S.	None
3	H.S.	H.S.	▨	None	None	J.S.
4	J.S.	J.S.	None	▨	None	None
5	S.	S.	None	None	▨	None
6	None	None	J.S.	None	J.S.	▨

Where None = Not significant Value of Z less than 1.96

J.S. = Just significant Value of Z more than 1.96 or 5% level

S. = Significant " " Z " " 2.58 or 1% "

H.S. = Highly Significant " " Z " " 3.31 or 0.1% "

Table 1.6 The significance of the differences of the Mean Weights of any two samples from the various offices. Derived from table 1.5.

PROPERTY	F-RATIO	SIGNIFICANCE
Weight	5.32	Highly significant (H.S.)
Length	1.66	Not significant (None)
Width	6.53	Highly significant (H.S.)
Height	3.40	Significant (S.)

where Not significant = Value of F less than 2.20
Just significant = " " F more than 2.20 5% level
Significant = " " F " " 3.05 1% "
Highly significant = " " F " " 4.2 0.1% "

for 5 & 2081 degrees of freedom.

Table 1.7 Significance of difference of the means, considering all the Offices together by the One-way Analysis of Variance Method of Daniell & Terrell (1975)

Fig. 1.8 The BASIC language programme for the INTERDATA computer to calculate the values of the F-ratio for One-way Analysis of Variance.

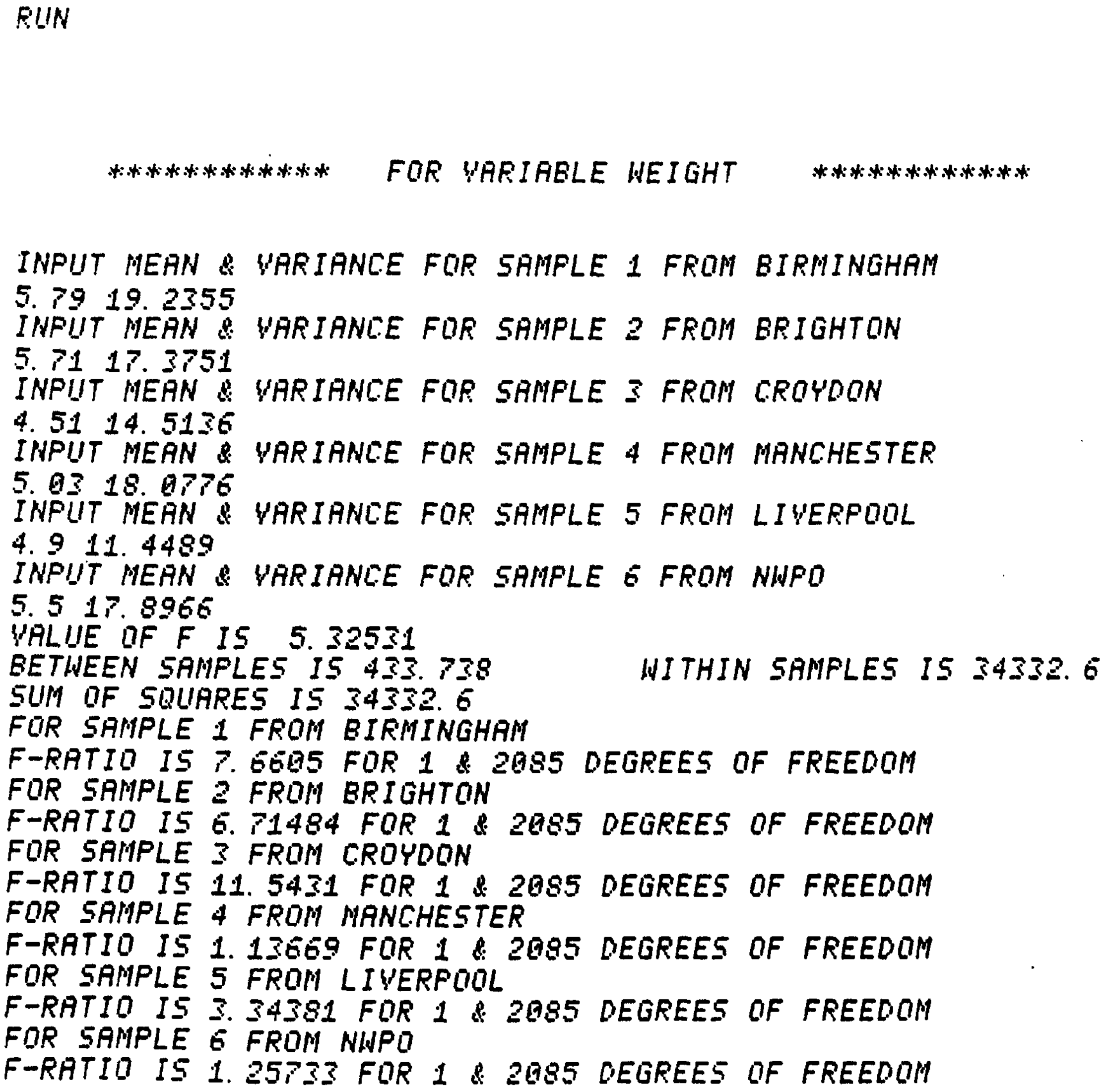
```
LIST
10 REM      ONE WAY ANALYSIS OF VARIANCE  F-TEST
20 DIM M(6),V(6),N(6),C(6)
30 DIM V1£(10,4),V£(10),O1£(25,6),O£(25)
40 V1£(1)="WEIGHT"
50 V1£(2)="LENGTH"
60 V1£(3)="WIDTH"
70 V1£(4)="HEIGHT"
80 O1£(1)="BIRMINGHAM"
90 O1£(2)="BRIGHTON"
100 REM      ANVAR  F-TEST PROGRAM
110 O1£(3)="CROYDON"
120 O1£(4)="MANCHESTER"
130 O1£(5)="LIVERPOOL"
140 O1£(6)="NWPO"
150 RESTORE
160 FOR I=1 TO 6
170 READ N(I)
180 NEXT I
190 FOR H=1 TO 4
200 X=0
210 N9=2087
220 C=0
230 B=0
240 V£=V1£(H)
250 ;
260 ;
270 ;
280 ;
290 ;"      ************   FOR VARIABLE";V£;"   ************"
300 ;
310 ;
320 FOR N=1 TO 6
330 ;"INPUT MEAN & VARIANCE FOR SAMPLE";N;"FROM";O1£(N)
340 INPUT M(N),V(N)
350 C=C+M(N)*N(N)
360 B=B+M(N)*M(N)*N(N)
370 NEXT N
380 M9=C
390 S=0
```

continued overleaf ....

Fig. 1.8 Continued ....

```
400 C=C*C/N9
410 FOR N=1 TO 6
420 V(N)=N(N)*(V(N)+M(N)*M(N))
430 S=S+V(N)
440 NEXT N
450 S=S-C
460 B=B-C
470 W=S-B
480 F=(B/5)/(W/(N9-6))
490 ;"VALUE OF F IS ";F
500 ;"BETWEEN SAMPLES IS";B;TAB(35),"WITHIN SAMPLES IS";S
510 ;"SUM OF SQUARES IS";S
520 FOR K=1 TO 6
530 V=M9-M(K)*N(K)
540 B3=M(K)*M(K)*N(K)+V*V/(N9-N(K))
550 B3=B3-C
560 W3=S-B3
570 F3=(B3/1)/(W3/(N9-2))
580 ;"FOR SAMPLE";K;"FROM";O1£(K)
590 ;"F-RATIO IS";F3;"FOR";"1";"&";N9-2;"DEGREES OF FREEDOM"
600 NEXT K
610 NEXT H
620 DATA 330,381,315,402,419,240
630 END
BASIC
```

Fig. 1.9 Results from the BASIC programme for evaluating F-ratio.



```
RUN


      ************   FOR VARIABLE WEIGHT    ************

INPUT MEAN & VARIANCE FOR SAMPLE 1 FROM BIRMINGHAM
5.79 19.2355
INPUT MEAN & VARIANCE FOR SAMPLE 2 FROM BRIGHTON
5.71 17.3751
INPUT MEAN & VARIANCE FOR SAMPLE 3 FROM CROYDON
4.51 14.5136
INPUT MEAN & VARIANCE FOR SAMPLE 4 FROM MANCHESTER
5.03 18.0776
INPUT MEAN & VARIANCE FOR SAMPLE 5 FROM LIVERPOOL
4.9 11.4489
INPUT MEAN & VARIANCE FOR SAMPLE 6 FROM NWPO
5.5 17.8966
VALUE OF F IS  5.32531
BETWEEN SAMPLES IS 433.738        WITHIN SAMPLES IS 34332.6
SUM OF SQUARES IS 34332.6
FOR SAMPLE 1 FROM BIRMINGHAM
F-RATIO IS 7.6605 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 2 FROM BRIGHTON
F-RATIO IS 6.71484 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 3 FROM CROYDON
F-RATIO IS 11.5431 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 4 FROM MANCHESTER
F-RATIO IS 1.13669 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 5 FROM LIVERPOOL
F-RATIO IS 3.34381 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 6 FROM NWPO
F-RATIO IS 1.25733 FOR 1 & 2085 DEGREES OF FREEDOM
```

For WEIGHT the F-ratio of 5.33 is Highly Significant at the 0.1% level, for 5 and 2081 degrees of freedom. (The F-ratio at 0.1% is 4.40)

Continued ....

Fig. 1.9 Continued .... Results for Length.

```
        ************   FOR VARIABLE LENGTH    ************

   INPUT MEAN & VARIANCE FOR SAMPLE 1 FROM BIRMINGHAM
   14.2 29.2129
   INPUT MEAN & VARIANCE FOR SAMPLE 2 FROM BRIGHTON
   15.2 26.7560
   INPUT MEAN & VARIANCE FOR SAMPLE 3 FROM CROYDON
   14.45 40.6139
   INPUT MEAN & VARIANCE FOR SAMPLE 4 FROM MANCHESTER
   14.78 37.1411
   INPUT MEAN & VARIANCE FOR SAMPLE 5 FROM LIVERPOOL
   15.04 31.7589
   INPUT MEAN & VARIANCE FOR SAMPLE 6 FROM NWPO
   15.21 41.0851
   VALUE OF F IS  1.66243
   BETWEEN SAMPLES IS 282.5          WITHIN SAMPLES IS 71008.3
   SUM OF SQUARES IS 71008.3
   FOR SAMPLE 1 FROM BIRMINGHAM
   F-RATIO IS 4.38609 FOR 1 & 2085 DEGREES OF FREEDOM
   FOR SAMPLE 2 FROM BRIGHTON
   F-RATIO IS 2.00961 FOR 1 & 2085 DEGREES OF FREEDOM
   FOR SAMPLE 3 FROM CROYDON
   F-RATIO IS 1.4655 FOR 1 & 2085 DEGREES OF FREEDOM
   FOR SAMPLE 4 FROM MANCHESTER
   F-RATIO IS .183519E-1 FOR 1 & 2085 DEGREES OF FREEDOM
   FOR SAMPLE 5 FROM LIVERPOOL
   F-RATIO IS .767384 FOR 1 & 2085 DEGREES OF FREEDOM
   FOR SAMPLE 6 FROM NWPO
   F-RATIO IS 1.23213 FOR 1 & 2085 DEGREES OF FREEDOM
```

For LENGTH the F-ratio of 1.66 is not significant, being well below the 5% level,..which is 2.27

Continued overleaf

Fig. 1.9 Continued ... Results for Width.

```
       ************   FOR VARIABLE WIDTH    ************

    INPUT MEAN & VARIANCE FOR SAMPLE 1 FROM BIRMINGHAM
    9. 07 14. 2829
    INPUT MEAN & VARIANCE FOR SAMPLE 2 FROM BRIGHTON
    9. 82 10. 34448
    INPUT MEAN & VARIANCE FOR SAMPLE 3 FROM CROYDON
    8. 69 12. 2917
    INPUT MEAN & VARIANCE FOR SAMPLE 4 FROM MANCHESTER
    9. 65 11. 0611
    INPUT MEAN & VARIANCE FOR SAMPLE 5 FROM LIVERPOOL
    9. 79 13. 3623
    INPUT MEAN & VARIANCE FOR SAMPLE 6 FROM NWPO
    8. 95 11. 9847
    VALUE OF F IS  6. 52965
    BETWEEN SAMPLES IS 399. 25        WITHIN SAMPLES IS 25847. 4
    SUM OF SQUARES IS 25847. 4
    FOR SAMPLE 1 FROM BIRMINGHAM
    F-RATIO IS 3. 29232 FOR 1 & 2085 DEGREES OF FREEDOM
    FOR SAMPLE 2 FROM BRIGHTON
    F-RATIO IS 6. 90965 FOR 1 & 2085 DEGREES OF FREEDOM
    FOR SAMPLE 3 FROM CROYDON
    F-RATIO IS 14. 862 FOR 1 & 2085 DEGREES OF FREEDOM
    FOR SAMPLE 4 FROM MANCHESTER
    F-RATIO IS 2. 68053 FOR 1 & 2085 DEGREES OF FREEDOM
    FOR SAMPLE 5 FROM LIVERPOOL
    F-RATIO IS 6. 72189 FOR 1 & 2085 DEGREES OF FREEDOM
    FOR SAMPLE 6 FROM NWPO
    F-RATIO IS 4. 279 FOR 1 & 2085 DEGREES OF FREEDOM
```

For WIDTH the F-ratio of 6.53 is Highly significant at the 0.1% level, which is 4.40 for 5 and 2081 degrees of freedom.

Continued overleaf ....

Fig. 1.9 Continued .... Results for Height.

```
        ************    FOR VARIABLE HEIGHT     ************

INPUT MEAN & VARIANCE FOR SAMPLE 1 FROM BIRMINGHAM
4. 78 6. 9584
INPUT MEAN & VARIANCE FOR SAMPLE 2 FROM BRIGHTON
4. 99 7. 2339
INPUT MEAN & VARIANCE FOR SAMPLE 3 FROM CROYDON
4. 53 7. 3491
INPUT MEAN & VARIANCE FOR SAMPLE 4 FROM MANCHESTER
4. 26 9. 2555
INPUT MEAN & VARIANCE FOR SAMPLE 5 FROM LIVERPOOL
4. 51 5. 5356
INPUT MEAN & VARIANCE FOR SAMPLE 6 FROM NWPO
4. 73 6. 7200
VALUE OF F IS  3. 41603
BETWEEN SAMPLES IS 123. 281        WITHIN SAMPLES IS 15143. 5
SUM OF SQUARES IS 15143. 5
FOR SAMPLE 1 FROM BIRMINGHAM
F-RATIO IS 1. 37558 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 2 FROM BRIGHTON
F-RATIO IS 8. 80243 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 3 FROM CROYDON
F-RATIO IS . 419048 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 4 FROM MANCHESTER
F-RATIO IS 8. 94671 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 5 FROM LIVERPOOL
F-RATIO IS . 884555 FOR 1 & 2085 DEGREES OF FREEDOM
FOR SAMPLE 6 FROM NWPO
F-RATIO IS . 449178 FOR 1 & 2085 DEGREES OF FREEDOM
BASIC
```

For HEIGHT the F-ratio of 3.42 is Significant at the 1% level, which is 3.15 for 5 and 2081 degrees of freedom.

	WEIGHT		LENGTH	
Office	F-ratio	Significance	F-ratio	Significance
1 Birmingham	7.66	S.	4.39	J.S.
2 Brighton	6.71	S.	2.01	None
3 Croydon	11.54	H.S.	1.47	None
4 Liverpool	1.14	None	0.02	None
5 Manchester	3.34	None	0.77	None
6 NWPO	1.26	None	1.23	None

	WIDTH		HEIGHT	
Office	F-ratio	Significance	F-ratio	Significance
1 Birmingham	3.29	None	1.38	None
2 Brighton	6.91	S.	8.80	S.
3 Croydon	14.86	H.S.	0.42	None
4 Liverpool	2.68	None	8.95	S.
5 Manchester	6.72	S.	0.88	None
6 NWPO	4.28	J.S.	0.45	None

where None = Not significant - Value of F less than 3.9
J.S. = Just Significant " "" " " over 3.9 at 5% level
S. = Significant " " " 6.7 " 1% ""
H.S. = Highly Significant " " " 10.9 " 0.1% "
for 1 and 2085 degrees of freedom.

Table 1.10 ONE-WAY ANALYSIS OF VARIANCE. Tables showing the F-ratio for comparison of the significance of difference in the means of Weight, Length, Breadth & Height of parcels samples from each of six offices.

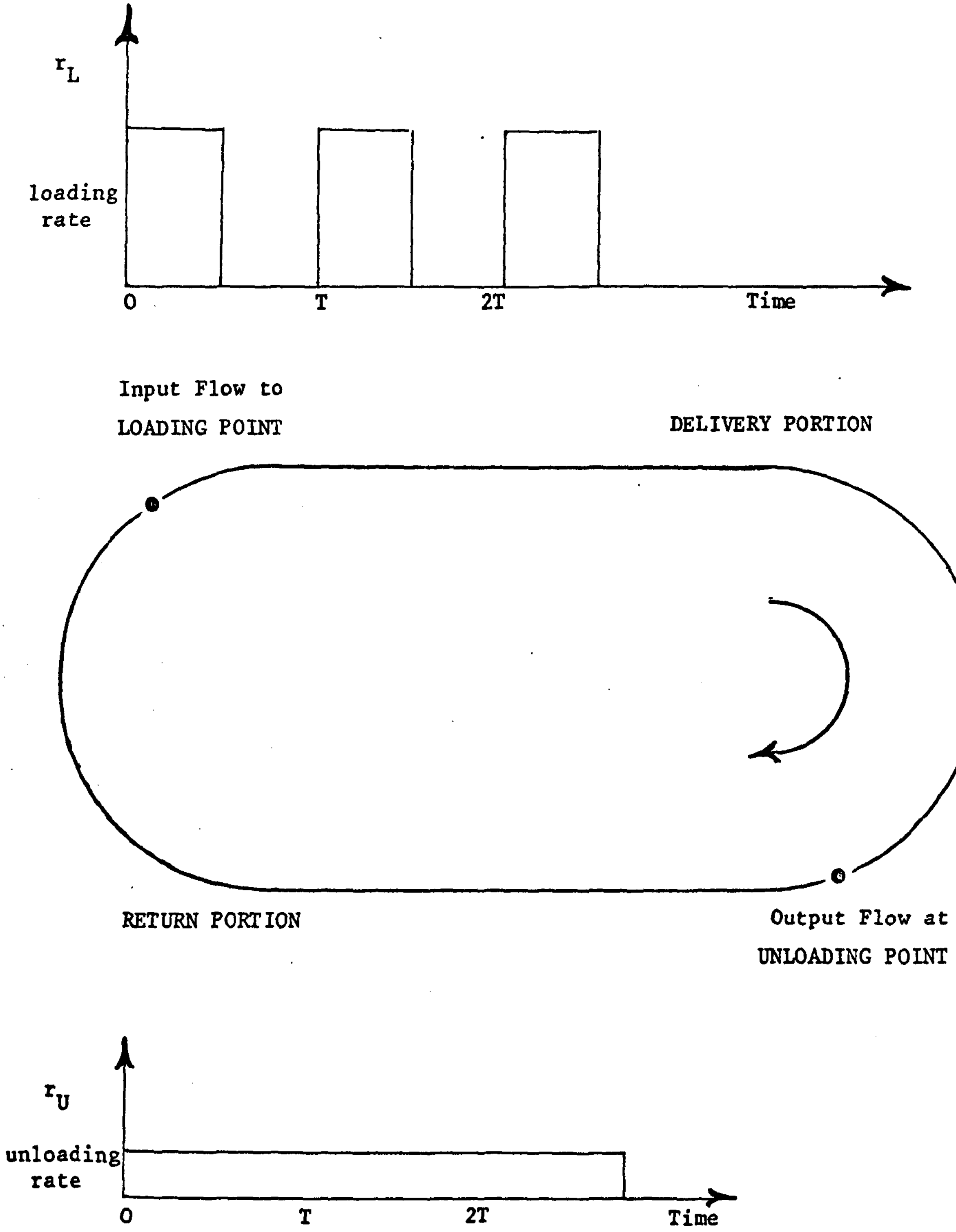
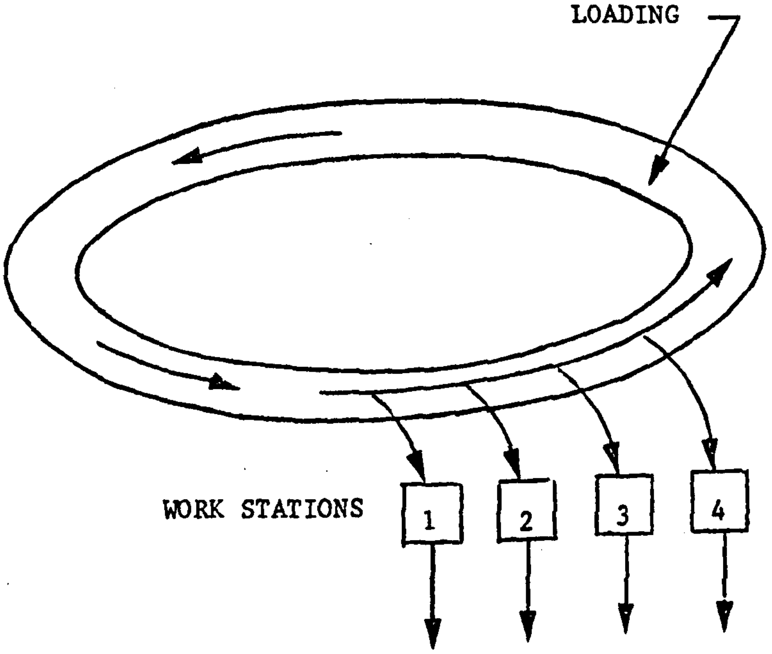


Fig. 2.1. The conveyor system studied by T. T. Kwo -
("A theory of Conveyors" Mgmt. Sci. 1959 V.6 1 51)



- A typical conveyor system

Fig. 2.2. The conveyor system studied by A. A. B. Pritsker, Rand Collection Report, No. P 3016.

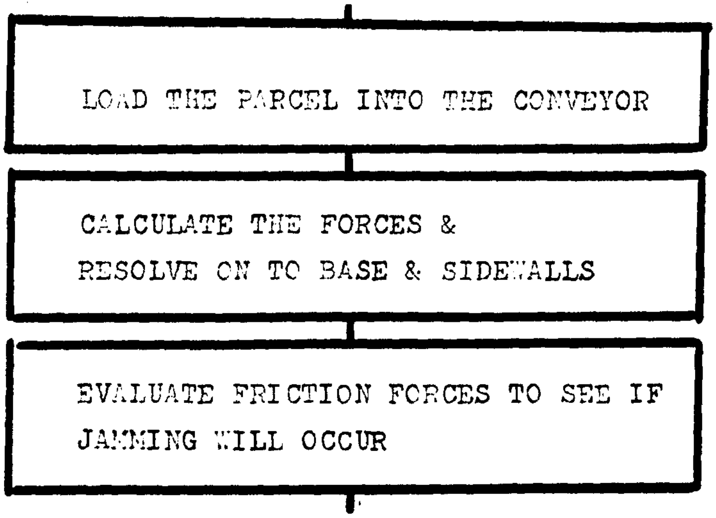
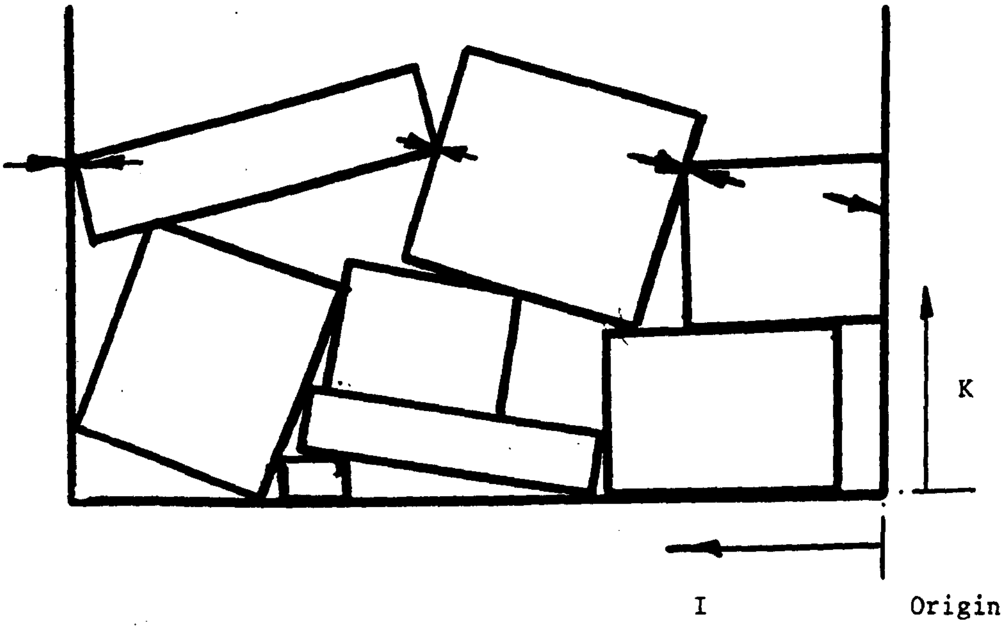


Fig 3.1 The three modules on which the simulation is based.

Fig 3.2 The concept of bridging which might be a cause of jamming, due to the arch of parcels.



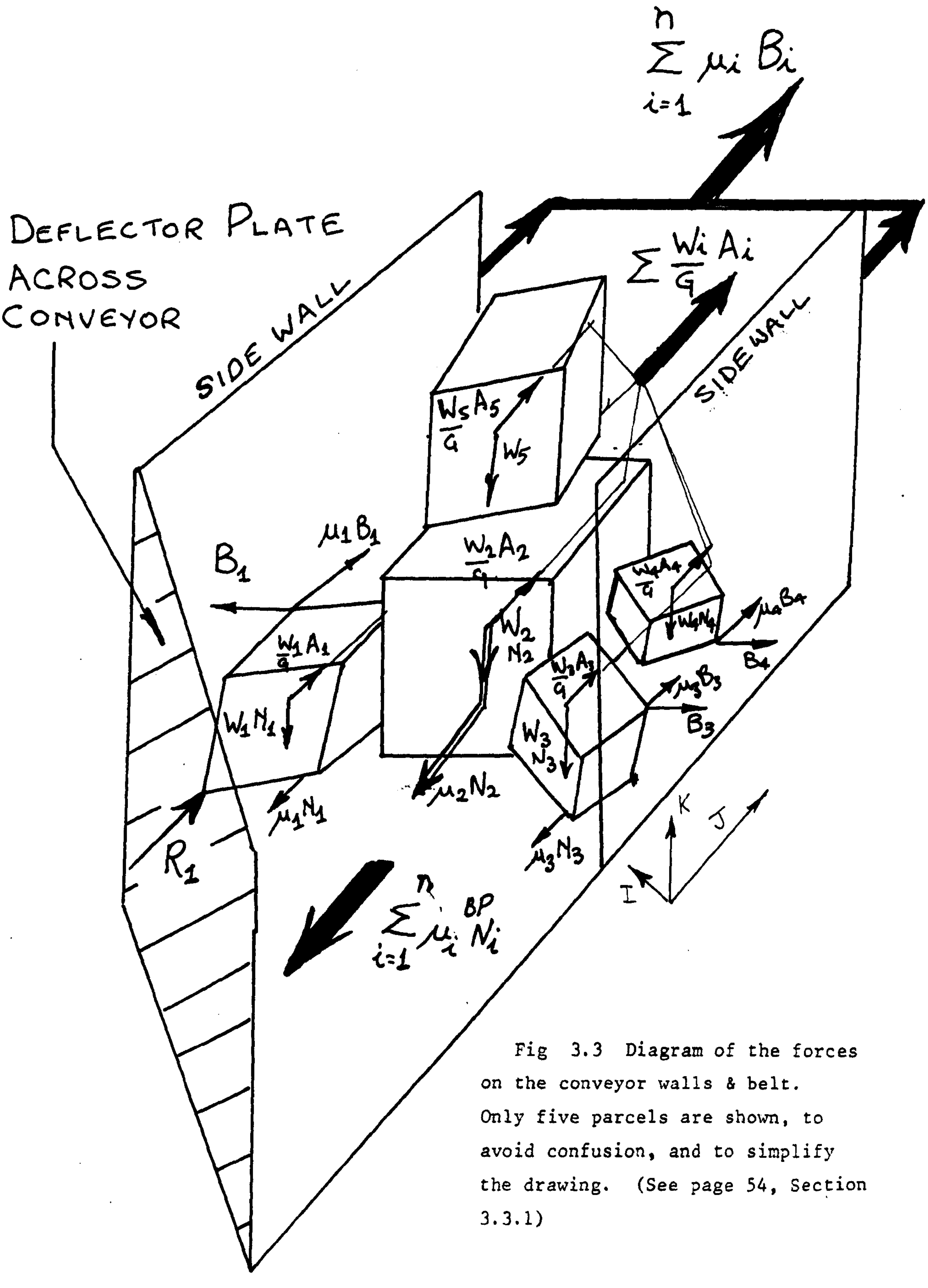


Fig 3.3 Diagram of the forces on the conveyor walls & belt. Only five parcels are shown, to avoid confusion, and to simplify the drawing. (See page 54, Section 3.3.1)

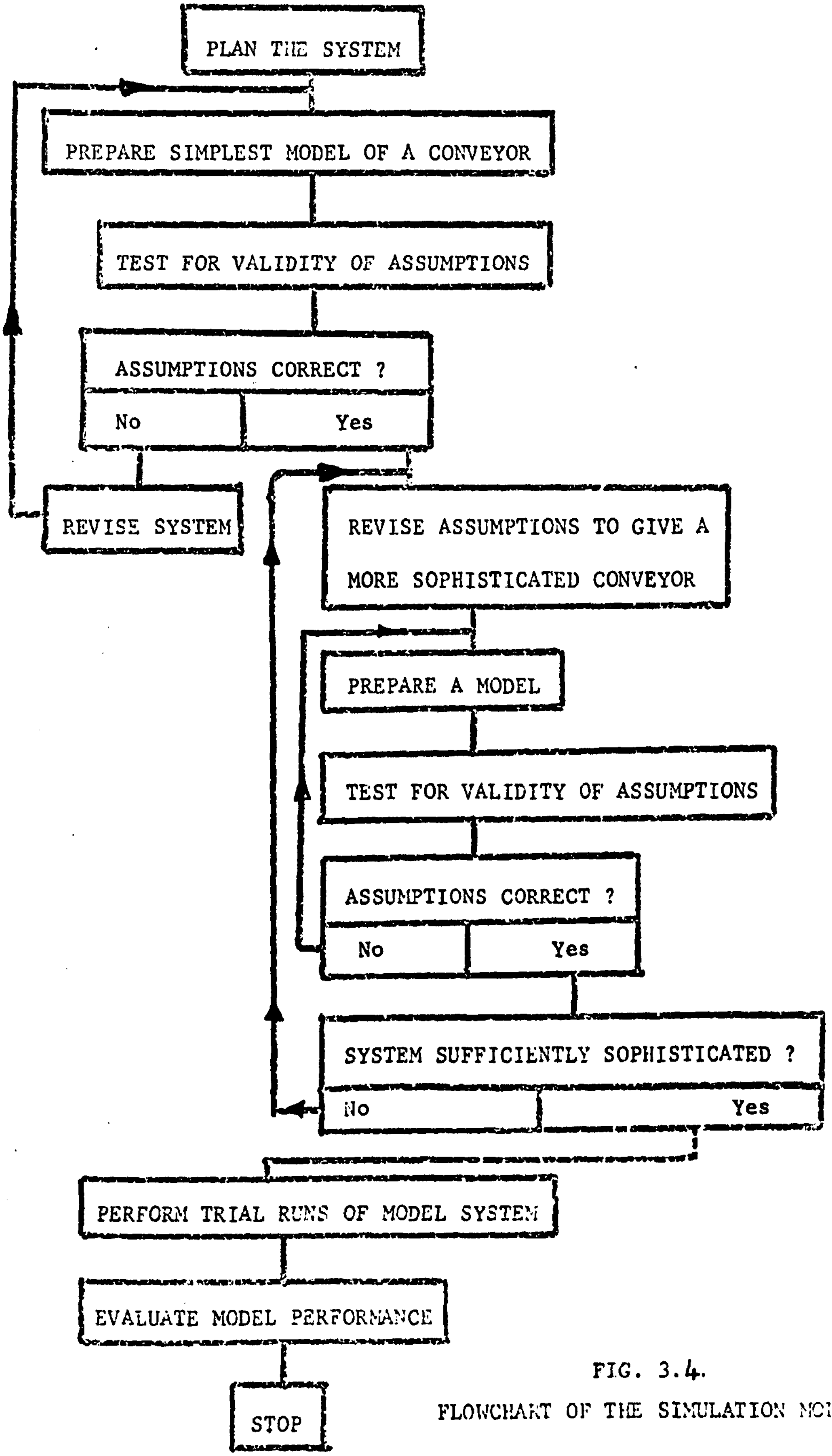
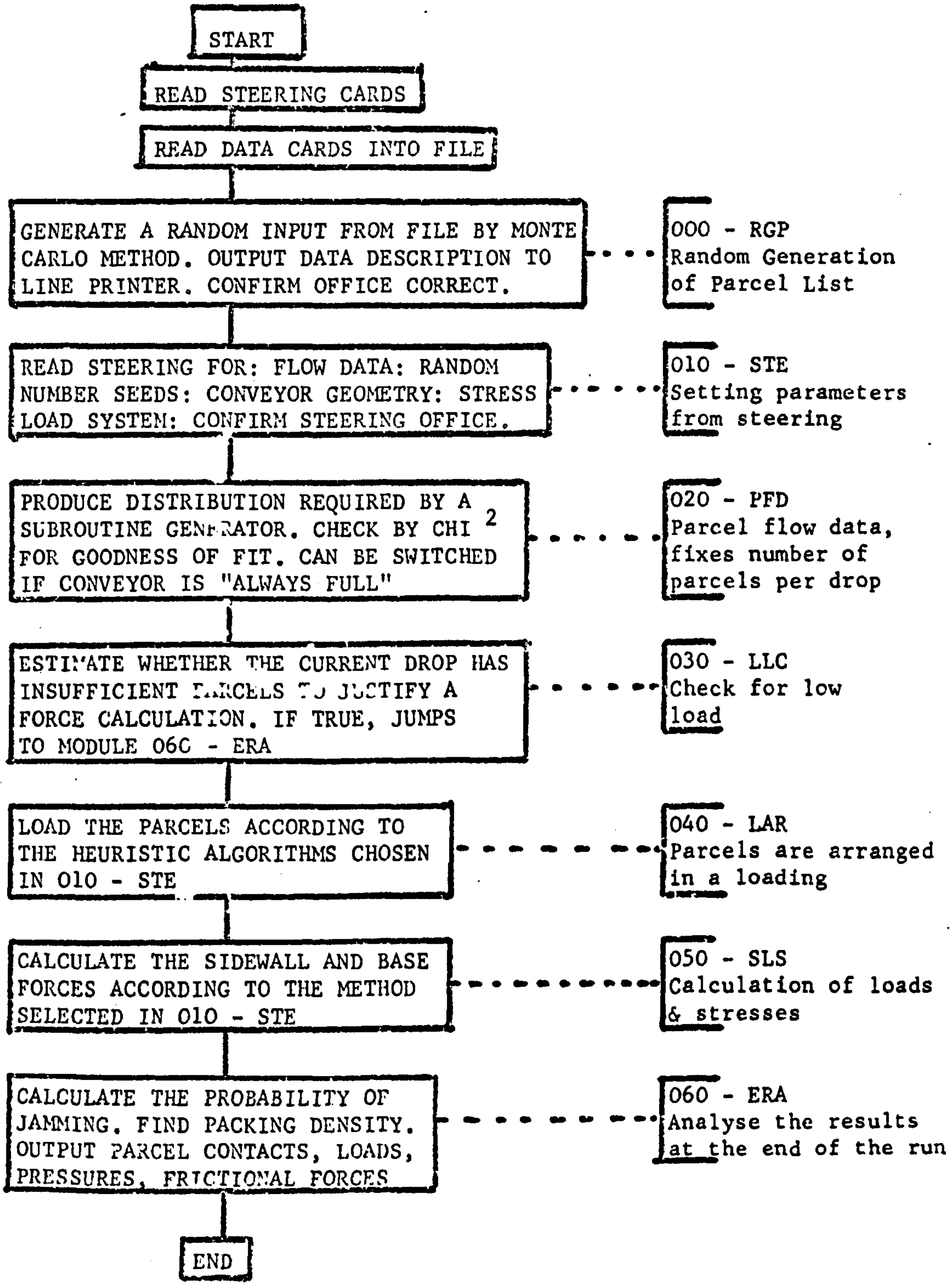


FIG. 3.4.

FLOWCHART OF THE SIMULATION MODEL



GENERATE A RANDOM INPUT FROM FILE BY MONTE CARLO METHOD. OUTPUT DATA DESCRIPTION TO LINE PRINTER. CONFIRM OFFICE CORRECT.

000 - RGP Random Generation of Parcel List

READ STEERING FOR: FLOW DATA: RANDOM NUMBER SEEDS: CONVEYOR GEOMETRY: STRESS LOAD SYSTEM: CONFIRM STEERING OFFICE.

010 - STE Setting parameters from steering

PRODUCE DISTRIBUTION REQUIRED BY A SUBROUTINE GENERATOR. CHECK BY CHI ^{2} FOR GOODNESS OF FIT. CAN BE SWITCHED IF CONVEYOR IS "ALWAYS FULL"

020 - PFD Parcel flow data, fixes number of parcels per drop

ESTIMATE WHETHER THE CURRENT DROP HAS INSUFFICIENT PARCELS TO JUSTIFY A FORCE CALCULATION. IF TRUE, JUMPS TO MODULE 060 - ERA

030 - LLC Check for low load

LOAD THE PARCELS ACCORDING TO THE HEURISTIC ALGORITHMS CHOSEN IN 010 - STE

040 - LAR Parcels are arranged in a loading

CALCULATE THE SIDEWALL AND BASE FORCES ACCORDING TO THE METHOD SELECTED IN 010 - STE

050 - SLS Calculation of loads & stresses

CALCULATE THE PROBABILITY OF JAMMING. FIND PACKING DENSITY. OUTPUT PARCEL CONTACTS, LOADS, PRESSURES, FRICTIONAL FORCES

060 - ERA Analyse the results at the end of the run

FIG. 3.5 FLOWCHART OF PROPOSED MODEL SYSTEM

Showing division into modules.

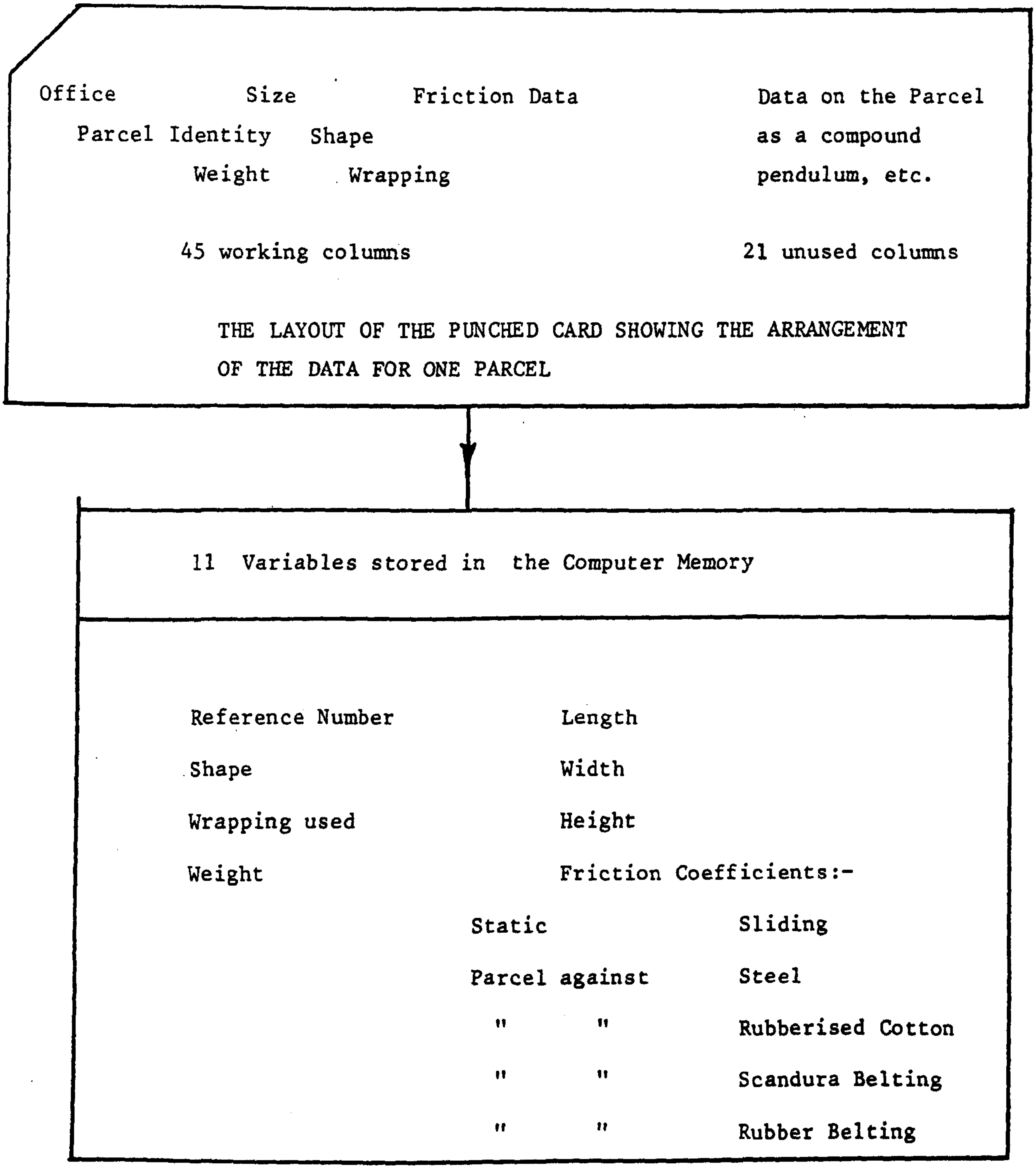


Fig 3.6 The Data Matrix (See Section 3.4 page 67)

TABLE FOR A PARCEL OF 64 CUBIC UNITS & RECTANGULAR SIDES, SHOWING THE EFFECT OF SHAPE UPON THE SHAPE FACTOR WITH VOLUME CONSTANT

Dimension (units)	Shape	Area (units^2)	Shape Factor S_v
4 x 4 x 4	Cube	96	0
8 x 2.828 x 2.828	Rod	106.5	0.138
16 x 2 x 2	Rod	136	0.660
40 x 1.265 x 1.265	Rod	205.6	2.540
64 x 1 x 1	Rod	258	4.330
8 x 8 x 1	Plate	160	0.416
16 x 16 x 0.25	Plate	272	1.69

Table 3.7 The effect of change of shape of a rectangular parcel upon the Shape Factor S_v. (See page 68, Section 3.4.1)

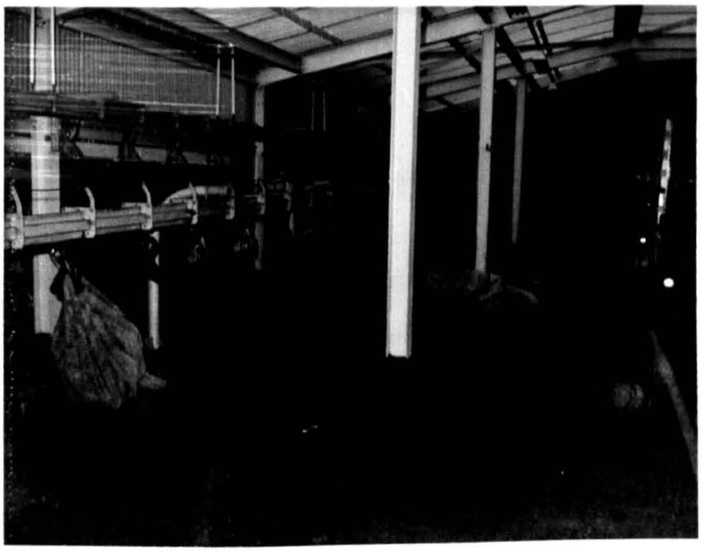


FIG. 4.1. UNIT CONVEYOR CARRYING BAGS FROM UNLOADING BAY TO THE CONVEYOR SYSTEM.

FIG. 4.2. TRANSFER CONVEYOR ON TO WHICH THE BAGS ARE UNLOADED

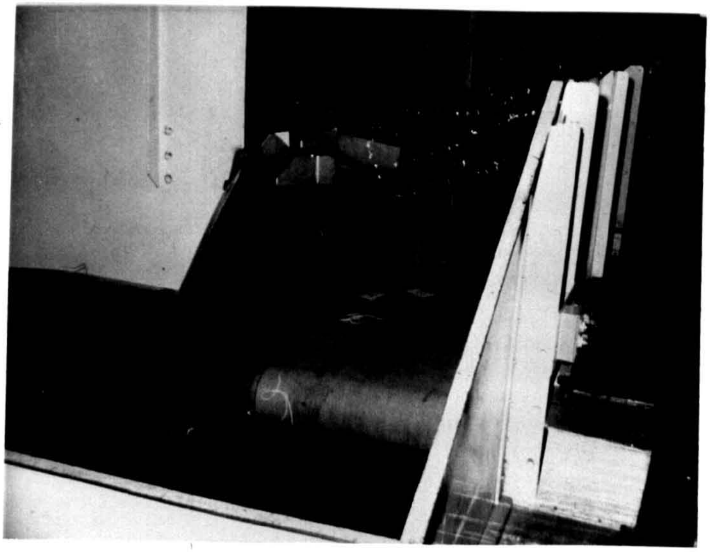


FIG. 4.3. THE 'L' TURN AS ONE BELT CONVEYOR TRANSFERS TO ANOTHER. IN THE BACKGROUND PARCELS ARE DROPPING OFF THE TRANSFER CONVEYOR ON TO THE BELT CONVEYOR

FIG. 4.4. TRANSFER FROM BELT TO GLACÉ

FIG. 4.5. A JAM ON A GLACÉ WHICH NEARLY REACHES THE BELT

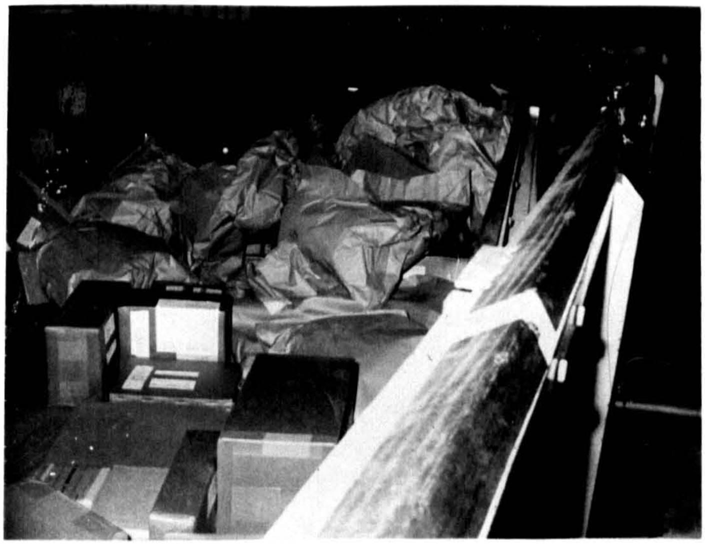
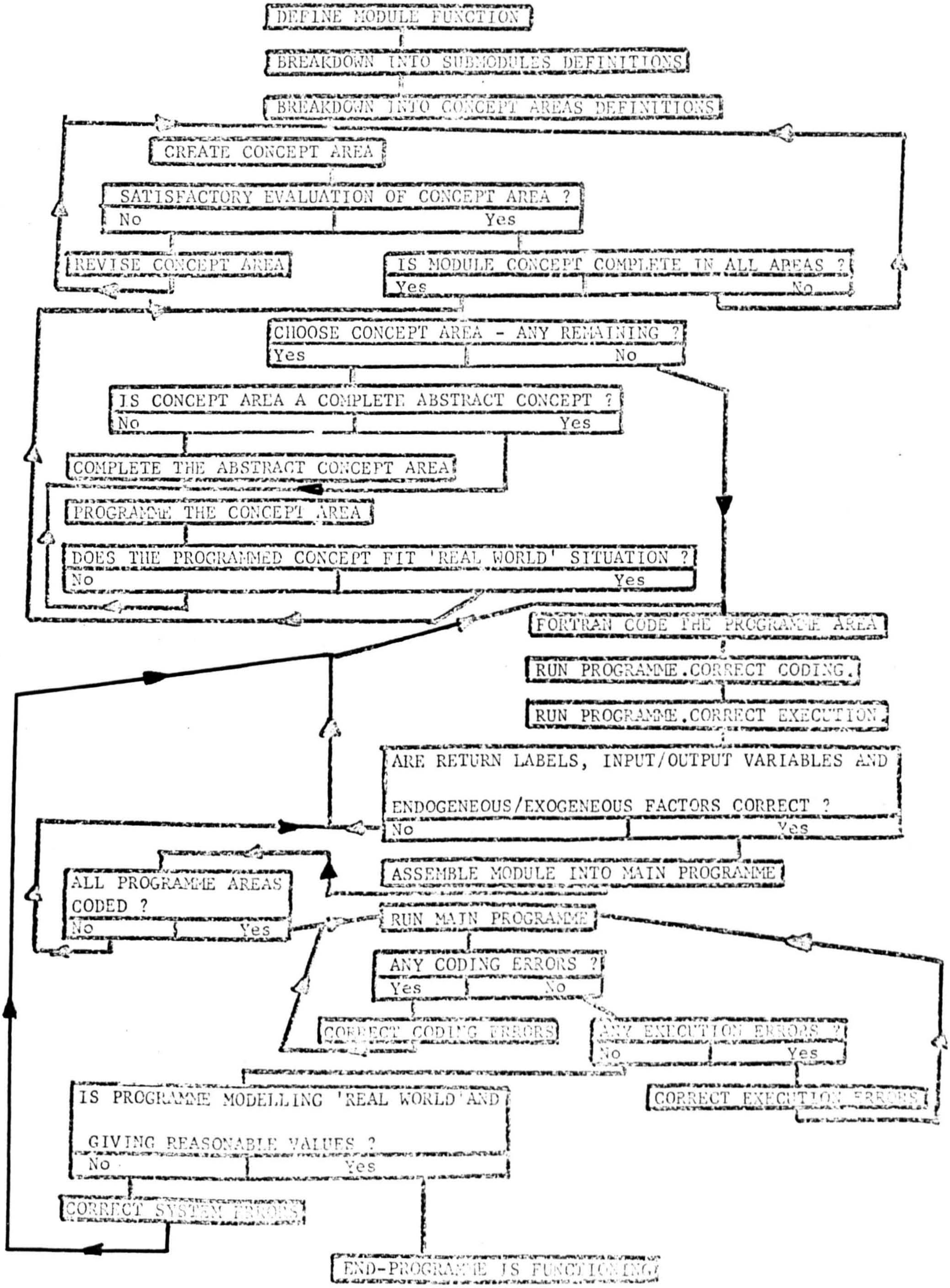


FIG. 4.6. THE JAM HAS SPREAD TO THE BELT

FIG. 4.7. THE CREATION OF A PROGRAMME MODULE BY A SYSTEMATIC APPROACH



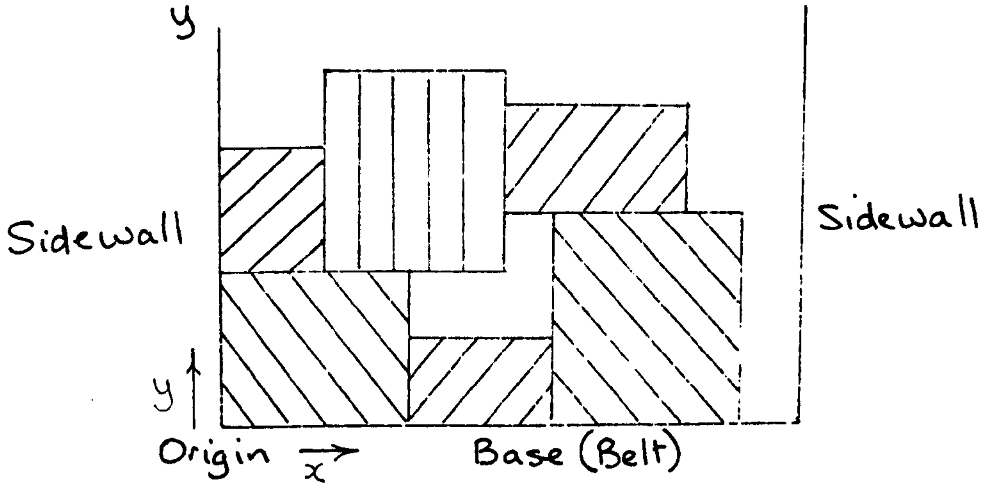


FIG. 4.8. TWO DIMENSIONAL: RIGHT RECTANGULAR PLACEMENT

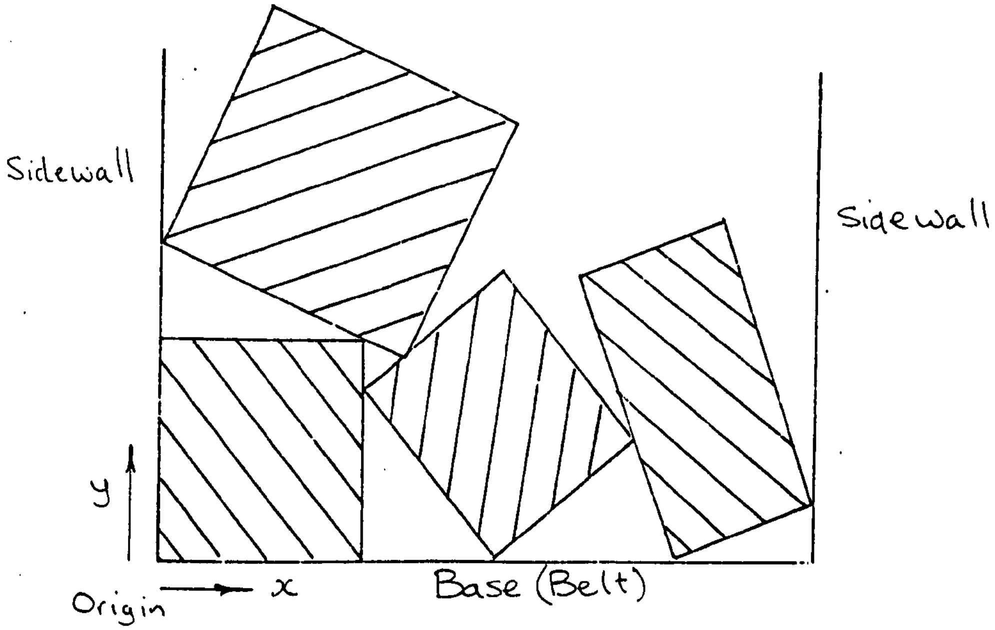


FIG. 4.9. TWO DIMENSIONAL: TILTED PLACEMENT

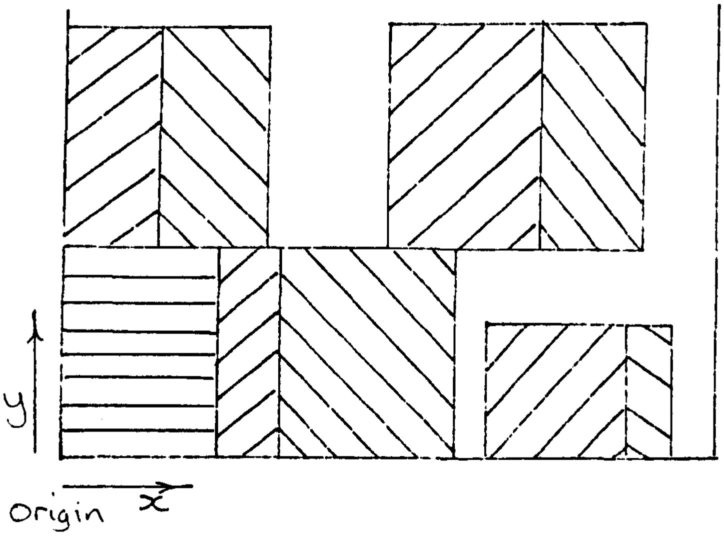


FIG. 4.10. TWO DIMENSIONAL: DIAGONALLY ROTATED PLACEMENT

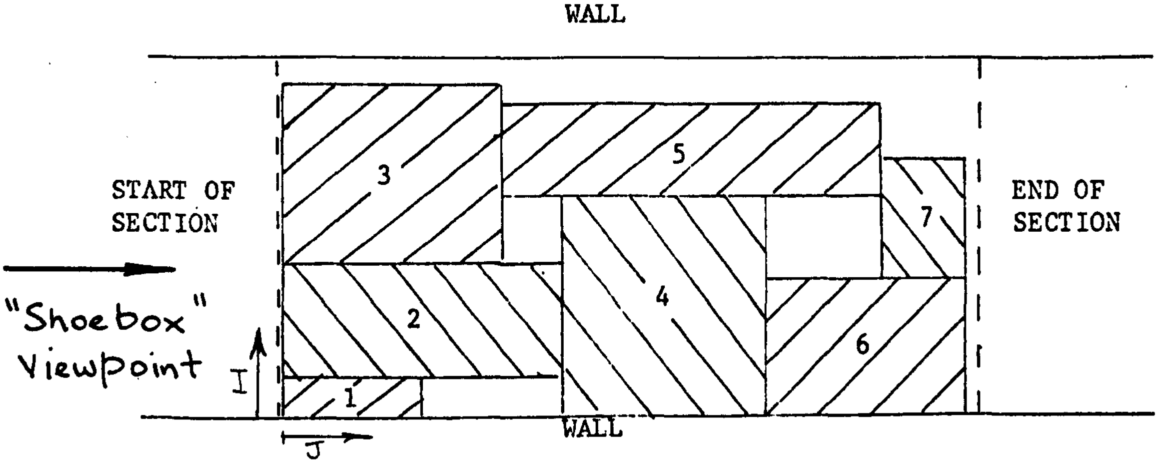


FIG. 4.11. THE 4.4.1. CLOSE PACKED and 4.4.2 CLOSE PACKED TILTED LOADINGS - FIRST LAYER OF PARCELS (PLAN VIEW)

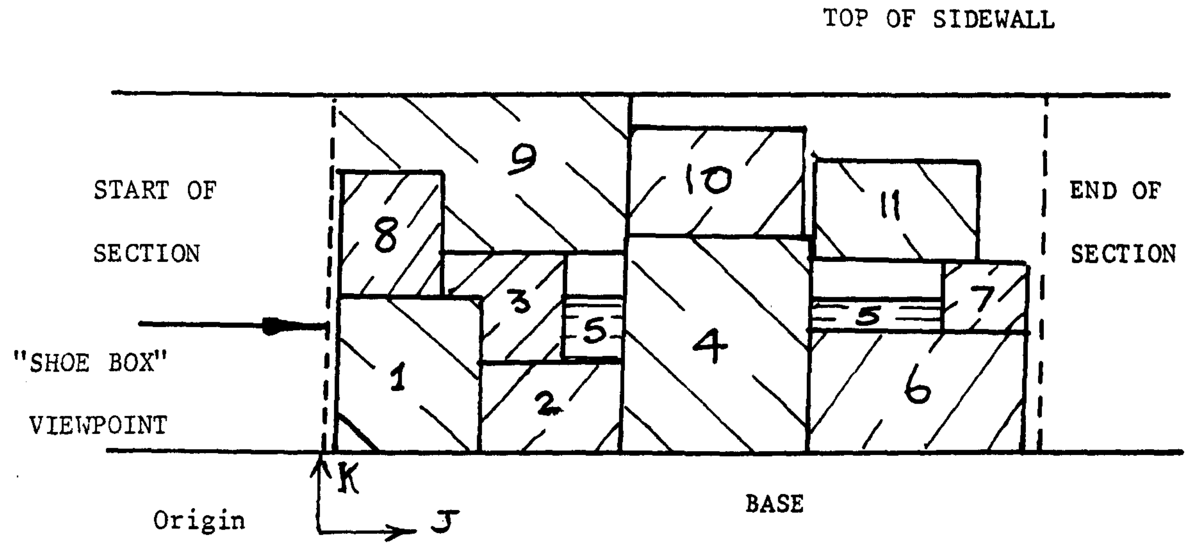


Fig. 4.12 The 4.4.1 Close Packed Loading (Side Elevation)

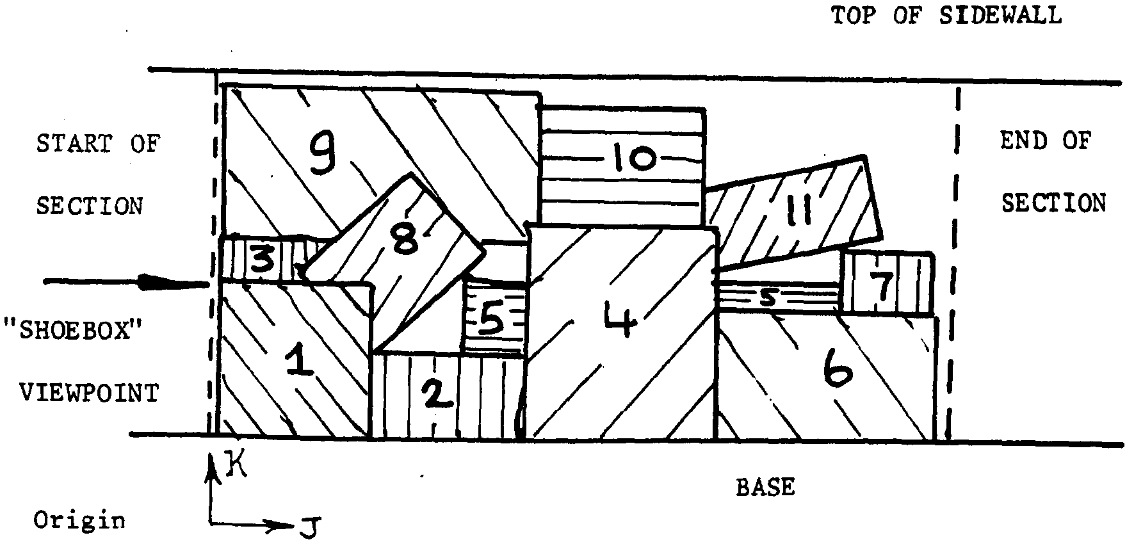


Fig. 4.13 The 4.4.2 Type Loading (Side Elevation).

The 4.4.3, 4.4.4, & 4.4.5 Loadings are somewhat similar.

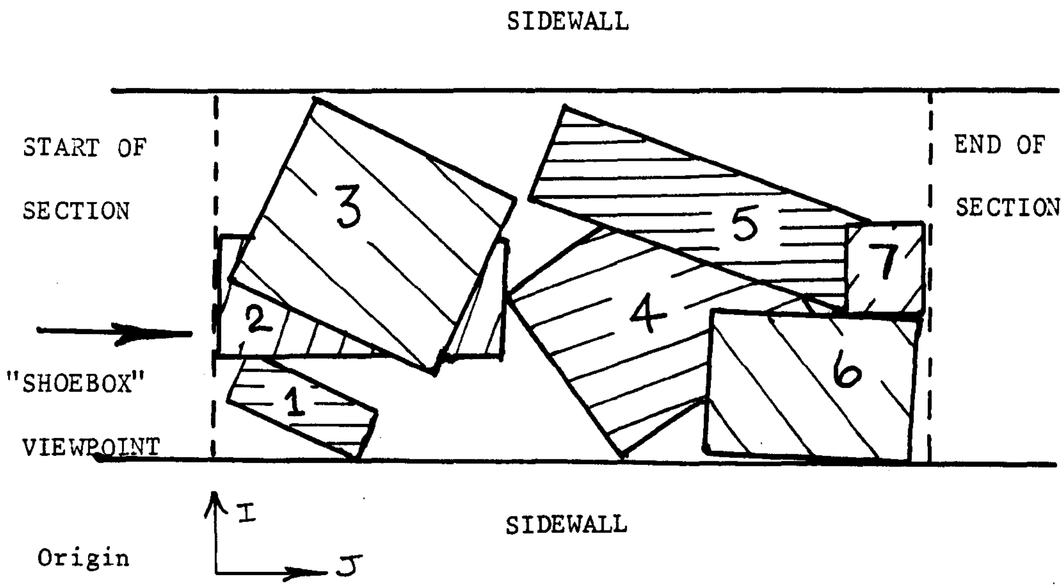
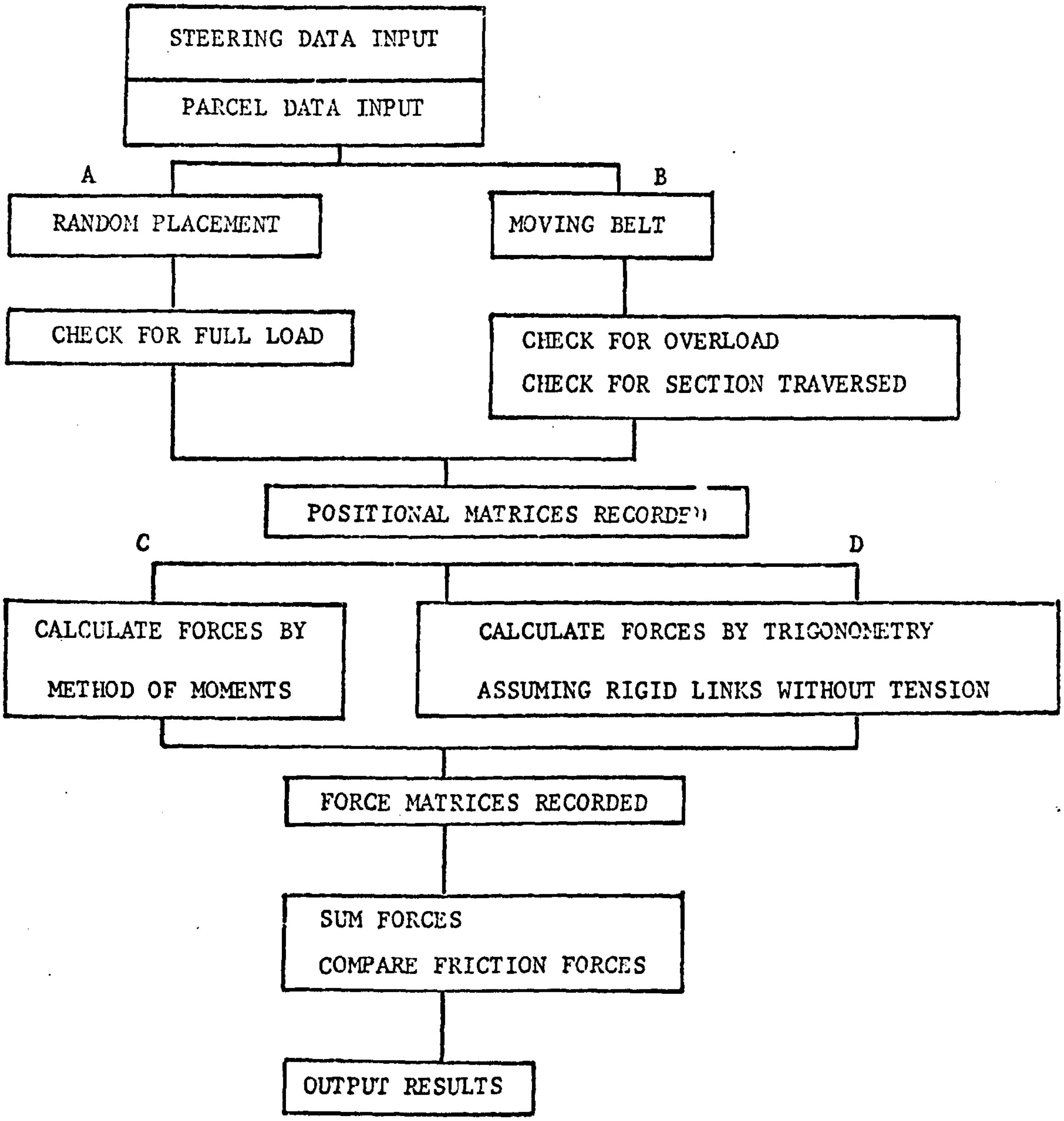


Fig. 4.14 The 4.4.3, 4.4.4 and 4.4.5 Type Loadings, showing the first parcels loaded. (Plan view)



Path A or B are alternatives, as are path C or D

FIG. 4.15. FLOWCHART SHOWING SIMPLIFIED MODEL SYSTEMS

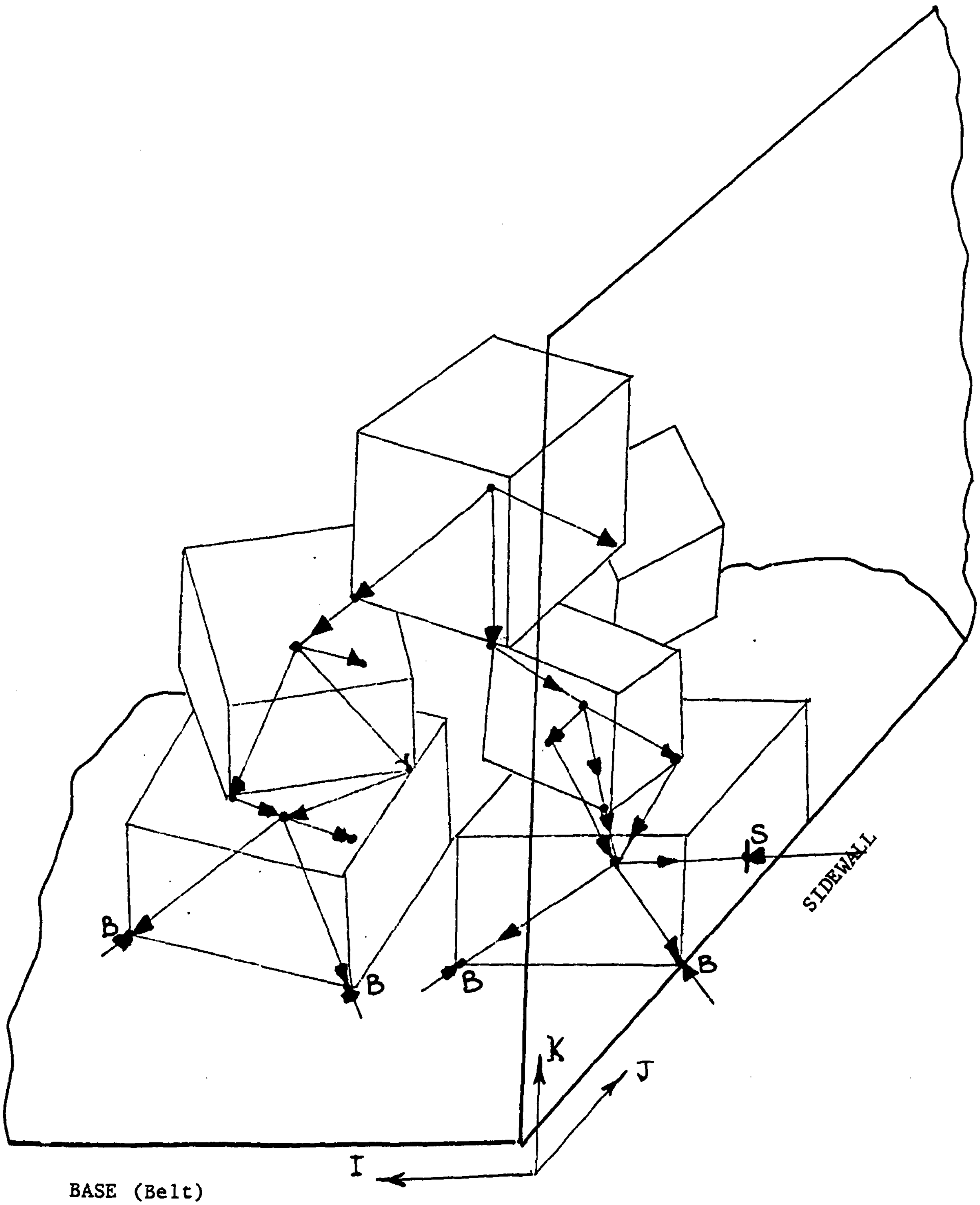


Fig. 4.16 The rigid Link Force Calculation Model, showing the network of hypothetical links which transmit the forces. Contact point S is on the Sidewall, & points B on the Base. (See Section 4.10, page 101)

```
          SUBROUTINE FRANUM(R,R1)
          RAN=100000.*R1
          RAN=23.*RAN
          I=RAN/100001.
          F=I
          RAN=RAN-100001.*F
          R=RAN/100000.
          RETURN
          END

  END OF SEGMENT, LENGTH     53, NAME  FRANUM
```

Fig. 4.17 Listing of the Sub-routine FRANUM, which generates Pseudo Random Number Strings.

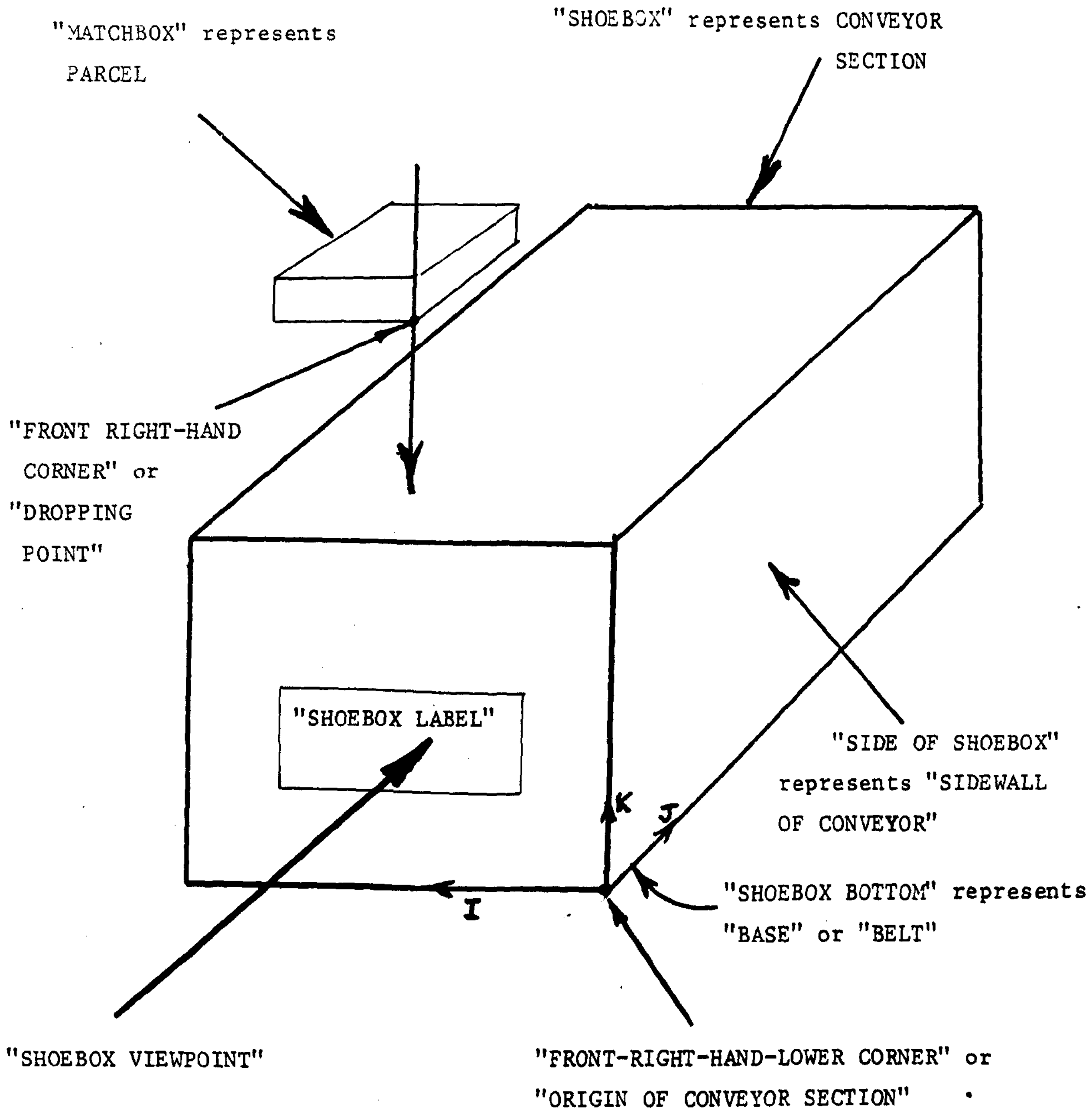


Fig. 4.18 The Shoebox Analogy of the Conveyor Section.

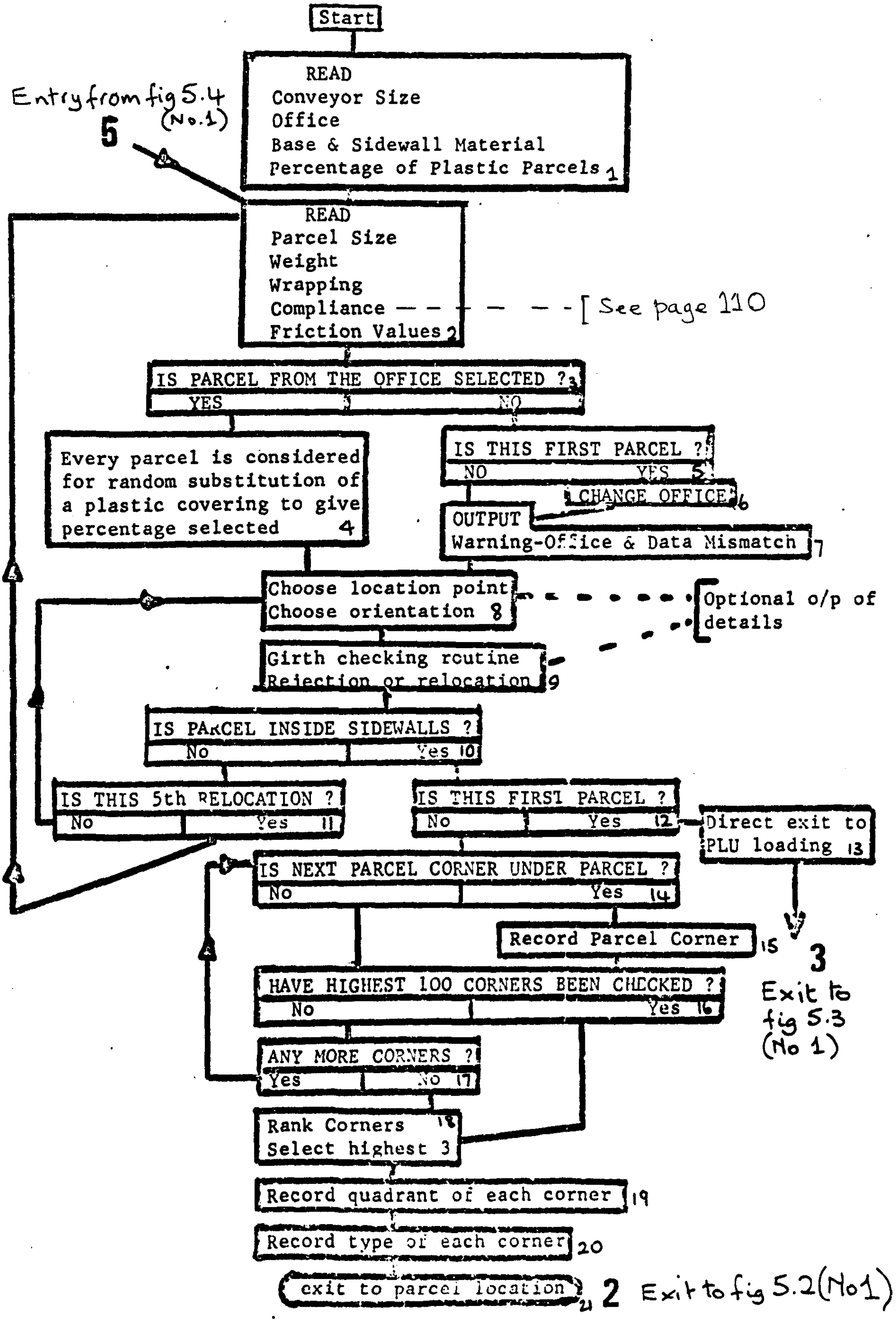
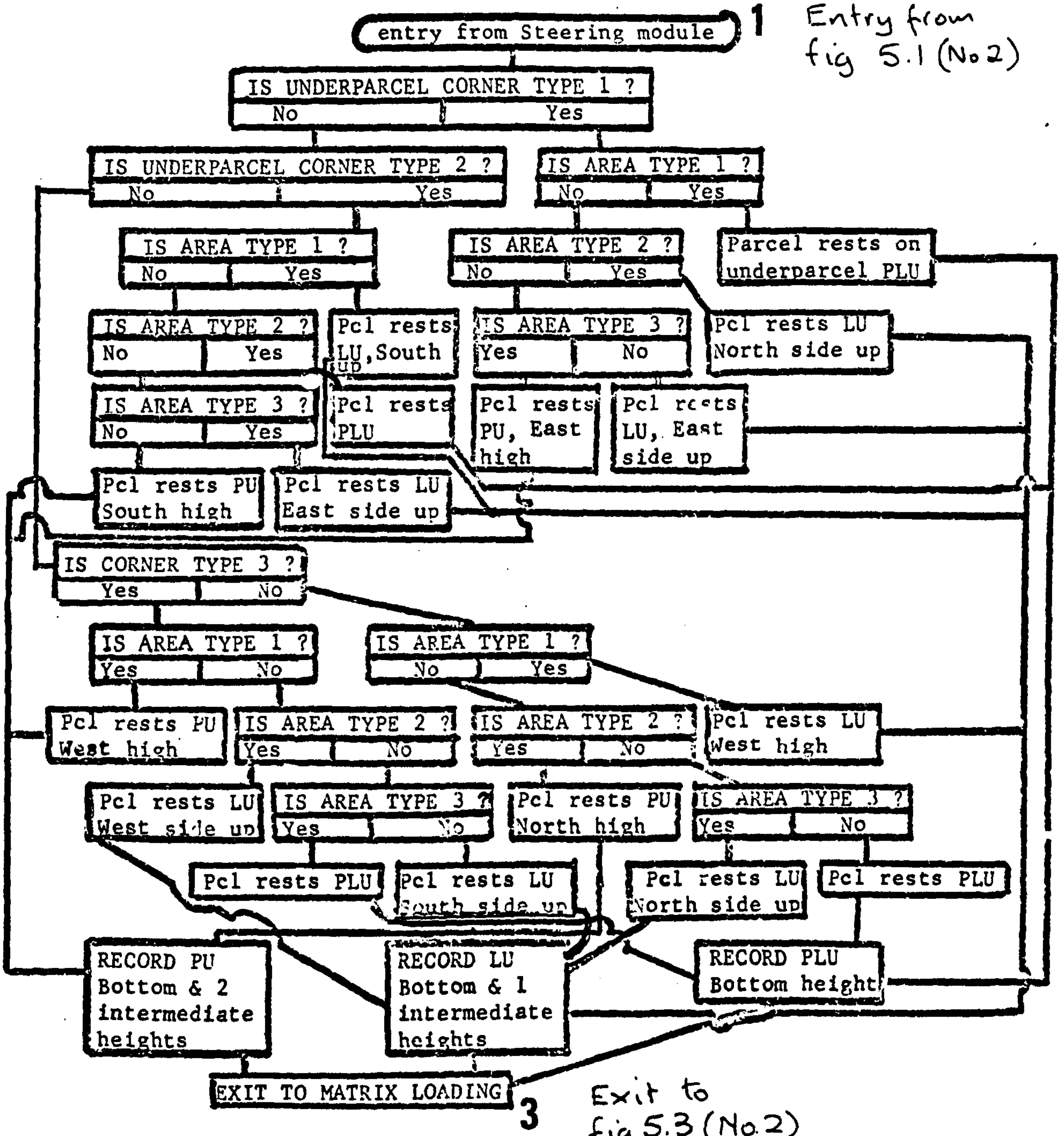


Fig. 5.1. A simplified flowchart, covering the first of the programme modules for Steering, including the substitution of plastic parcels, and location of the parcel area, and any parcels underneath.

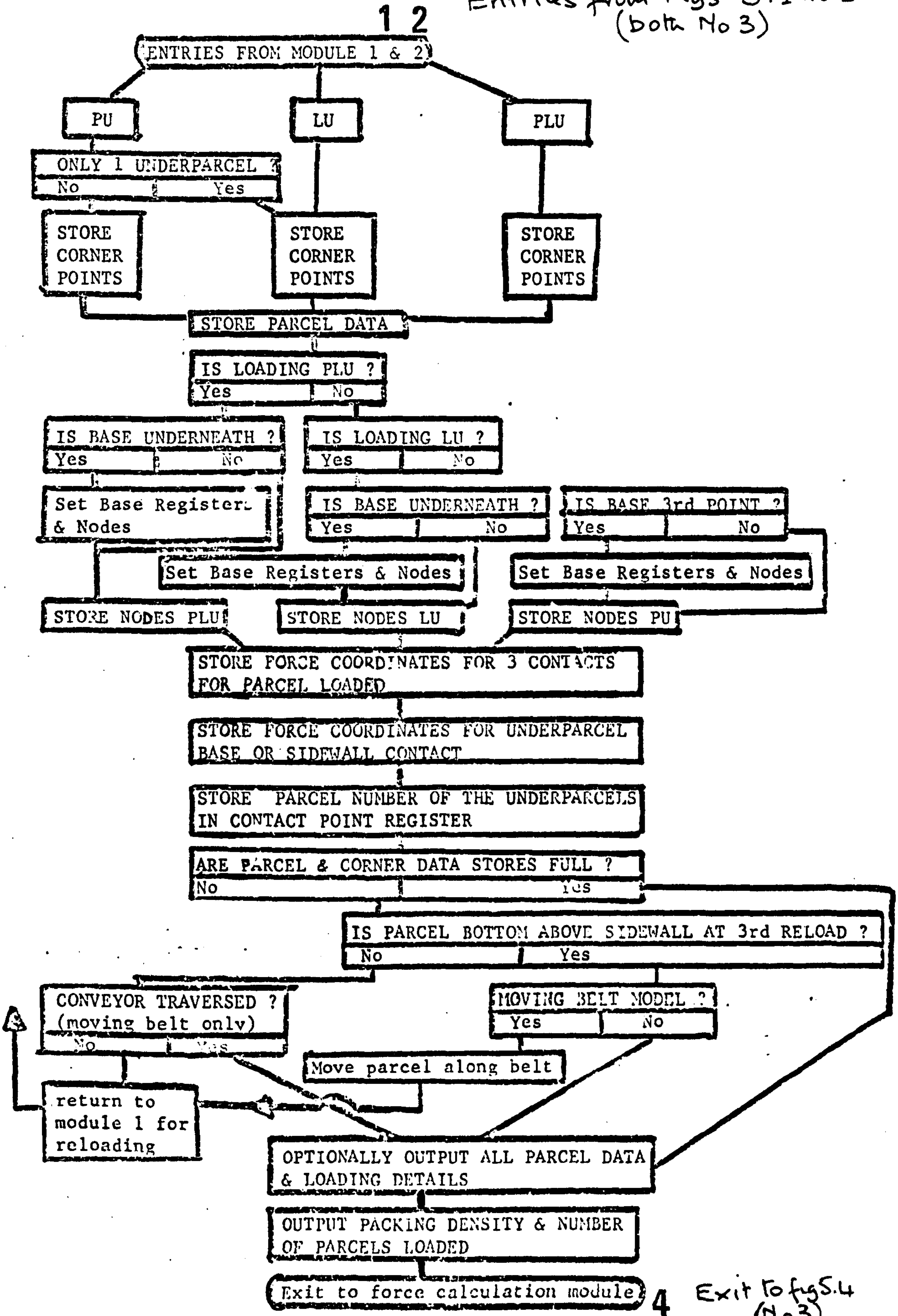


Entry from fig 5.1 (No 2)

Exit to fig 5.3 (No.2)

Figure 5.2 A simplified flowchart covering the second module showing the placing of the parcel in the conveyor section.

Entries from Figs 5.1 & 5.2
(both No 3)



Exit to fig5.4
(No3)

Fig 5.3 Simplified flowchart of third module

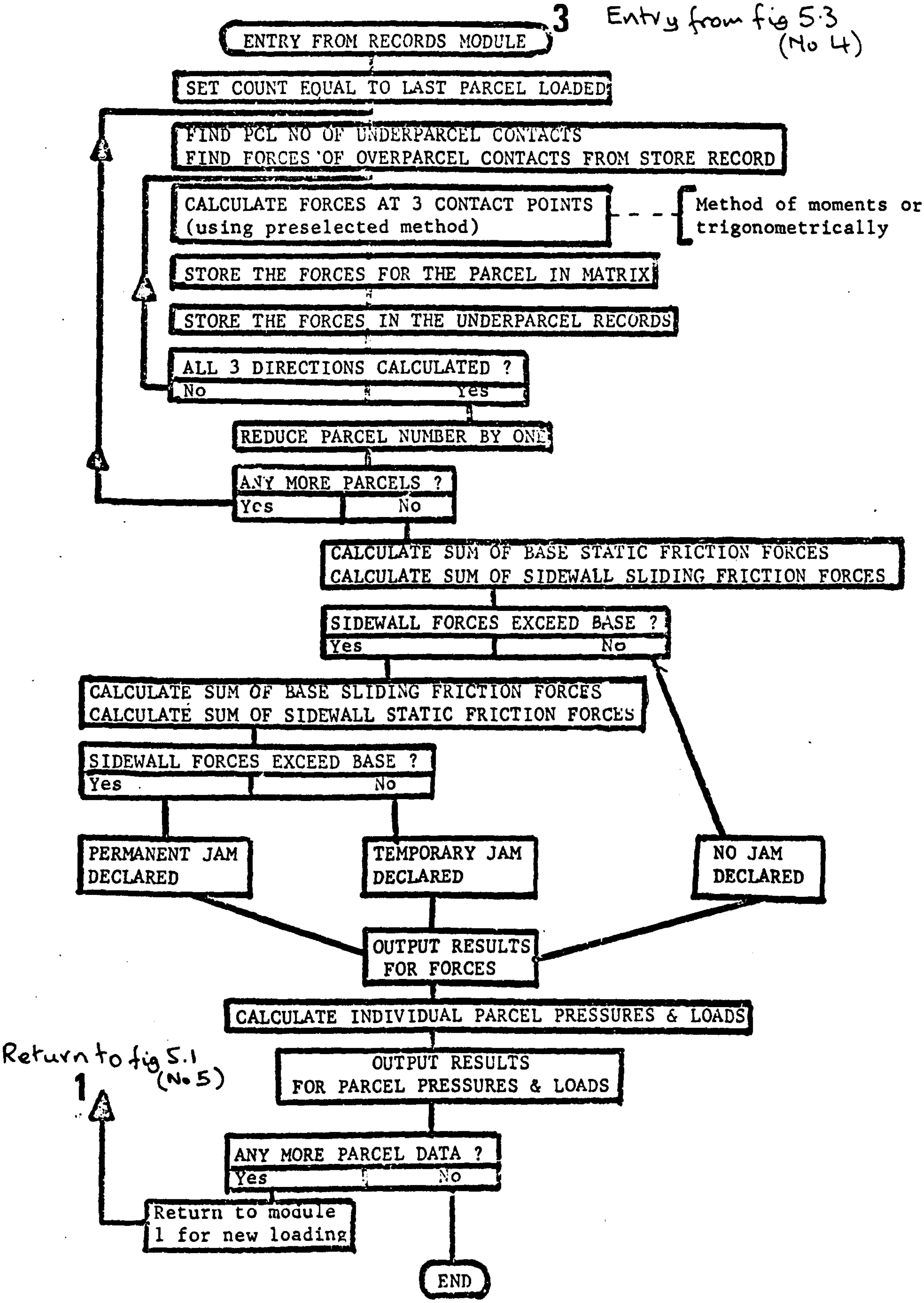
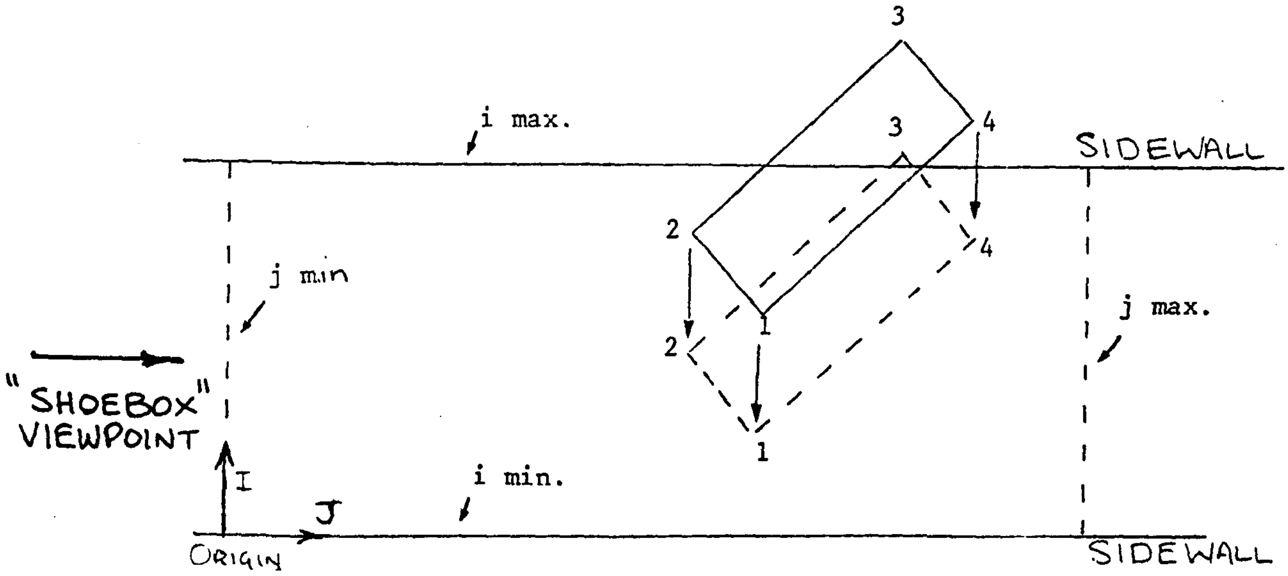
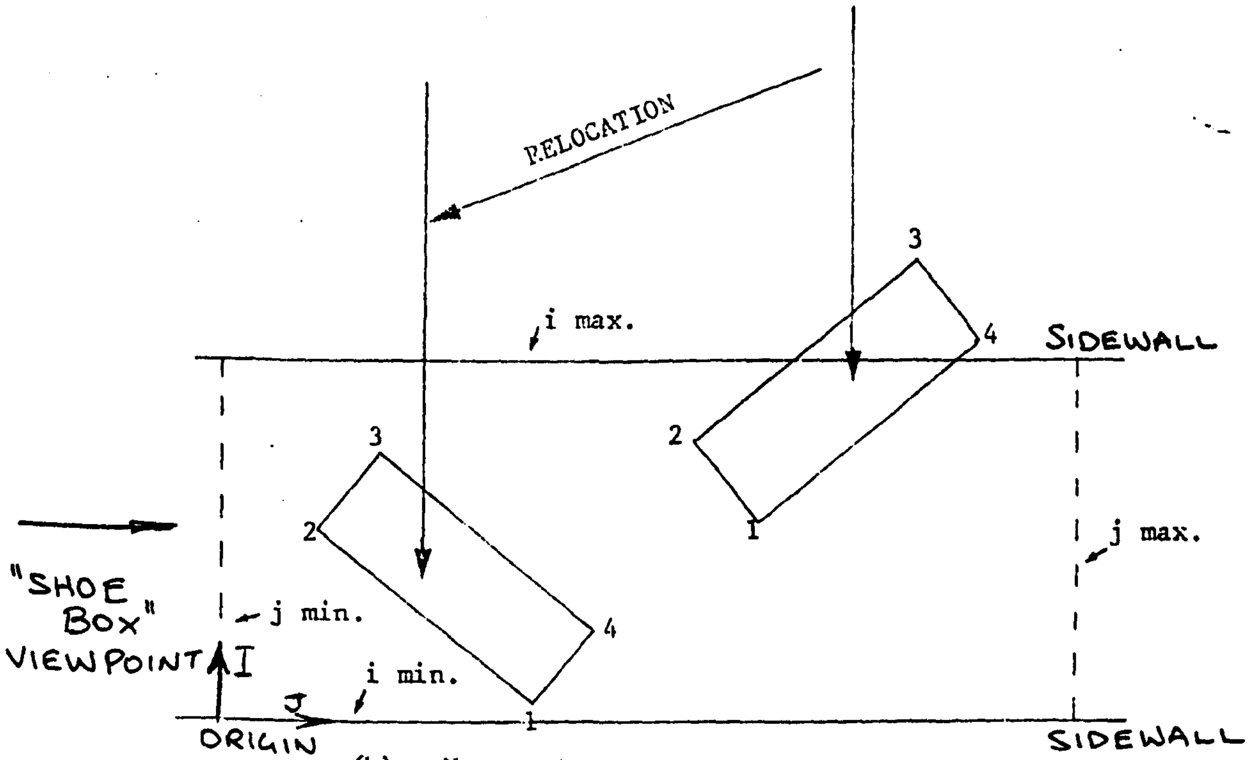


Fig 5.4 A simplified flowchart of module four, the force calculation and module five, the jamming and pressure & parcel load calculation.



(a) Original system



(b) New system

FIG. 5.5. Relocation of Parcels overlapping sidewalls.
See 5.1.4. for details (P.112)

DESCRIPTION OF CORNER POST PRINCIPLE

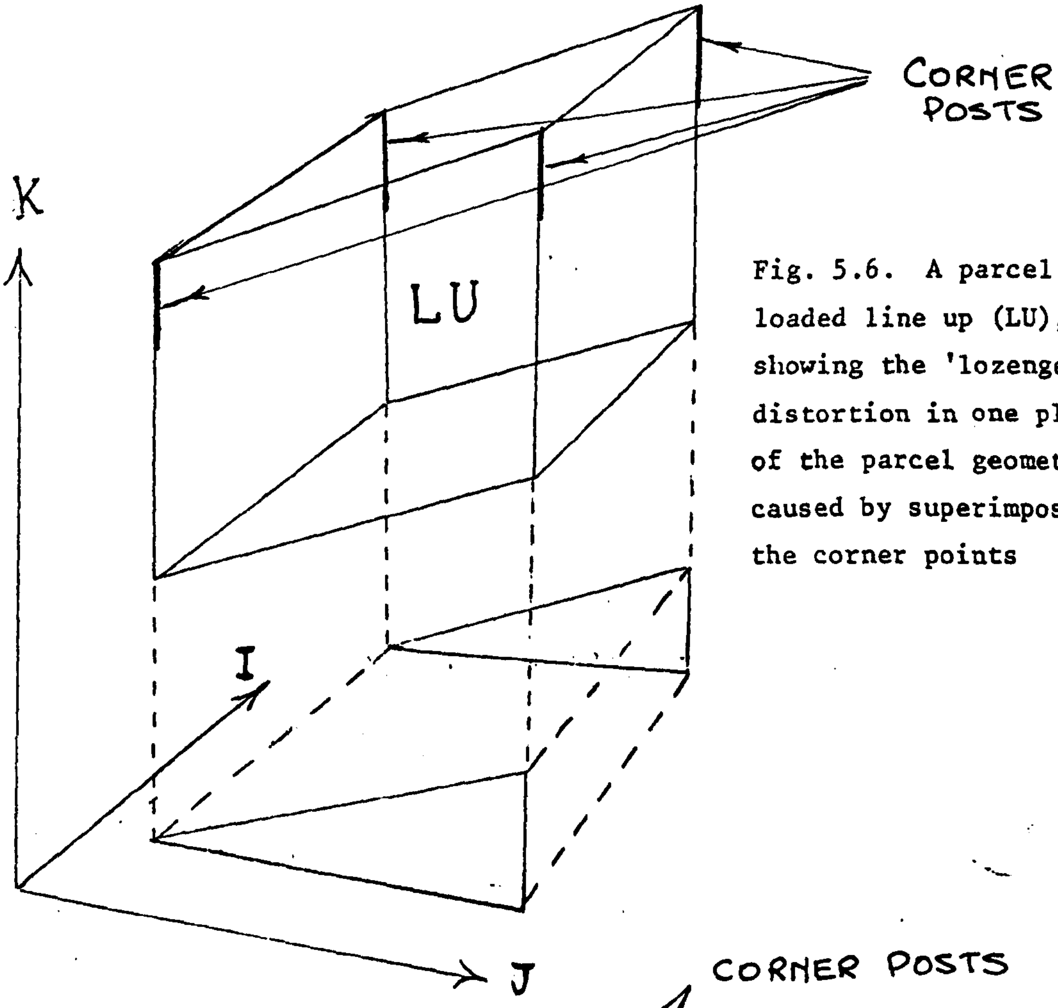


Fig. 5.6. A parcel loaded line up (LU), showing the 'lozenge' distortion in one plane of the parcel geometry caused by superimposing the corner points

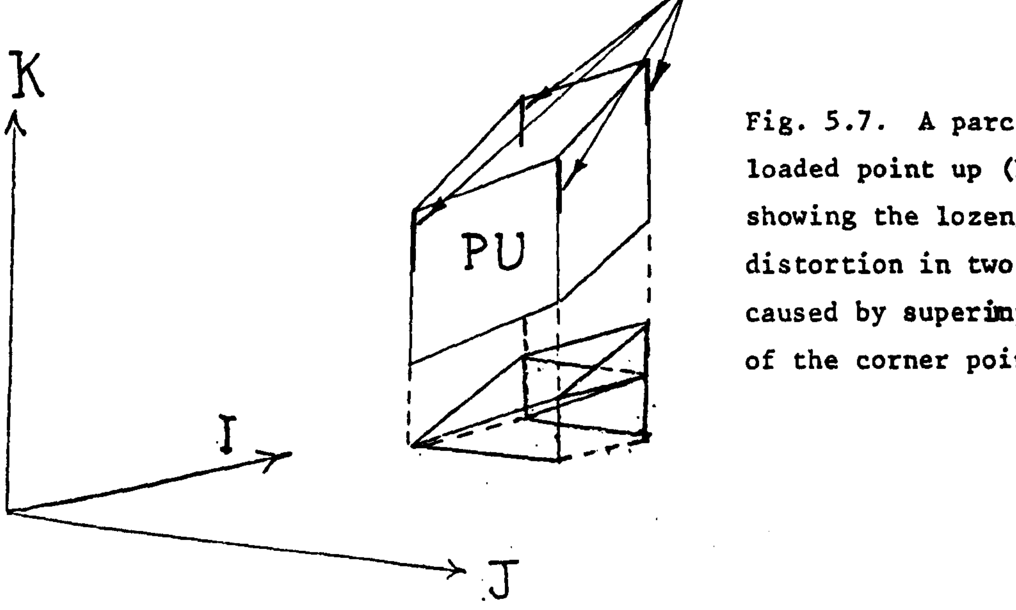


Fig. 5.7. A parcel loaded point up (PU), showing the lozenge distortion in two planes caused by superimpositio of the corner points.

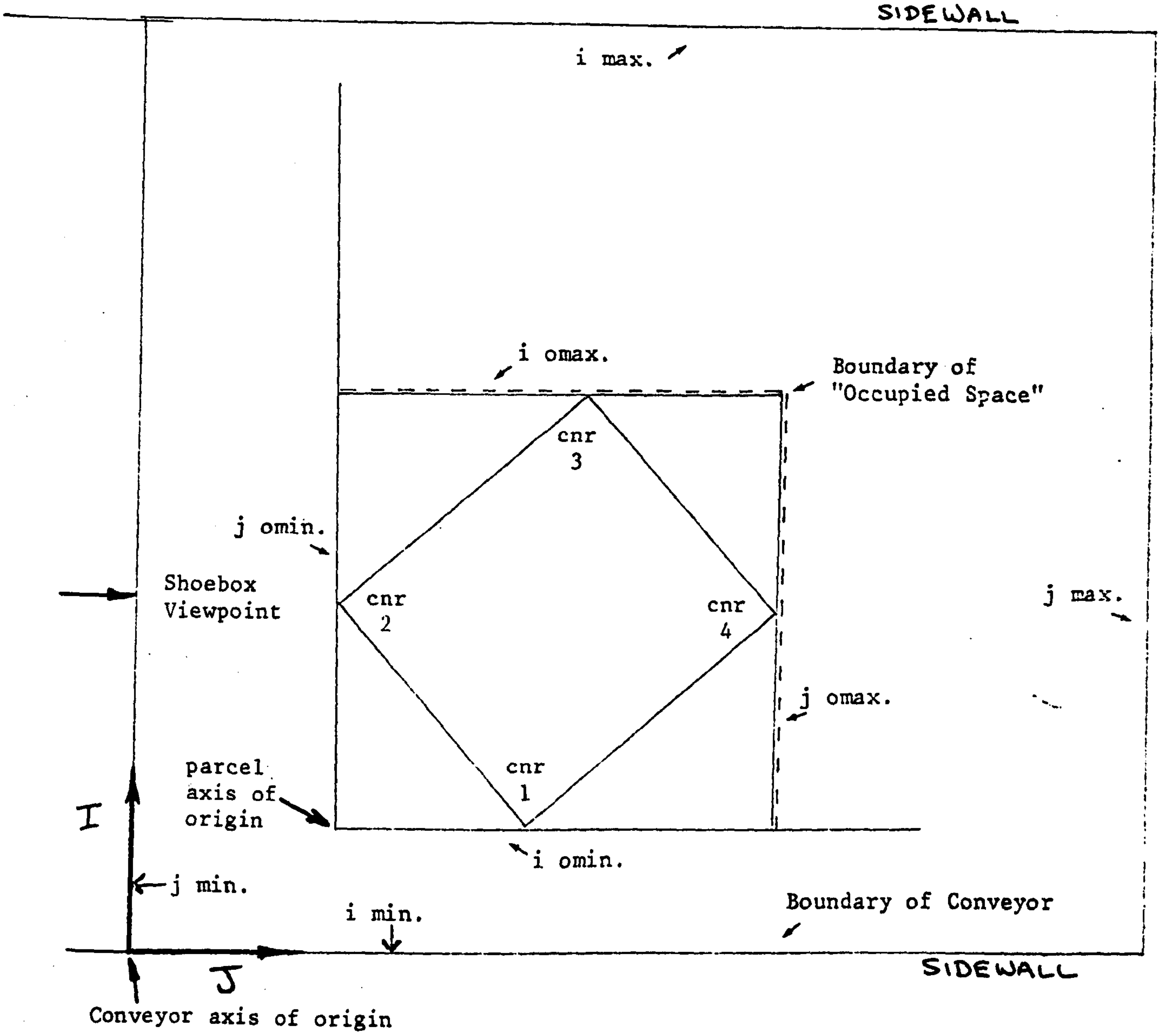


Fig. 5.8. Diagram of "Occupied Space" (For explanation see 5.2.2. "Position of Underparcels").

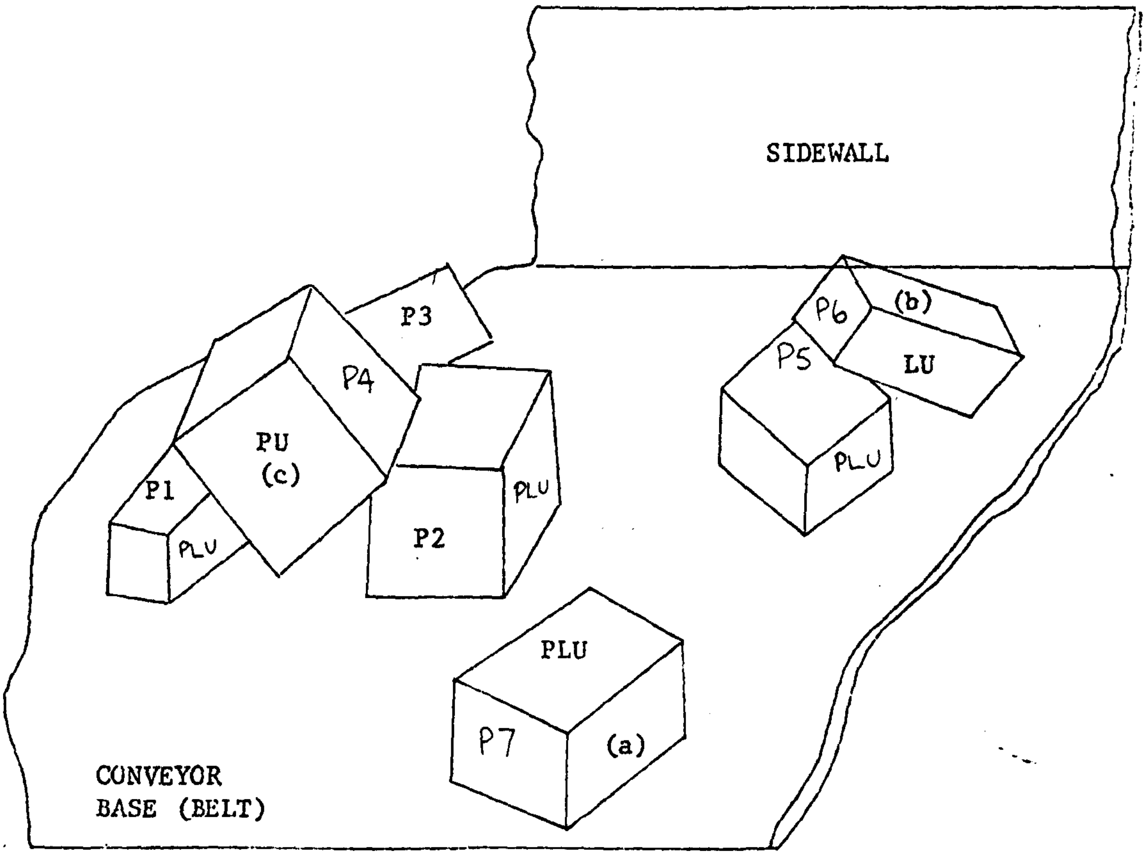


Fig. 5.9. Diagram showing the three mutually exclusive cases of loading type :

(a) PLU - plane up

(b) LU - line up

(c) PU - point up

NOTE: The 'I' & 'J' cordinates are expressed as IOMIN, IMN, IMF & IOMAX, & similarly for 'J' as JOMIN, etc. The 'J' cordinates are not defined, for the sake of clarity. The four areas are marked as 1, 2, 3 & 4, in clockwise order.

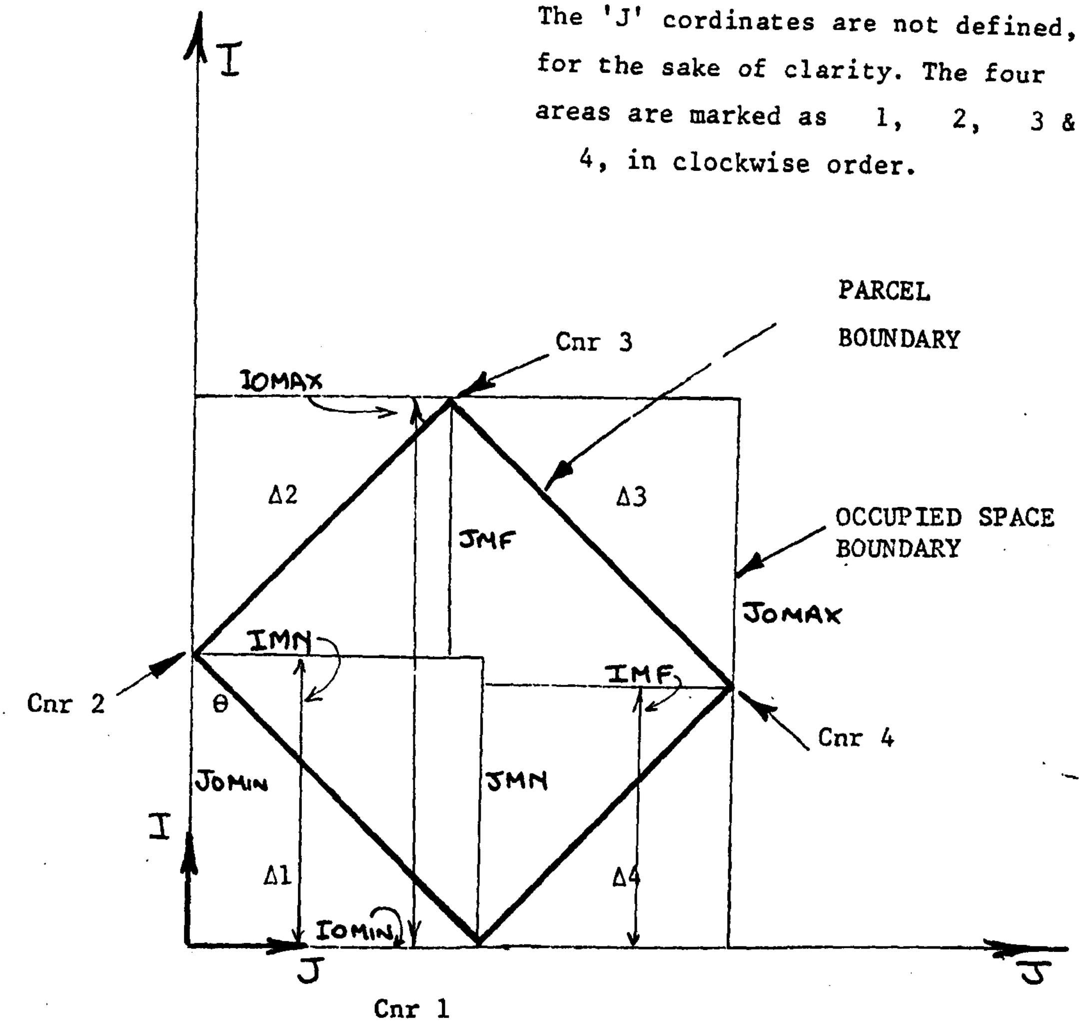


Fig. 5.10. Diagram showing the division of "occupied space" into four areas. Notice the areas are not symmetrical when the parcel is rotated.

See 5.2.3. "The position of the 3 nodes in occupied space".

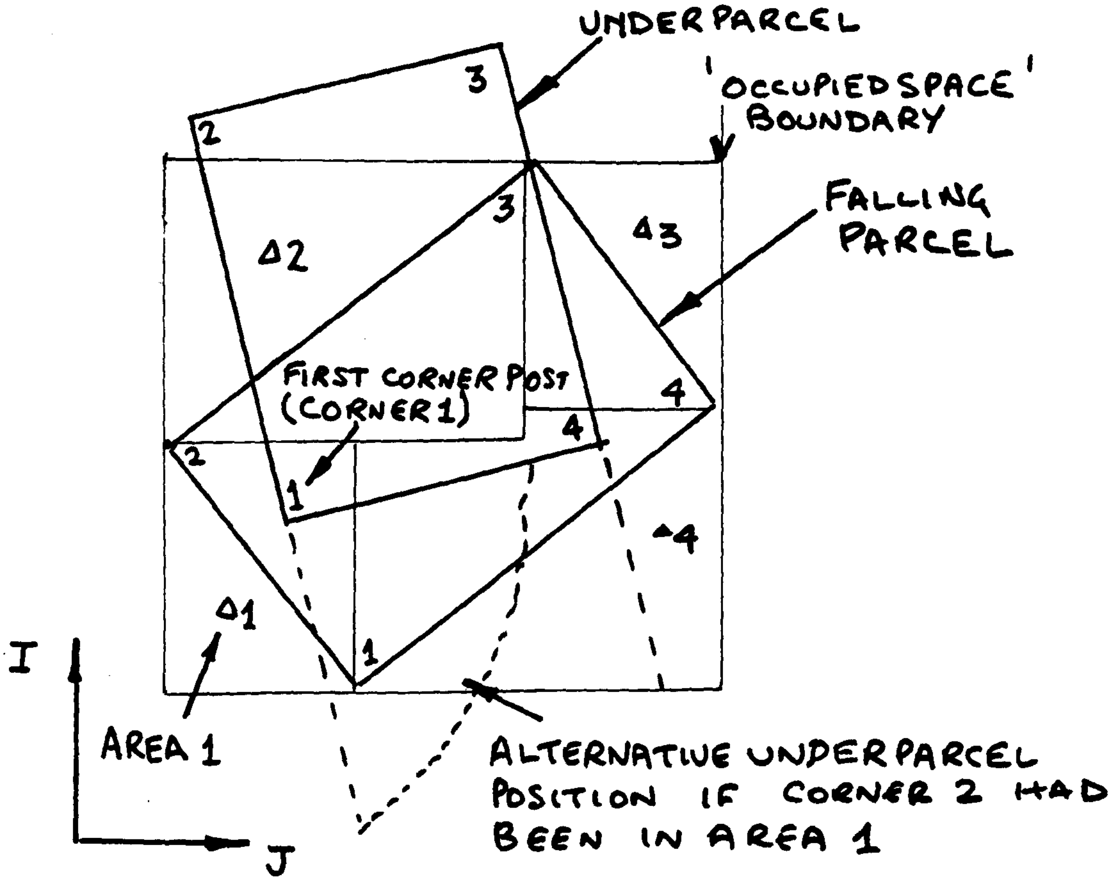


Fig. 5.11 Diagram showing how the geometry of a parcel underneath the parcel being loaded, affects the location of the upper parcel. (See page 119, section 5.2.4 - Selection of Loading Type - PU, LU or PLU)

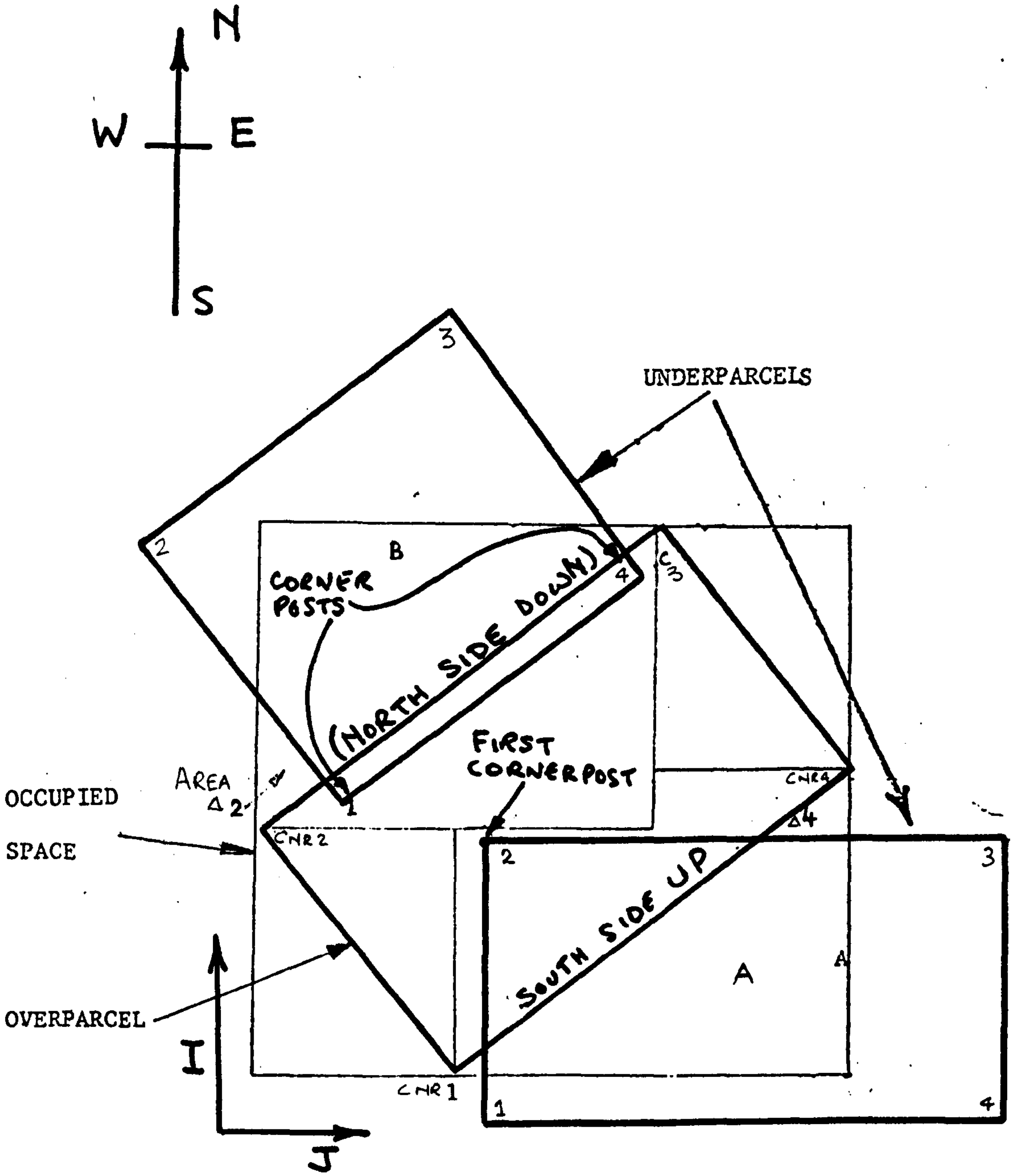


Fig. 5.12 Diagram showing a parcel being loaded in the Line-Up mode. (See page 120, section 5.2.4)
The parcel is regarded as being supported on three corner posts. The upper corner post is on the side of parcel A.(Corner type 2,area 4) Since the lower two corner posts are of equal height, provided by the corners of parcel B,(Corner type 1,area 2 & corner type 4,area 2) the upper parcel will load in the Line-Up position. The highest feature is the upper parcel's South oriented edge, hence it is called "South Side Up".

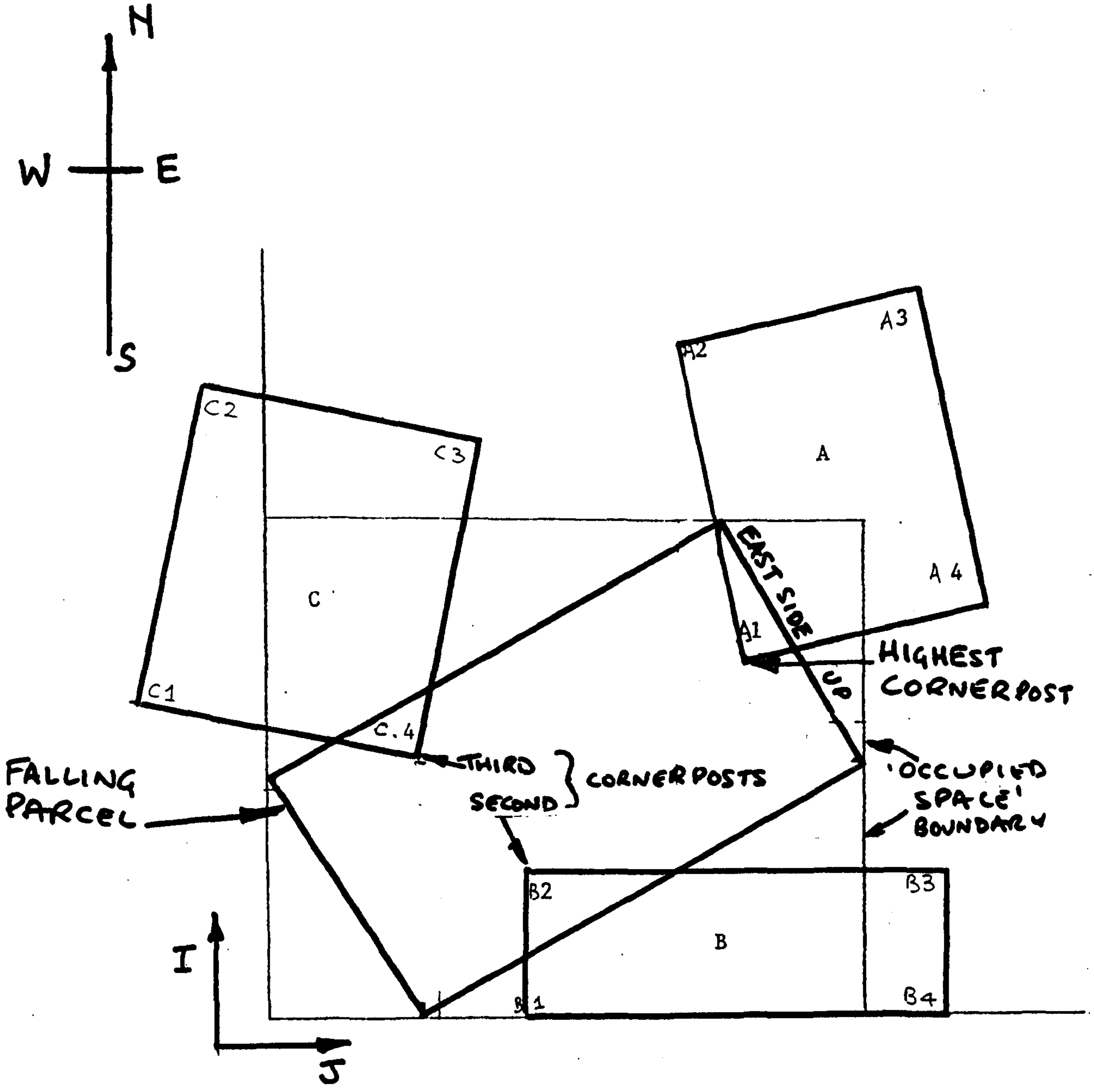


Fig. 5.13 Loading in the Point Up (PU) mode - East Side Up. The parcel is supported upon three points of differing heights. The highest point is over corner 1 of underparcel A, the next highest is over corner 2 of underparcel B, and the lowest point is over corner 4 of underparcel C.

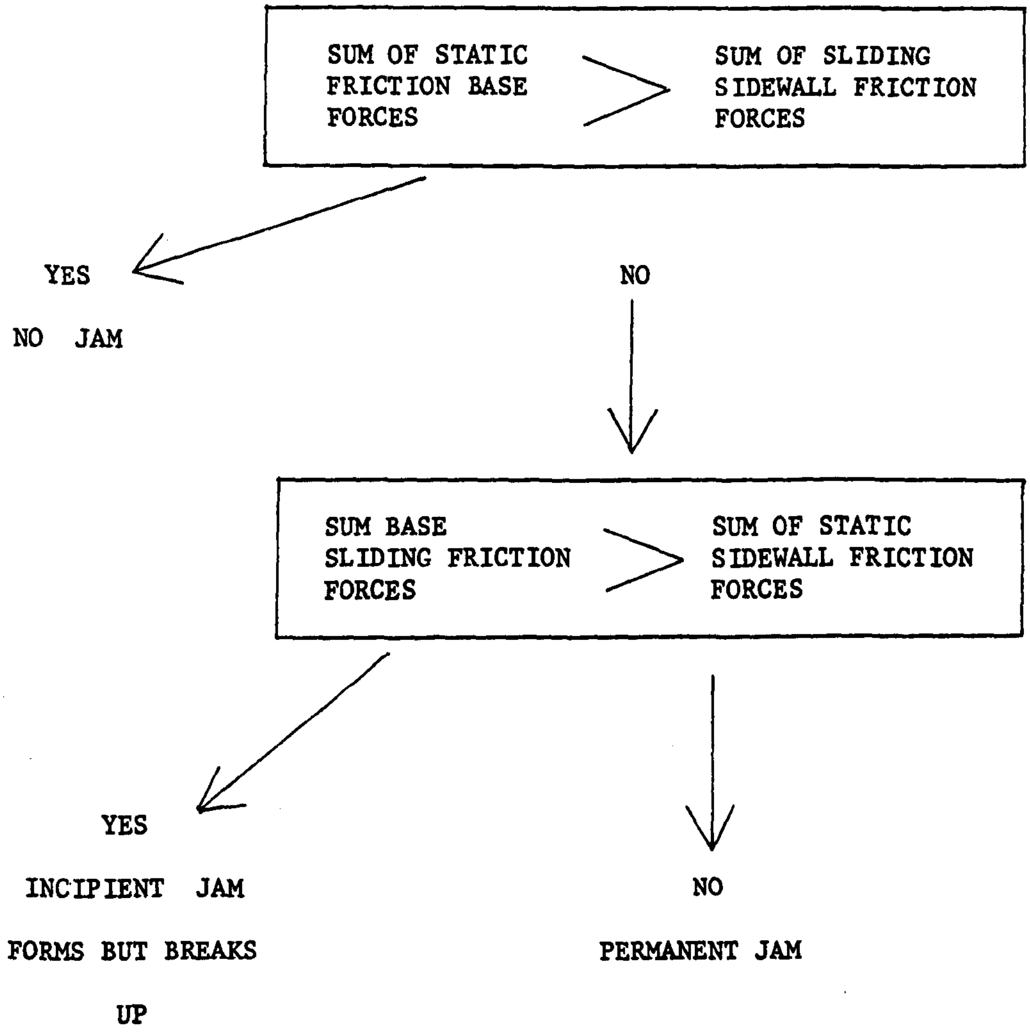


FIG. 5.14 FLOW CHART OF TEST FOR JAMMING CONDITION

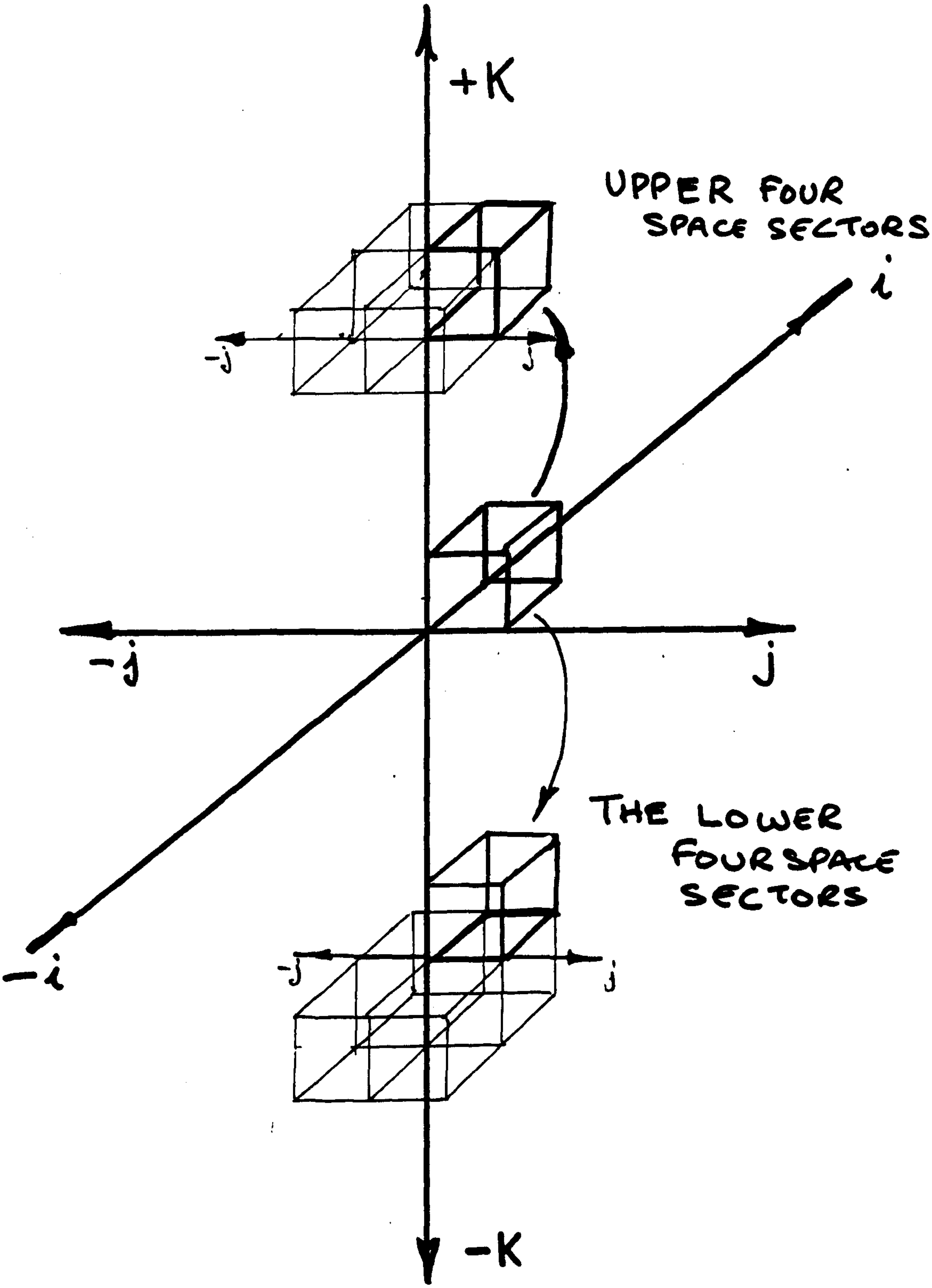


Fig. 5.15 The 8 "Space Sectors" involved in the force calculations. (See page 128)

TABLE 6.1. The Job Card Pack for the COPYOUT Operation for File Storage on Magnetic Tape

```
JB JR-COPYOUT,:PR
DP 1,2400' POOL TAPE PLEASE
GET JR-FILES(*MT)
COPYOUT JR-FILES,T////

JR-B3,A1
JR-B4,A2

JR-PS1,B1
JR-PS2,B2
JR-PS3,B3
JR-PS4,B4

JR-D1,C1
JR-D2,C2
JR-D3,C3
JR-D4,C4
JR-D5-C5
JR-D6,C6

JR-PBS1,D1
JR-PBS2,D2
JR-PBS3,D3
JR-PBS4,D4

JR-SF2F,E1
JR-SF2G,E2
JR-SF3F,E3
JR-SF3G,E4
JR-SF4F,E5
JR-SF4G,E6

JR-PRUN,F1
JR-SRUN,F2

JR-DN1,G1
JR-DN2,G2
JR-DN3,G3
JR-DN4,G4
JR-DN5,G5
JR-DN6,G6

JR-PD1D,H1
JR-PD2D,H2
JR-PD3D,H3
JR-PD4D,H4
JR-PD5D,H5
JR-PD6D,H6
JR-PD7D,H7

JR-PD1S,I1
JR-PD2S,I2
JR-PD3S,I3
JR-PD4S,I4
JR-PD5S,I5

JR-CHECK,J1
JR-PA,J2
JR-SEQ,J3
JR-DATARS,J4

JR-PBSC,K1
JR-PBA,K2
JR-BA,K3
JR-PB2,K4

JR-P3,L1
JR-P4,L2

////
EJ
****
```

Table 7.1 Proportion of Various Wrappings which occur in the data of Castellano, Clinch & Vick (1971)

TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	1340	64.2
Cardboard	708	33.9
Sacking	11	0.5
Plastic	18	0.9
Wood	4	0.2
Fibre & Other	6	0.3
Total	2087	100.0

SIZE OF SAMPLES FROM THE VARIOUS OFFICES				
OFFICE	REFERENCE	NUMBER OF PARCELS	%	TABLE
Birmingham	1	330	15.81	7.2
Brighton	2	381	18.26	7.3
Croydon	3	315	15.09	7.4
Liverpool	4	402	19.26	7.5
Manchester	5	419	20.08	7.6
NWPO	6	240	11.50	7.7
Total	All	2087	100.00	7.8

Table 7.2 Proportion of Various Wrappings in the sample of parcels from Birmingham Office.

SAMPLE FROM BIRMINGHAM OFFICE		
TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	216	65.45
Cardboard	108	32.73
Plastic	4	1.21
Other	2	0.61
Total	330	100.00

Table 7.3 Proportion of Various Wrappings in the sample of parcels from Brighton Office.

SAMPLE FROM THE BRIGHTON OFFICE		
TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	246	64.57
Cardboard	134	35.17
Plastic	1	0.26
Other	0	0.00
Total	381	100.00

Table 7.4 Proportions of Various Wrappings in the sample of parcels from Croydon Office.

SAMPLE FROM THE CROYDON OFFICE		
TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	190	60.32
Cardboard	118	37.46
Plastic	4	1.27
Other	3	0.95
Total	315	100.00

Table 7.5 Proportions of Various Wrappings in the sample of parcels from Liverpool Office.

SAMPLE FROM THE LIVERPOOL OFFICE		
TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	283	70.40
Cardboard	105	26.12
Plastic	6	1.49
Other	8	1.99
Total	402	100.00

Table 7.6 Proportions of Various Wrappings in the sample of parcels from Manchester Office.

SAMPLE FROM THE MANCHESTER OFFICE		
TYPES OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	261	62.29
Cardboard	151	36.03
Plastic	2	0.48
Other	5	1.20
Total	419	100.00

Table 7.7 Proportions of Various Wrappings in the sample of parcels from North Western Post Office.

SAMPLE FROM THE NWPO		
TYPES OF WRAPPINGS	NUMBER OF PARCELS	%
Brown Paper	144	60.00
Cardboard	92	38.33
Plastic	1	0.42
Other	3	1.25
Total	240	100.00

Table 7.8 Proportions of the Various Wrappings for all the parcels from the data of Castellano, Clinch & Vick (1971). This table is derived from table 7.1, and it groups the parcel wrappings into the same four classes of wrappings as the tables 7.2 to 7.7.

AGGREGATE OF ALL SAMPLES FROM ALL OF THE SIX OFFICES		
TYPE OF WRAPPING	NUMBER OF PARCELS	%
Brown Paper	1340	64.21
Cardboard	708	33.92
Plastic	18	0.86
Other	21	1.01
Total	2087	100.00

Table 7.9 χ^2 calculation tables. This is the Observed Values for the number of parcels for each office.

OBSERVED VALUES - ALL OFFICES						
OFFICE		PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham	1	216	108	4	2	330
Brighton	2	246	134	1	0	381
Croydon	3	190	118	4	3	315
Liverpool	4	283	105	6	8	402
Manchester	5	261	151	2	5	419
NWPO	6	144	92	1	3	240
Total		1340	708	18	21	2087

Table 7.10 χ^2 calculation tables. This is the Expected Values for the number of parcels in each office.

EXPECTED VALUES - ALL OFFICES					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	211.9	111.9	2.9	3.3	330
Brighton 2	244.6	129.3	3.3	3.8	381
Croydon 3	202.2	106.9	2.7	3.2	315
Liverpool 4	258.1	136.4	3.5	4.0	402
Manchester 5	269.1	142.1	3.6	4.2	419
NWPO 6	154.1	81.4	2.1	2.4	240

Table 7.11 χ^2 calculation tables. This is the χ^2 Values for the number of parcels of various wrappings for each of the offices.

χ^2 VALUES - ALL OFFICES					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL χ^2 ROWS
Birmingham 1	0.080	0.139	0.469	0.525	1.213
Brighton 2	0.008	0.175	1.589	3.833	5.605
Croydon 3	0.743	1.161	0.608	0.009	2.521
Liverpool 4	2.399	7.217	1.855	3.870	15.341
Manchester 5	0.240	0.552	0.724	0.146	1.662
NWPO 6	0.662	1.375	0.552	0.142	2.731
TOTAL χ^2 COLUMNS	4.132	10.619	5.797	8.525	29.073

The Critical Value for χ^2 = 30.58 at the 1% significance level
& the " " " χ^2 = 25.00 " " 5% " "
for 15 degrees of freedom. The diffence is just significant at $\chi^2 = 29.073$

Table 7.12 χ^2 calculation tables. This is the contingency table for Observed Values for the remaining 5 offices of contingency table 7.9, once the values for Brighton are removed.

OBSERVED VALUES - OFFICES 1 & 3 - 6: BRIGHTON REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	216	108	4	2	330
Croydon 3	190	118	4	3	315
Liverpool 4	283	105	6	8	402
Manchester 5	261	151	2	5	419
NWPO 6	144	92	1	3	240
Total	1094	574	17	21	1706
% of Total	64.13	33.65	0.01	0.01	100.00

Table 7.13 χ^2 calculation tables. This is the table of Expected Values for the remaining 5 offices, with the values for Brighton removed.

EXPECTED VALUES - OFFICES 1 & 3 - 6: BRIGHTON REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	211.62	111.03	3.29	4.06	330
Croydon 3	202.00	105.98	3.14	3.88	315
Liverpool 4	257.79	135.26	4.00	4.95	402
Manchester 5	268.69	140.98	4.17	5.16	419
NWPO 6	153.90	80.75	2.40	2.95	240
Total	1094	574	17	21	1706

Table 7.14 χ^2 calculation tables. This is the table of Values of χ^2 for the remaining 5 offices, with Brighton Office removed.

χ^2 VALUES — OFFICES 1 & 3 - 6: BRIGHTON REMOVED

OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL χ^2 ROWS
Birmingham 1	0.091	0.083	0.153	1.045	1.372
Croydon 3	0.713	1.363	0.236	0.200	2.512
Liverpool 4	2.465	6.770	1.000	1.879	12.114
Manchester 5	0.220	0.712	1.129	0.005	2.066
NWPO 6	0.637	1.567	0.817	0.000	3.021
TOTAL χ^2 COLUMNS	4.126	10.495	3.335	3.129	21.085

The Critical Value for χ^2 = 26.22 at the 1% significance level
& the " " " χ^2 = ? 21.03 " " 5% " "
for 12 degrees of freedom. The difference is just significant at χ^2 = 21.085

Table 7.15 χ^2 calculation tables. This is the table of Observed Values for the Various Wrappings, for the remaining 4 offices, once Brighton & Liverpool Offices have been removed.

OBSERVED VALUES — OFFICES 1, 3, 5 & 6: BRIGHTON & LIVERPOOL REMOVED

OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	216	108	4	2	330
Croydon 3	190	118	4	3	315
Manchester 5	261	151	2	5	419
NWPO 6	144	92	1	3	240
Total	811	469	11	13	1304
% of Total	62.19	35.97	0.84	1.00	100.00

Table 7.16 χ^2 calculation tables. Expected values for the 4 Offices remaining, once Brighton & Liverpool were removed

EXPECTED VALUES - OFFICES 1, 3, 5 & 6: BRIGHTON & LIVERPOOL REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	205.24	118.69	2.78	3.29	330
Croydon 3	195.91	113.29	2.66	3.14	315
Manchester 5	260.59	150.70	3.53	4.18	419
NWPO 6	149.26	86.32	2.03	2.39	240
Total	811	469	11	13	1304

Table 7.17 χ^2 calculation tables. Values of χ^2 for the remaining 4 offices, once Brighton & Liverpool have been removed.

χ^2 VALUES - OFFICES 1, 3, 5 & 6: BRIGHTON & LIVERPOOL REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL χ^2 ROWS
Birmingham 1	0.564	0.963	0.535	0.506	2.568
Croydon 3	0.178	0.196	0.675	0.006	1.055
Manchester 5	0.001	0.001	0.663	0.161	0.826
NWPO 6	0.185	0.374	0.523	0.156	1.238
TOTAL χ^2 COLUMNS	0.928	1.534	2.396	0.829	5.687

The Critical Value for χ^2 = 21.67 at the 1% significance level
& the " " " χ^2 = 16.92 " " 5% " "
for 9 degrees of freedom. The difference is not significant at χ^2 = 5.687

Table 7.18 χ^2 calculation tables. Observed Values for Various Wrappings, from the 5 Offices remaining when Liverpool is removed.

OBSERVED VALUES - OFFICES 1 - 3 & 5 - 6; LIVERPOOL REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	216	108	4	2	330
Brighton 2	246	134	1	0	381
Croydon 3	190	118	4	3	315
Manchester 5	261	151	2	5	419
NWPO 6	144	92	1	3	240
Total	1057	603	12	13	1685
% of Total	62.73	35.79	0.71	0.77	100.00

Table 7.19 χ^2 calculation tables. Expected Values for Various Wrappings , from the 5 Offices remaining once Liverpool is removed.

EXPECTED VALUES - OFFICES 1 - 3 & 5 - 6; LIVERPOOL REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL
Birmingham 1	207.01	118.09	2.35	2.55	330
Brighton 2	239.00	136.35	2.71	2.94	381
Croydon 3	197.60	112.73	2.24	2.43	315
Manchester 5	262.84	149.94	2.99	3.23	419
NWPO 6	150.55	85.89	1.71	1.85	240
Total	1057	603	12	13	1685

Table 7.20 χ^2 calculation tables. χ^2 Values for the Various Wrappings, from the 5 Offices which remain, once the sample from Liverpool Office is removed.

χ^2 VALUES - OFFICES 1 - 3 & 5 - 6: LIVERPOOL REMOVED					
OFFICE	PAPER	CARDBOARD	PLASTIC	OTHER	TOTAL χ^2 ROWS
Birmingham 1	0.382	0.865	1.178	0.114	2.539
Brighton 2	0.205	0.041	1.079	2.930	4.255
Croydon 3	0.292	0.245	1.383	0.139	2.059
Manchester 5	0.013	0.007	0.317	0.970	1.307
NWPO 6	0.285	0.433	0.288	0.715	1.721
TOTAL χ^2 COLUMNS	1.177	1.591	4.245	4.868	11.881

The Critical Value for χ^2 = 26.22 at the 1% significance level
& the " " " χ^2 = 21.03 " " 5% " "
for 12 degrees of freedom. The difference is not significant at χ^2 = 11.881 for the Various Wrappings in this sample from selected Offices.

Table 7.21 Average coefficients for the frictional performance of parcel, belt and sidewall materials, in both static and sliding mode. Values derived from parcel data.

WRAPPING/ BELT OR SIDEWALL	STEEL		COTTON		RUBBER		SCANDURA	
	Stat	Slid	Stat	Slid	Stat	Slid	Stat	Slid
Paper	.2113	.5745	.4568	.8402	.4498	.8489	.7901	1.1681
Cardboard	.2042	.5984	.4577	.8415	.4213	.8545	.7866	1.1820
Sacking	.2016	.5974	.4407	.8391	.6205	.7128	.8518	1.4281
Plastic	.2070	.5228	.4678	.8391	.4329	.6614	.8160	1.2854
Wood	.2311	.6942	.4407	.8391	.5190	1.0380	.8044	1.3210
Other	.2035	.6201	.4663	.8391	.5117	.8127	.8391	1.4281
All Parcels	.2102	.5937	.4573	.8401	.4802	.7735	.8110	1.236

Table 7.22 Values for the average dimensions and volumes of samples of a given number of parcels or packets.

OFFICE	AVERAGE DIMENSIONS FOR A GIVEN NUMBER OF PARCELS				
	LENGTH $\overline{L}$ (in)	BREADTH $\overline{B}$ (in)	HEIGHT $\overline{H}$ (in)	VOLUME $\overline{V}$ (in^3)	NUMBER N
BIRMINGHAM	14.202	9.073	4.781	727.906	330
BRIGHTON	15.196	9.818	4.990	792.411	381
CROYDON	14.398	8.644	4.470	728.027	301
LIVERPOOL	14.783	9.647	4.258	657.774	402
MANCHESTER	15.108	9.823	4.502	720.907	411
NWPO	15.207	8.954	4.733	688.738	240
ALL PARCELS	14.890	9.370	4.625	720.231	2065
WDO. (PACKETS)	10.101	5.866	1.132	59.019	337

The above tables are derived from the data used by Castellano, Clinch & Vick (1971)

Table 7.23 Factors for irregularity of shape (See Sec. 3.4) Comparison of the Product of average dimensions, P, with the average Volume, $\overline{V}$, to give the Ratio R_p and for further comparison, the Shape Factor, S_v.

OFFICE	P PRODUCT $\overline{L}*\overline{B}*\overline{H}$ in^3	$\overline{V}$ AVERAGE VOLUME in^3	R_p RATIO	S_v SHAPE FACTOR
BIRMINGHAM	616.190	727.906	0.8465	1.0397
BRIGHTON	744.480	792.411	0.9395	1.0807
CROYDON	556.320	728.027	0.7641	1.0192
LIVERPOOL	607.240	657.774	0.9232	1.0995
MANCHESTER	668.123	720.907	0.9268	1.0942
NWPO	644.462	688.738	0.9357	1.0906
WDO	67.074	59.019	1.136	1.4637

Table 7.24 Ratio of sliding friction coefficient to static friction coefficient

WRAPPING/ BELT OR WALL	STEEL	COTTON	RUBBER	SCANDURA
Paper	2.71	1.83	1.89	1.48
Cardboard	2.90	1.83	2.02	1.50
Plastic	2.52	1.79	1.53	1.57
Sacking	2.96	1.90	1.50	1.26
Wood	3.02	1.90	2.00	1.64
Other	3.04	1.79	1.58	1.70
All Parcels	2.82	1.84	1.61	1.52

The above tables are derived from the data from the work of Castellano, Clinch & Vick (1971)

Fig. 7.25 A plot of the frictional effect with a horizontal force which increases with time, exerted upon a body which is initially static. (From Shames, I.H. (1959), Engineering Mechanics - Statics).

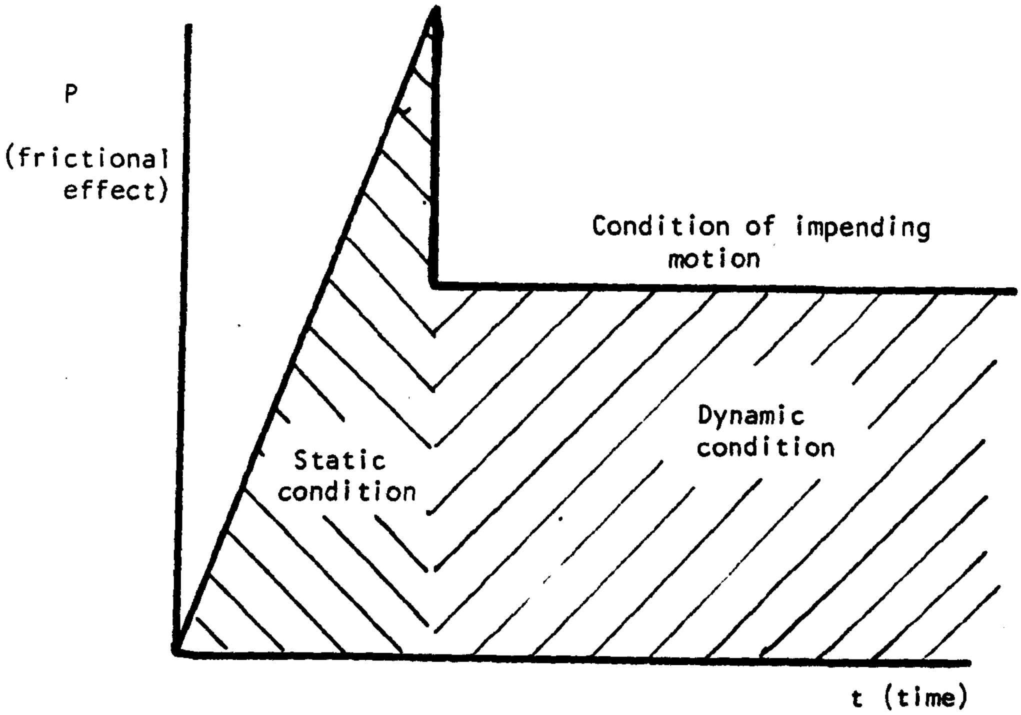


Fig. 7.26 Comparing the Friction Ratios of Belt/Sidewall Combinations.

DRAGGING/PULLING FORCE RATIO (See 7.3.1, page 167)	Reduction in the dragging/pulling force ratio when a parcel jams on sidewall. Steel figures derived from parcel data; maplewood figures from friction tests		
SIDEWALL & WRAPPING/ BELT MATERIAL	COTTON	RUBBER	SCANDURA
STEEL versus			
Polythene	0.221	0.259	0.252
Paper	0.201	0.195	0.249
PLAIN MAPLE WOOD versus			
Polythene	0.490	0.549	0.535
Paper	0.546	0.529	0.676
VARNISHED MAPLEWOOD versus			
Polythene	0.349	0.408	0.398
Paper	0.455	0.441	0.563

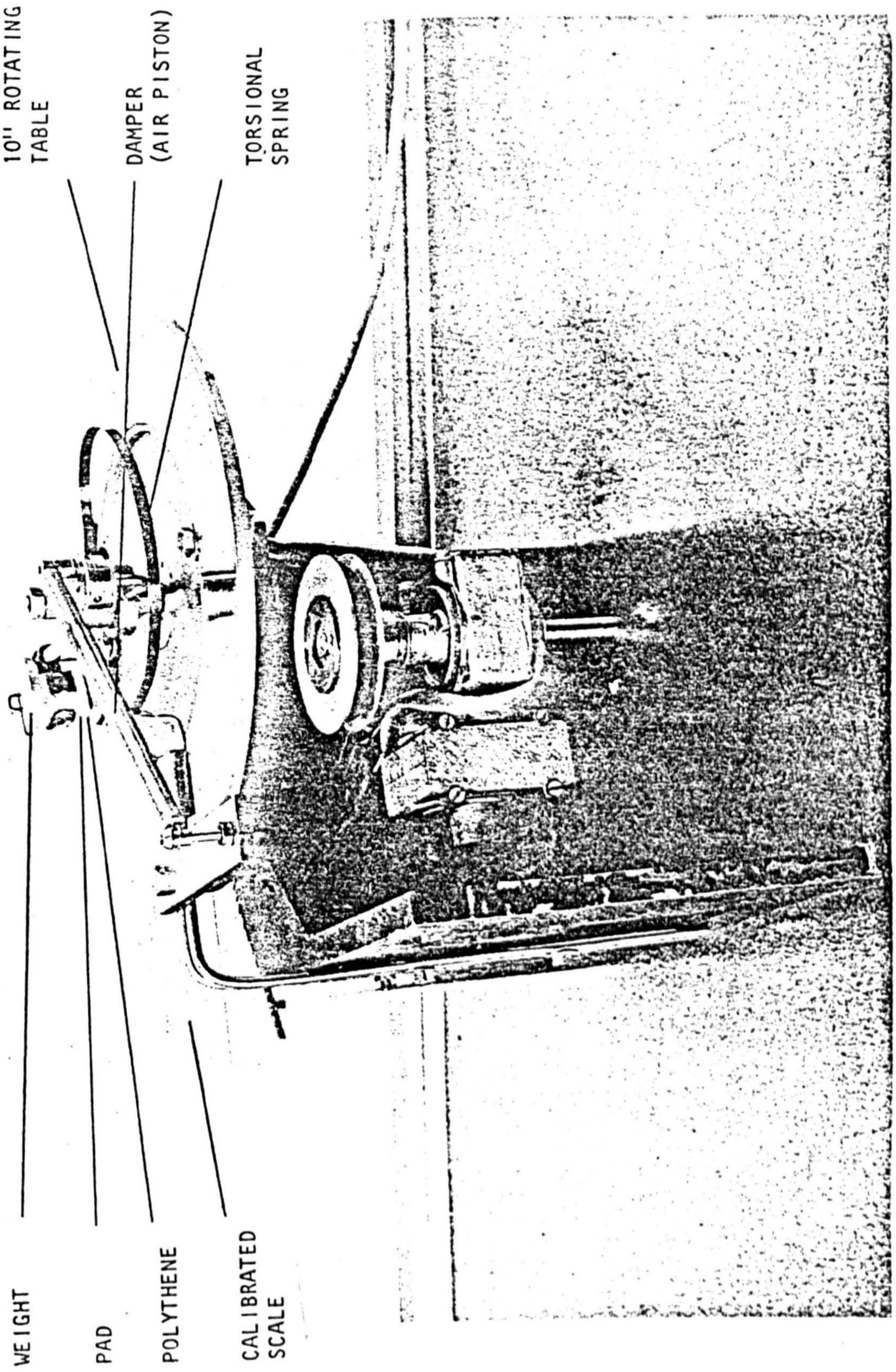


Fig. 7.27 The apparatus for evaluating friction coefficients.

Fig 7.28 Friction Coefficients of Maplewood against Polythene or Brown Paper. The effect of Rubbing Speed between the two materials is plotted against friction coefficient, μ .(Relative Humidity RH was 45-50%,Temperature 18-21° C & Contact Pressure 0.7 lbf/in^2)

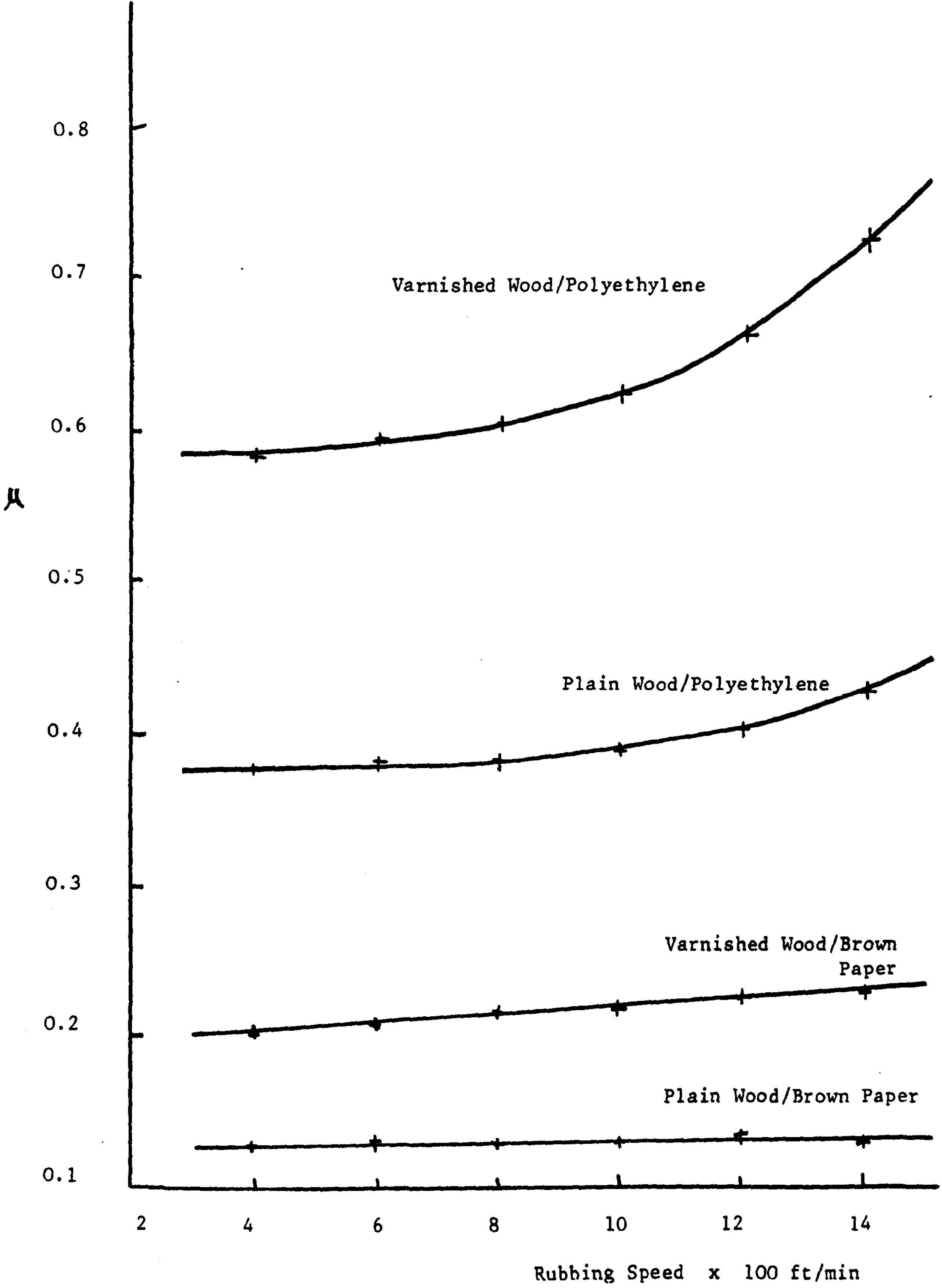


Fig. 7.29 Friction Coefficients of Maplewood against Polythene or Brown Paper. The effect of Contact Pressure between the two materials is plotted against μ (Relative Humidity RH was 45-50%. Temperature was 18-21° C, and the Rubbing Speeds were 250 and 1500 feet/min.)

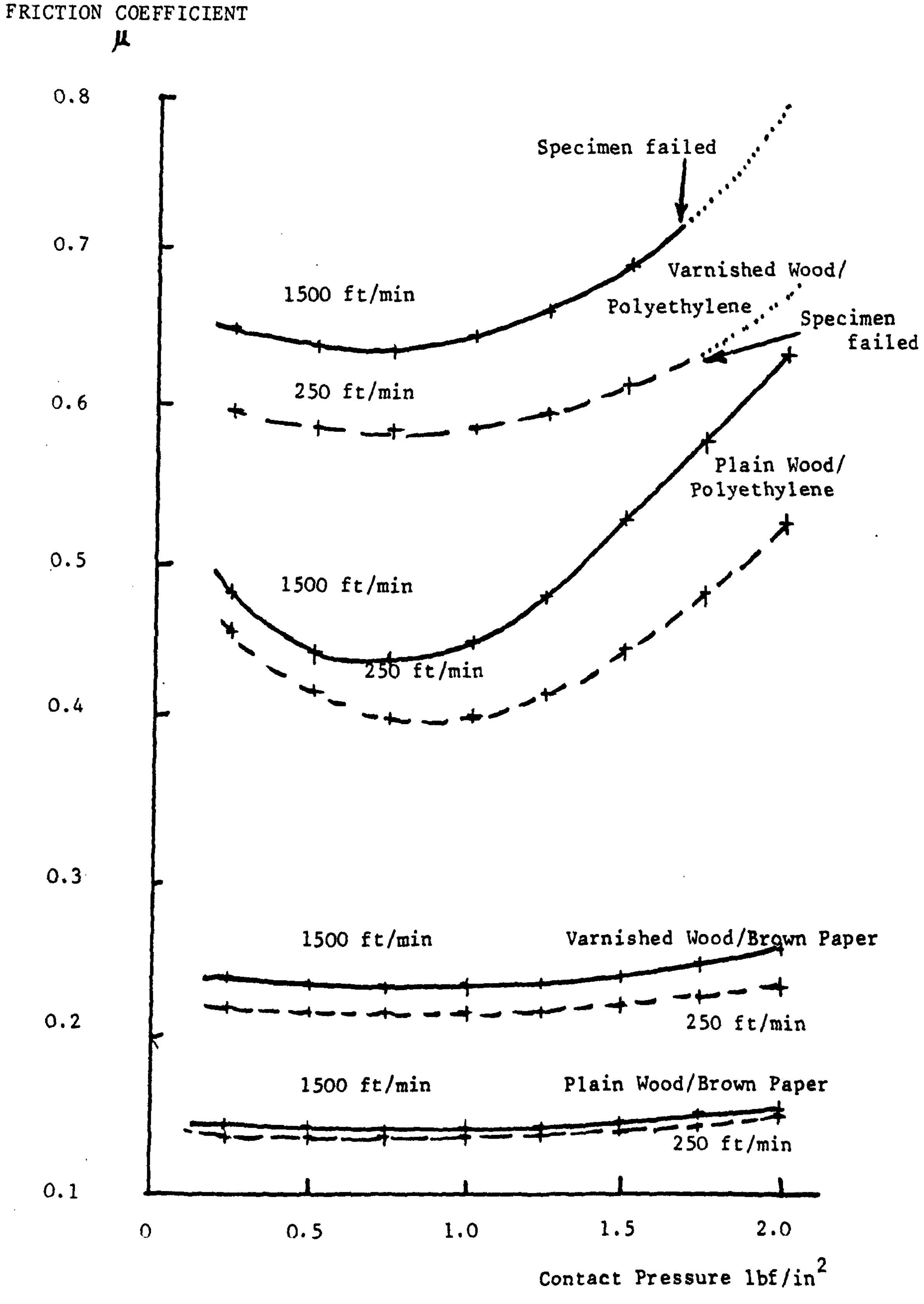


Fig. 7.30 Friction Coefficients of Mild Steel against Brown Paper, showing the effect of Speed & Pressure of the sliding surfaces. The materials had static friction coefficients ranging from 0.20 to 0.24. (Published in Castellano, Clinch & Vick (1971))

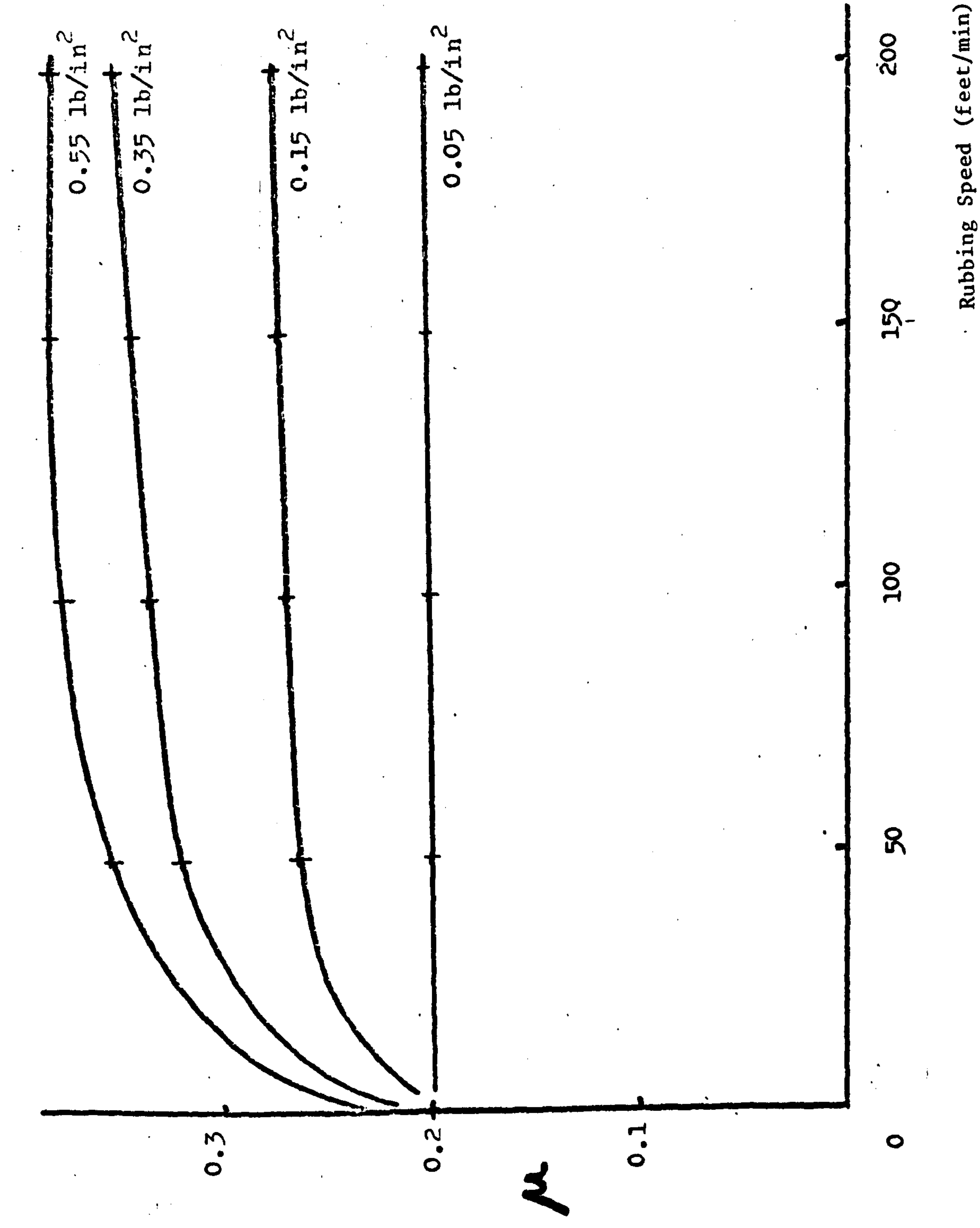
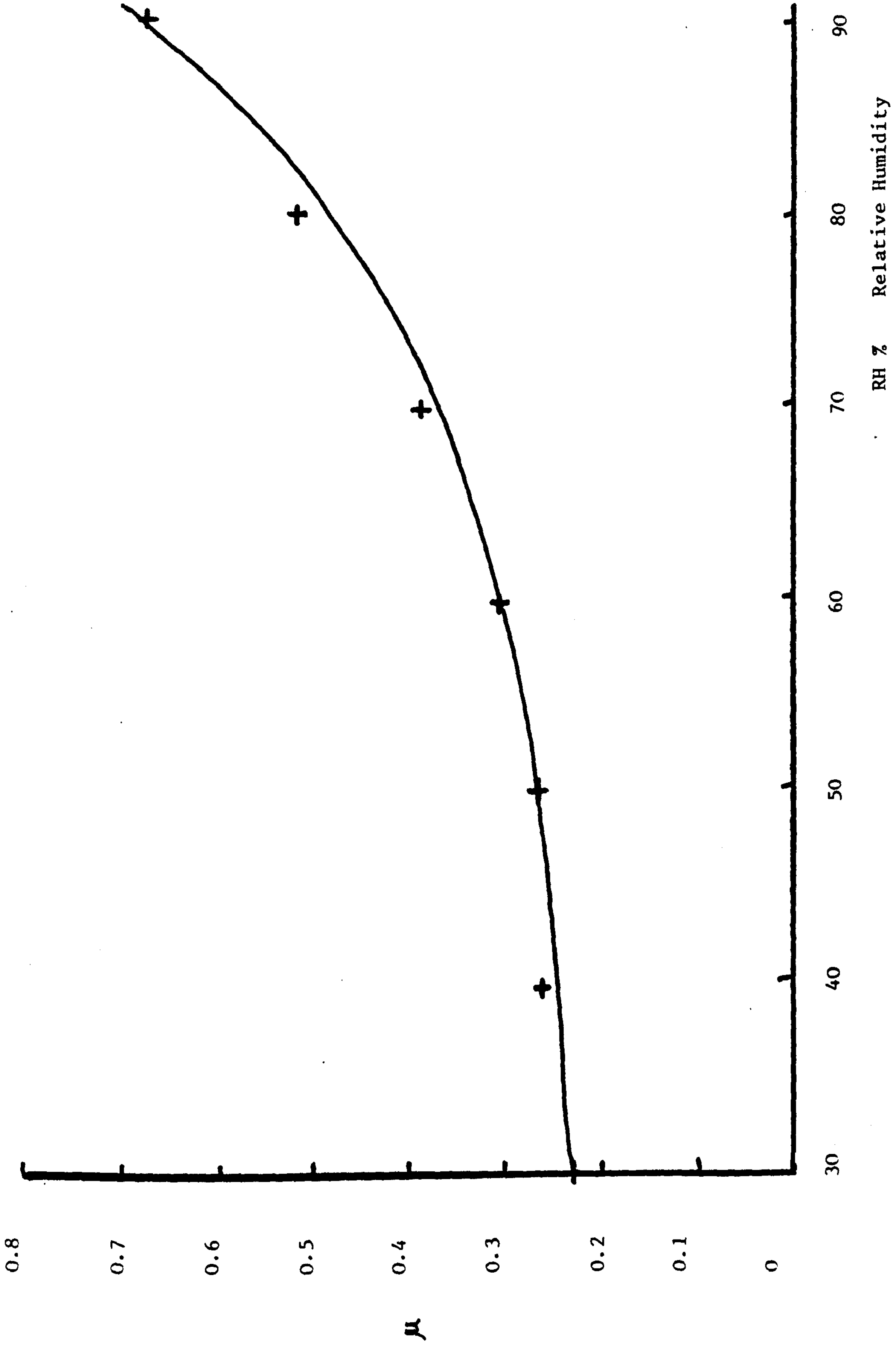


Fig. 7.31 Friction Coefficients of Mild Steel against Brown Paper, showing the effect of Relative Humidity. (Rubbing Speed was 180 ft/min, Temperature was 24° C and Pressure was 0.05 lbf/in^2)



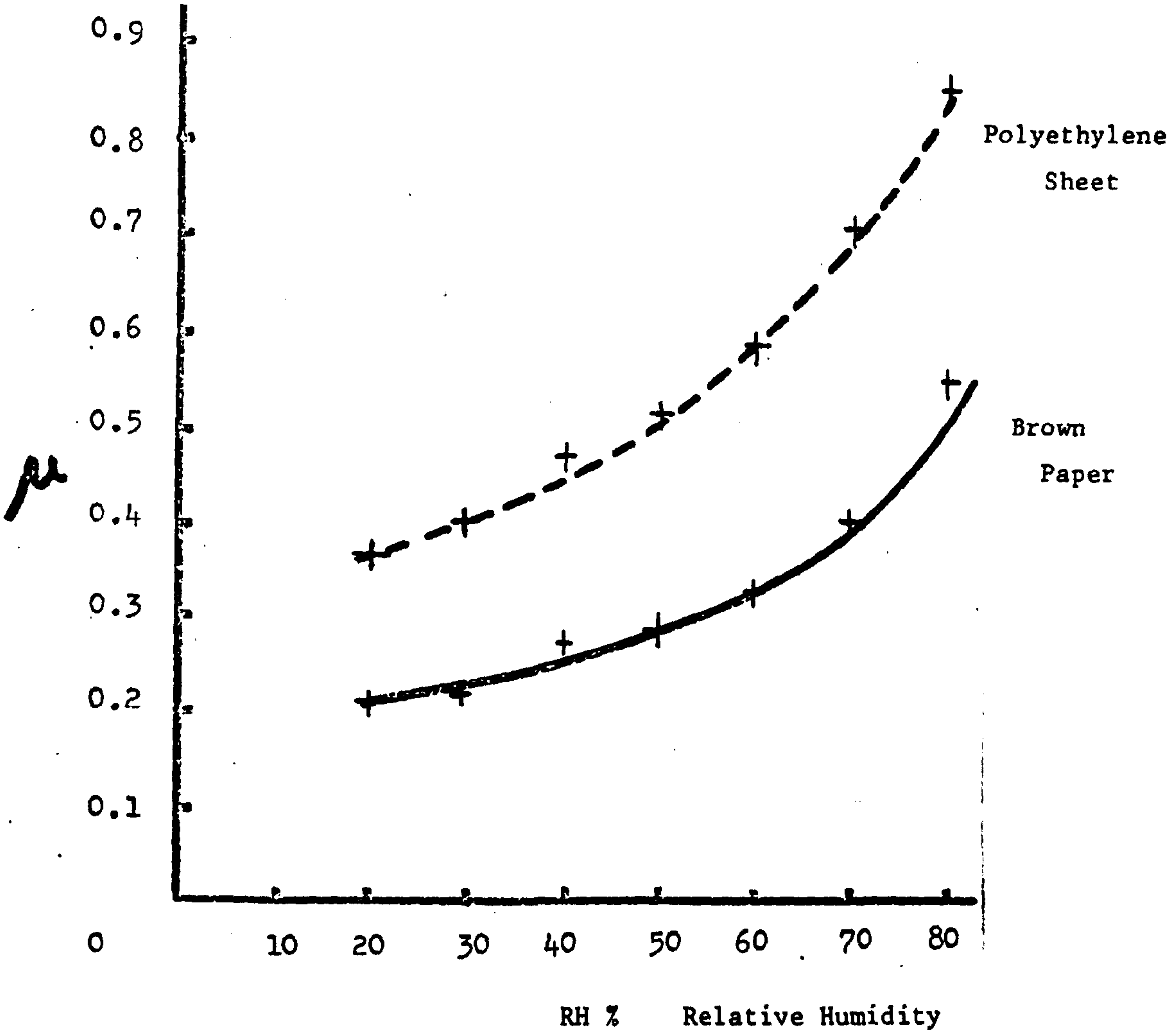


Fig. 7.32 Friction Coefficient of Mild Steel against Brown Paper, compared to Mild Steel against Polyethylene Sheet, showing the effects of Relative Humidity.

(Rubbing Speed is 180ft/min, Temperature 24° C and the Pressure is 0.05 lbf/in^2)

Table 7.33 Coefficient of sliding friction for polythene in various surface states against polished mild steel obtained on the laboratory test rig, at various humidities. (See page 174)

Mild Steel versus Polythene in Surface Condition:		SLIDING FRICTION COEFFICIENT			
	RH	40%	50%	60%	70%
Damp		0.46	0.57	0.71	0.85
Scratched		0.42	0.45	0.52	0.61
Dusty		0.38	0.42	0.48	0.55
Greasy		0.49	0.52	0.55	0.70
Mean value		0.44	0.49	0.57	0.68

Table 7.34 Value of the multiplier PEXP derived from Tab 7.33. (See sec 7.3.2, page 175)

Mild Steel versus Polythene in Surface Condition		MULTIPLIER PEXP			
	RH	40/50%	50/60%	60/70%	Average
Damp		1.23	1.24	1.20	1.22
Scratched		1.07	1.15	1.17	1.13
Dusty		1.10	1.14	1.14	1.13
Greasy		1.06	1.06	1.27	1.13
Mean value		1.12	1.15	1.20	1.15

Table 7.35 The 13 hour Average Temperatures & Relative Humidities for various point in the British Isles. The values for Relative Humidity on a 7 hour or 18 hour basis would be considerably higher. (Abstracted from data in Averages of Humidity for the British Isles, Meteorological Office,1949)

LOCATION	TEMPERATURE °F AVERAGE FOR 13 HRS	RELATIVE HUMIDITIES AVERAGE FOR 13 HRS	
		YEARLY AVERAGE	LOWEST MONTHS AVERAGE
TOWNS			
Birmingham	52.4	71	63
Croydon	54.8	69	60
Liverpool	51.5	74	68
London	55.1	67	57
COUNTIES			
Hampshire	54.7	72	68
Kent	53.0	73	65
Lancashire	52.9	75	68
Lincolnshire	53.4	75	65
Northumberland	50.9	77	74
Norfolk	52.7	79	72
Yorkshire-East Riding	51.2	81	77
" -West Riding	51.3	73	67

Values are for the period approximately 1920 to 1938. See Appendix VIII, page 327, for details of Relative Humidity and its measurement.

Fig 7.36 The arrangement for the load-deflection tests upon parcels for estimation of stiffness.

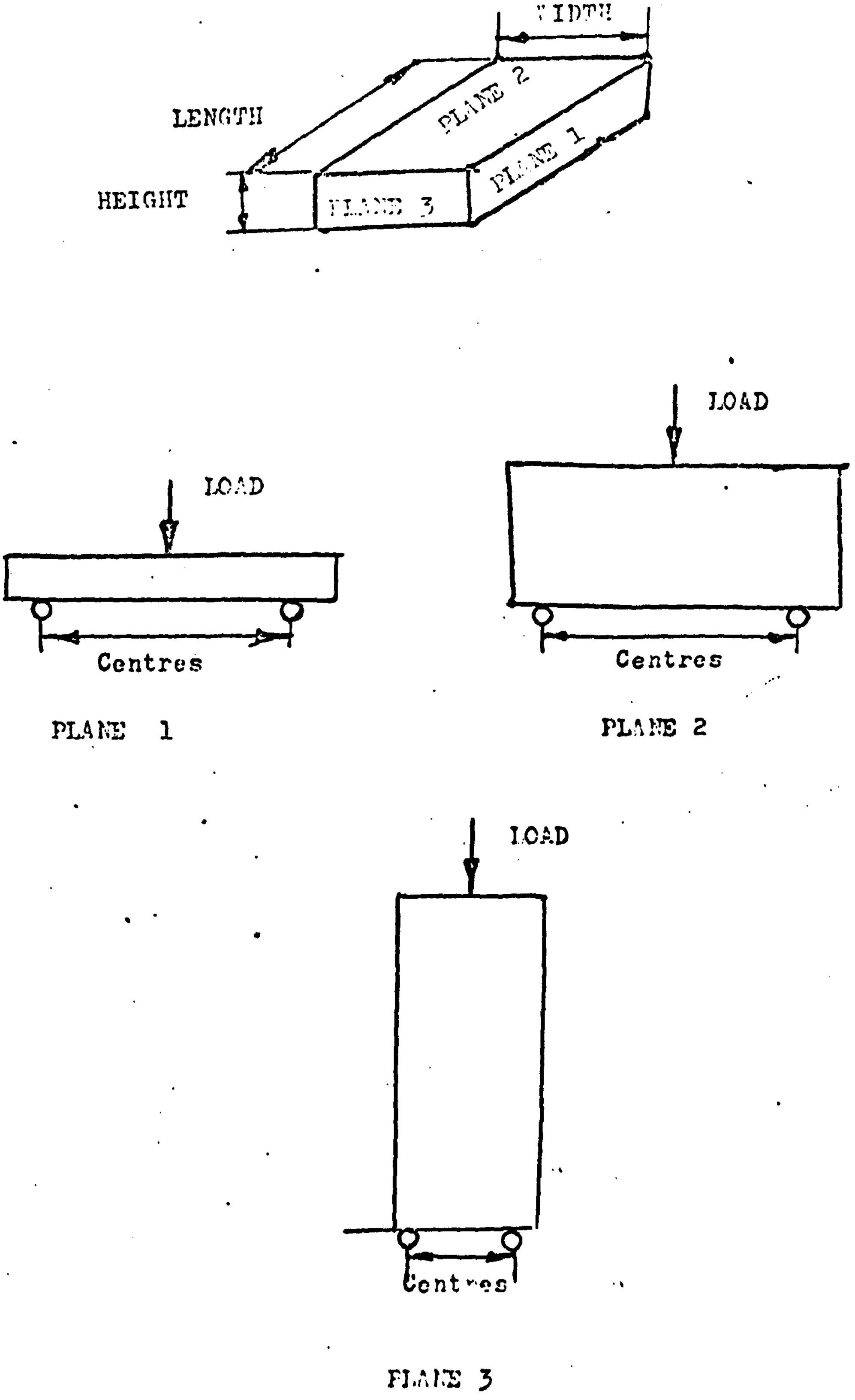


Table 7.37 Table of Load/Deflection Values & Stiffness, with Correlation Coefficients.

PARCEL NO	PLANE NO	LOAD lbs	DEFLECTION inches	STIFFNESS lb/inch	CORRELATION COEFFICIENT	INTERCEPT lbs
1	1	5	0.19			
		10	0.50			
		15	0.75	17.79	0.998	1.46
1	2	5	0.03			
		10	0.06			
		15	0.09			
		20	0.25	59.74	0.907	6.08
Value	for	Load	20 lbs	excluded	gives:	
1	2	as	before	166.67	1.000	0.00
1	3	5	0.03			
		10	0.06			
		15	0.11	122.45	0.989	1.84
2	1	5	0.06			
		10	0.12			
		15	0.21			
		20	0.31	58.82	0.994	2.21
2	2	5	0.03			
		10	0.06			
		15	0.12			
		20	0.15	116.67	0.989	2.00
2	3	5	0.07			
		10	0.12			
		15	0.18			
		20	0.25	82.87	0.997	-0.34

Figure 7.38 The Interdata Computer Programme for the calculation of Stiffness, Second Moment and Modulus of Elasticity. (For the data file creation programme,see Appendix III,page 262)

```
LIST
100 REM  PSTF & MODULUS PROGRAM
105 DIM U(8)
110 DIM S(3,2),D(3,8),N(4),AS(5),Y$(3),N$(2)
120 Y$="YES"
130 N$="NO"
150 S1=0
160 FOR Z=1 TO 3
170 FOR Z1=1 TO 8
172 D(Z,Z1)=0
174 NEXT Z1
176 FOR Z2=1 TO 2
178 S(Z,Z2)=0
180 NEXT Z2
182 NEXT Z
200 ;"HOW MANY PARCELS ?"
210 INPUT N1
212 ;"ON WHICH CHANNEL IS YOUR DATA FILE /"
214 INPUT X
220 ;"IS THE DATA ALREADY ON FILE ?"
230 INPUT A$
240 IF A$=Y$ THEN 300
250 IF A$=N$ THEN 350
260 ;"PLEASE ANSWER YES OR NO"
270 GOTO 220
300 S9=1
340 GOTO 400
350 S9=2
360 ;"INPUT DATA WHEN * IS PRINTED, IN 7 LINES : THUS"
365 ;"      LINE 1 : PCL NO, LENGTH , WIDTH, HEIGHT"
370 ;"      FOR PLANE 1 ; LINE 2 : PLANE 1 CENTRE,NO OF POINTS"
372 ;"      FOR PLANE 1 ; LINE 3 : LOAD,DEFLECTION,  ETC"
374 ;"      FOR PLANE 2 ; LINES 4&5 SIMILAR TO 2&3"
376 ;"      FOR PLANE 3 ; LINES 6&7 SIMILAR TO 2&3"
380 ;
382 ;"BEGINNING NOW :"
400 ;"PLANE","STIFFNESS","2ND MOMENT","MODULUS OF ELASTICITY"
405 FOR N9=1 TO N1
407 F=(N9-1)*7
410 IF S9=1 THEN 600
415 IF S9=2 THEN 420
417 ;"SWITCH S9 NOT 1 OR 2"
419 GOTO 9990
420 ;"*"
430 INPUT N,L,W,H
440 FOR A=1 TO 3
450 INPUT S(A,1),S(A,2)
460 FOR A9=1 TO S(A,2)
470 INPUT D(A,1+(A9-1)*2),D(A,2+(A9-1)*2)
480 NEXT A9
490 NEXT A
```

Continued overleaf ....

Figure 7.38 Computer Programme for Stiffness, etc .... continued ....

```
500 ; ON (X,1+F)N;L;W;H
505 FOR A=1 TO 3
510 G=(A-1)*2
520 ; ON (X,2+F+G)S(A,1);S(A,2)
530 FOR H1=1 TO 8
540 U(H1)=D(A,H1)
550 NEXT H1
560 ; ON (X,3+F+G)U(1);U(2);U(3);U(4);U(5);U(6);U(7);U(8)
570 NEXT A
580 GOTO 1000
600 INPUT ON (X,1+(N9-1)*7)N,L,W,H
610 FOR A=1 TO 3
617 G=(A-1)*2
620 INPUT ON (X,2+G+F)S(A,1),S(A,2)
640 INPUT ON (X,3+G+F)U(1),U(2),U(3),U(4),U(5),U(6),U(7),U(8)
650 FOR H1=1 TO 8
660 D(A,H1)=U(H1)
670 NEXT H1
680 NEXT A
690 GOTO 1000
1000 ;
1010 ;
1020 ;"*****    PARCEL NUMBER ";N9
1030 ;
1060 FOR C=1 TO 3
1070 S8=0
1100 FOR B=1 TO S(C,2)
1110 S8=S8+(D(C,1+(B-1)*2)/D(C,2+(B-1)*2))
1120 NEXT B
1130 IF C=1 THEN LET S1=S8/S(1,2)
1140 IF C=2 THEN LET S2=S8/S(2,2)
1150 IF C=3 THEN LET S3=S8/S(3,2)
1160 NEXT C
1200 M1=W*(H↑3)/12
1210 M2=H*(W↑3)/12
1220 M3=H*(L↑3)/12
1240 E1=S1*(S(1,1)↑3)/(48*M1)
1250 E2=S2*(S(2,1)↑3)/(48*M2)
1260 E3=S3*(S(3,1)↑3)/(48*M3)
1300 ;"1",S1,M1,E1
1310 ;"2",S2,M2,E2
1320 ;"3",S3,M3,E3
1400 NEXT N9
9990 ;"RUN NOW ENDS"
9999 END
BASIC
```

Figure 7.39 Table of results from the Interdata Computer Programme, written by the authos, to obtain values of Stiffness, Second Moment, and the apparent Modulus of Elasticity.

```
*AS 502
*RU BASIC
BASIC
REW 10
LOAD 10
BASIC
RUN
HOW MANY PARCELS ?
8
ON WHICH CHANNEL IS YOUR DATA FILE /
11
IS THE DATA ALREADY ON FILE ?
YES
PLANE          STIFFNESS      2ND MOMENT     MODULUS OF ELASTICITY

*****     PARCEL NUMBER  1

1              22.1053        1.46484        160.966
2              145            75.9374        20.3677
3              156.566        180            9.27799

*****     PARCEL NUMBER  2

1              75.6528        15.5976        101.047
2              147.917        167.062        18.4458
3              79.5238        503.479        .710769

*****     PARCEL NUMBER  3

1              289.683        60             276.003
2              50.2502        474.609        6.05263
3              136.409        1710.99        .850402

*****     PARCEL NUMBER  4

1              123.611        59.2974        119.169
2              185.691        1018.12        10.4264
3              203.629        1910.04        3.83794
```

The remainder of the output is similar.

Table 7.40 Computers used in the Project.

MAKE & MODEL	TYPE	SIZE Kwd	USES IN PROJECT
ICL 1903A	Mainframe	32-96	Simulation, ASCOP statistical package.
CDC 6600/7600 Batch	Highspeed Mainframe	64 Fast 256 Slow	SPSS Statistical package
CTL Modula 1 RJE Terminal	Mini	16	Remote job batch entry for CDC 7600
CYBERNET SIGMA 9	Highspeed Mainframe and Mini	96	STAN statistical package
DEC PDP 8 Terminal/VDU	Mini	16	Subsidiary analysis
LEASCO Hewlett Packard HP 2000	Mini	32	Subsidiary programs, statistical analysis.
Open University HP 2116 Terminal	Mini	32	" " "
CSL MINIC Terminal	Mini	16	Subsidiary programs
INTERDATA 70	Mini	32	Subsidiary analysis, statistics

Table 7.41 FORTRAN Compilers used in the Project

MACHINE TYPE	SIZE Kwds	COMPILER TYPE	SIZE Kwds
ICL 1903A 2 EDS 8 Discs	32	XFAT Magnetic Tape	16 K
ICL 1903A 4 EDS 8 Discs 4 MT	48	XFAE Disc	19
ICL 1903A 4 EDS 8 Discs 2 EDS 60 "	96	XFIV Disc	32
CDC 7600 4 EDS 60 Discs	64 fast	MNF Disc	32
	256 slow	FTN	32

Fig. 7.42 The listing of the MSD BASIC language programme for the INTERDATA computer. The Mean, the Standard Deviation and the Student's t-test are evaluated, with the aid of statistical tables for the critical values of 't'.

```
LIST
10 REM       MEAN & S.D. PLUS 'T' TEST
20 DIM A£(5)
30 S1=0
40 S2=0
50 ;"INPUT DATA ON * : TERMINATE WITH 999999"
60 C=0
70 ;"*"
80 INPUT X
90 IF X=999999 THEN 140
100 S1=S1+X
110 S2=S2+X*X
120 C=C+1
130 GOTO 70
140 ;
150 ;"*******"
160 M=S1/C
170 V=ABS(S2-S1*S1/C)/(C-1)
180 D=SQR(V)
190 ;"MEAN = ";M;"   STANDARD DEVIATION =  ";D
200 ;"FOR 2 SAMPLE TEST USE SEPARATE PROGRAM"
210 ;"DO YOU WANT SINGLE SAMPLE T TEST ?"
220 INPUT A£
230 IF A£="NO" THEN 530
240 ;"DEGREES OF FREEDOM ARE ";C-1
250 ;"GIVE T TEST VALUE FROM TABLE, & YOUR CONFIDENCE LEVEL "
260 INPUT T,C9
270 S=D/SQR(C)
280 ;"BEST ESTIMATE OF SIGMA POPULATION = ";S
290 ;"DO YOU KNOW POPULATION MEAN ?"
300 INPUT A£
310 IF A£="YES" THEN 380
320 M9=M+T*S
330 M8=M-T*S
340 ;"POPULATION MEAN LIES BETWEEN ";M8;"  AND  ";M9
350 ;"  AT  ";C9;"  LEVEL OF CONFIDENCE"
360 ;
370 GOTO 530
```

Continued overleaf ....

Fig. 7.42 The MSD computer programme ......continued

```
380 ;"GIVE POPULATION MEAN ?"
390 INPUT M1
400 T1=(M-M1)/S
410 IF ABS(T1)<T THEN 500
420 ;"T TEST VALUE IS ";T1;" AGAINST TABLE VALUE OF ";T
430 ;"  REJECT NULL HYPOTHESIS AT ";C9;"CONFIDENCE LEVEL"
440 ;"DO  YOU WISH TO REVISE TABLE VALUE & CONFIDENCE LEVEL ?"
450 INPUT A£
460 IF A£="NO" THEN 530
470 ;"INPUT NEW TABLE VALUE FOR T,  & CONFIDENCE LEVEL **"
480 INPUT T,C9
490 GOTO 410
500 ;"T TEST VALUE IS ";T1;" AGAINST TABLE VALUE OF ";T
510 ;"ACCEPT NULL HYPOTHESIS AT";C9;"CONFIDENCE LEVEL"
520 GOTO 440
530 ;"ANY MORE ?"
540 INPUT A£
550 IF A£="YES" THEN 30
560 IF A£="NO" THEN 590
570 ;"TYPE YES OR NO ,  PLEASE"
580 GOTO 530
590 ;"RUN COMPLETED"
600 END
BASIC
```

Fig. 7.43 Sample Output from the MSD programme run on the INTERDATA computer. The Mean & Standard Deviation are calculated for a sample of loadings of parcel traffic for the Croydon Office. The number of parcels ranges from an average value for the group of from 51.3 to 67.5, according to the sample chosen.

```
RUN
INPUT DATA ON * : TERMINATE WITH 999999
*
76
*
57
*
41
*
52
*
63
*
58
*
999999

*******
MEAN =   57.8333     STANDARD DEVIATION =     11.6175
FOR 2 SAMPLE TEST USE SEPARATE PROGRAM
DO YOU WANT SINGLE SAMPLE T TEST ?
NO
ANY MORE ?
NO
RUN COMPLETED
BASIC
```

Fig. 7.44 The CO2 programme in the BASIC language to calculate the Mean & Standard Deviation, and also the Slope, Intercept and the Correlation Coefficient for pairs of values for two related dependent and independent variables.

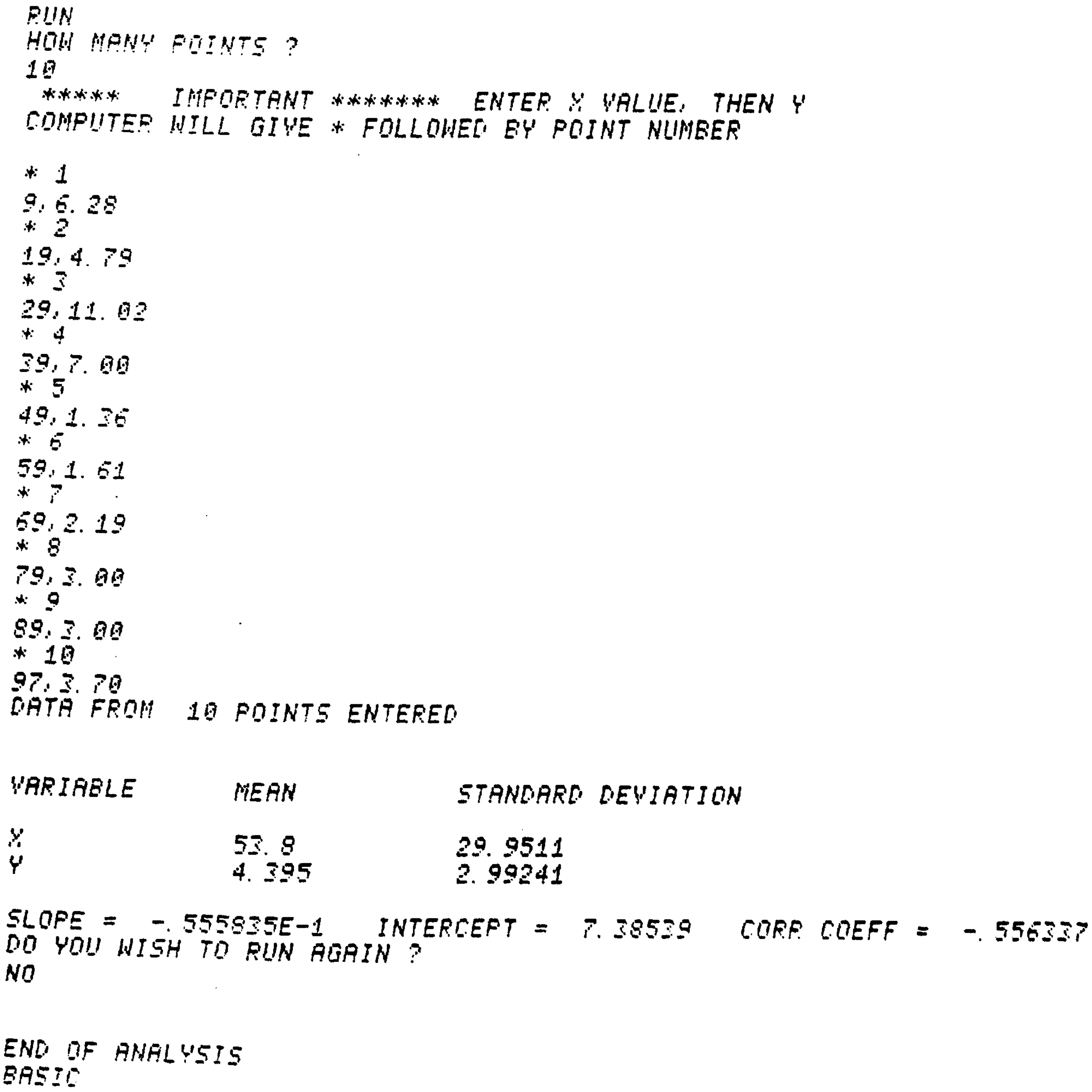
```
LIST
100 REM          MEAN, SD & CORRELATION OF SETS OF 2 DIMENSIONAL POINTS
105 DIM A£(5)
110 DIM X(100), Y(100)
120 ;"HOW MANY POINTS ?"
130 INPUT N
140 ;" *****    IMPORTANT *******  ENTER X VALUE, THEN Y "
150 ;"COMPUTER WILL GIVE * FOLLOWED BY POINT NUMBER "
160 ;
200 FOR I=1 TO N
205 ;"*";I
210 INPUT X(I),Y(I)
230 NEXT I
240 ;"DATA FROM ";N;"POINTS ENTERED"
250 ;
260 S1=0
270 S2=0
280 S3=0
290 S4=0
300 S5=0
310 FOR J=1 TO N
320 S1=S1+X(J)
330 S2=S2+Y(J)
340 S3=S3+X(J)*Y(J)
350 S4=S4+X(J)*X(J)
360 S5=S5+Y(J)*Y(J)
370 NEXT J
380 M1=S1/N
390 M2=S2/N
395 Q=ABS(S4-(S1*S1/N))/(N-1)
400 D1=SQR(Q)
405 Q1=ABS(S5-(S2*S2/N))/(N-1)
410 D2=SQR(Q1)
420 U=(N*S4-S1*S1)
430 S=(N*S3-S1*S2)
435 B=S/U
440 A=(S2-B*S1)/N
460 T=U*(N*S5-S2^2)
470 R=S/(SQR(T))
480 ;
490 ;"VARIABLE","MEAN","STANDARD DEVIATION"
```

Continued overleaf ....

Fig. 7.44 Continued .... The CO2 programme.

```
500 ;
510 ;"X";M1;D1
520 ;"Y";M2;D2
530 ;
540 ;"SLOPE = ";B;"  INTERCEPT = ";A;"  CORR COEFF = ";R
600 ;"DO YOU WISH TO RUN AGAIN ?"
610 INPUT A£
620 IF A£="NO" THEN 900
630 ;
640 ;
650 ;
660 ;" ENTER NEW VALUES OF Y NOW "
670 FOR J=1 TO N
680 ;"*";J
690 INPUT Y(J)
700 NEXT J
710 GOTO 240
900 ;
910 ;
920 ;"END OF ANALYSIS"
999 END
BASIC
```

Fig. 7.45 Sample output from the CO2 programme when run on the INTERDATA computer. The results are for the independent variable x, which is the number of parcels dropped into a conveyor section, (40 in wide x 36 in high x 72 in long), against the dependent variable y, which is the maximum sidewall base force ratio.



```
RUN
HOW MANY POINTS ?
10
 *****    IMPORTANT *******  ENTER X VALUE, THEN Y
COMPUTER WILL GIVE * FOLLOWED BY POINT NUMBER

* 1
9,6.28
* 2
19,4.79
* 3
29,11.02
* 4
39,7.00
* 5
49,1.36
* 6
59,1.61
* 7
69,2.19
* 8
79,3.00
* 9
89,3.00
* 10
97,3.70
DATA FROM  10 POINTS ENTERED

VARIABLE        MEAN            STANDARD DEVIATION

X               53.8            29.9511
Y               4.395           2.99241

SLOPE =  -.555835E-1   INTERCEPT =  7.38539   CORR COEFF =  -.556337
DO YOU WISH TO RUN AGAIN ?
NO

END OF ANALYSIS
BASIC
```

Table 7.46 Comparison of Intensity of Packing between location of Parcels by either Random Placement (Static) or Moving Belt Models.

MODEL	AVERAGE NUMBER OF PARCELS	PACKING DENSITY % of conveyor volume	WEIGHT lbs	WIDTH OF CONVEYOR inches	OFFICE
R P Static	64.6	35.0	330.3	40	All six
Moving Belt	98.7	62.3	520.7	40	All six
R P Static	70.9	35.31	336.0	40	Croydon
Moving Belt	97.0	47.5	449.5	40	Croydon
R P Static	68.8	33.5	321.4	32-72	Croydon
Moving Belt	98.1	48.2	455.3	32-72	Croydon
R P Static	62.7	34.2	322.4	32-72	All six
Moving Belt	99.1	59.1	526.3	32-72	All six

where

$$\text{PACKING DENSITY} = \frac{\text{VOLUME OF PARCELS LOADED}}{\text{VOLUME OF CONVEYOR SECTION}} \times 100\ \%$$

Table 7.47 The Ratio of Packing Parameters R

THE RATIOS FOR				
AVERAGE NUMBER OF PARCELS	PACKING DENSITY	WEIGHT	WIDTH OF CONVEYOR (in)	OFFICE
1.53	1.78	1.58	40	All six
1.37	1.35	1.34	40	Croydon
1.43	1.44	1.41	32-72	Croydon
1.58	1.73	1.63	32-72	All six

where

$$R = \frac{\text{MOVING BELT PARAMETER}}{\text{RANDOM PLACEMENT PARAMETER}}$$

Table 7.48 A comparison of the intensity of packing for varying widths of conveyor for samples of 3 test loadings of parcels into a constant area of 2880 square inches in plan.

AVERAGE NUMBER OF PARCELS	PACKING DENSITY % Conveyor volume	WEIGHT (lbs)	WIDTH OF CONVEYOR (in)
72.00	35.35	349.04	32
63.67	30.66	294.15	36
62.67	37.54	364.88	40
72.33	35.69	348.08	44
69.30	33.59	323.60	48
74.30	37.19	348.08	52
63.00	30.66	289.98	56
68.70	32.92	315.36	60
69.33	33.65	322.61	64
64.33	31.35	293.69	68
63.00	30.14	286.69	72

Table 7.49 ANALYSIS OF VARIANCE TABLES

Table 7.49.1 Analysis of variance for 11 sample loadings for conveyor widths from 32 to 72 inches and constant area in plan of 2880 square in. Each sample contained 3 parcel loadings from Croydon Office data.

VARIATION SOURCE WIDTH CHANGING	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE ESTIMATE
Within samples	3344.69	22	152.03
Between samples	547.56	10	54.76
Total	3892.25	32	

CONFIDENCE LEVEL	VALUES OF THE F-RATIO	
	CRITICAL VALUES AT 22,10 df	ACTUAL
95%	2.76	2.78
99%	4.37	Just Sig.

Table 7.49.2 Analysis of variance for 7 sample loadings for 40 inch conveyor width. Each sample contained 3 parcel loadings from Croydon data.

VARIATION SOURCE WIDTH CONSTANT	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE ESTIMATE
Within samples	2867.31	14	204.81
Between samples	473.94	6	78.99
Total	3341.25	20	

CONFIDENCE LEVEL	VALUES OF THE F-RATIO	
	CRITICAL VALUES AT 14,6 df	ACTUAL
95%	3.96	2.59
99%	7.61	Not Sig.

```
  HUMIDITY IS  60%
  FRICTION FORCES ARE:
                                         BASE:                                              SIDE WALL
    295.02 SLIDING,     193.39 STATIC.                               0.00 SLIDING,     0.00 STATIC.
NO JAM OCCURS.



  HUMIDITY IS  70%
  FRICTION FORCES ARE:
                                         BASE:                                              SIDE WALL
    429.10 SLIDING,     284.07 STATIC.                               0.00 SLIDING,     0.00 STATIC.
NO JAM OCCURS.
 PARCEL LOADS, & PRESSURES (LBF/IN2)
 NUMBER                LOAD              LOAD 2                LOAD 3                PRESSURE
     1                      1.0000                3.9000                27.5000                0.3682
     2                      1.2000               48.1000                 2.5000                0.4111
     3                      0.7000                0.7000                 1.5000                0.0279
     4                      0.4000                0.4000                 3.9000                0.0339
     5                      0.4000                0.4000                43.2000                0.4000
     6                      2.3000                2.3000                 4.6000                0.0585
     7                     43.8000                6.9000                 5.2000                1.0656
     8                      0.6000                2.7000                11.8000                0.4194
     9                      0.3000                0.3000                14.9000                0.5536
    10                      0.8000                0.8000                 1.6000                0.0653
    11                      0.3000                0.3000                 0.7000                0.1083
    12                      0.4000                7.2000                 6.7000                0.1702
    13                      1.1000                5.9000                 2.3000                0.0275
    14                      1.9000                1.3000                 2.7000                0.0615
    15                      4.3000                4.3000                21.1000                0.1757
    16                      1.8000                1.8000                 5.0000                0.0672
    17                     75.0000                0.9000                 5.3000                0.3404
    18                      7.0000               22.3000                 2.9000                0.1941
    19                      2.1000                2.1000                29.7000                0.4708
    20                     54.1000                4.0000                16.0000                0.7125
    21                      0.5000                0.5000                 1.1000                0.0875
    22                      0.8000                0.8000                 1.6000                0.1600
    23                      0.5000                2.1000                 7.9000                0.0868
    24                     10.9000                5.3000                 1.6000                0.1187
    25                      2.0000                5.6000                 4.6000                0.1356
    26                     10.1000                1.5000                 3.0000                0.1604
    27                      0.9000                3.6000                 4.1000                0.0769
    28                      1.6000                2.1000                19.7000                0.1125
    29                      0.6000               15.5000                 5.4000                0.7679
    30                      1.1000                1.1000                 2.3000                0.0714
    31                      0.5000                0.5000                 1.1000                0.0389
    32                      0.5000               43.2000                 9.0000                0.3660
    33                      0.5000                0.5000                 1.0000                0.0303
    34                      0.7000                0.7000                 1.4000                0.0259
    35                      1.8000               13.1000                 6.2000                0.1279
    36                      0.5000                0.5000                 1.1000                0.0350
    37                      1.0000                1.0000                 2.1000                0.0325
    38                      4.0000                4.0000                33.0000                0.4271
    39                      1.8000                4.4000                 1.8000                0.0606
    40                      1.0000                1.4000                 2.0000                0.0458
    41                      3.5000                3.5000                 7.8000                0.1265
    42                      0.8000                6.8000                14.6000                0.0822
    43                      1.5000                1.0000                 2.0000                0.0433
    44                      0.9000                0.9000                 3.9000                0.1163
    45                      0.9000                0.9000                 1.8000                0.0745
    46                      0.4000                0.4000                 0.8000                0.0205
    47                      0.4000                0.4000                 0.8000                0.0229
    48                      0.5000                0.5000                 2.2000                0.0296
    49                      1.4000                1.4000                 3.2000                0.0513
    50                      0.4000                0.4000                 0.8000                0.0348
    51                      4.1000                4.1000                 8.3000                0.1269
    52                      0.8000                0.8000                 1.7000                0.0317
    53                      4.3000                4.3000                 8.7000                0.1331
```

Fig. 7.50 Computer printout of the Load & Pressure values of a loading of parcels using Brighton Office data. The values calculated are those which are oriented along the orthogonal axes of the conveyor and not the parcel axes.

Table 7.51 Parcel Pressures for Brighton Parcels, giving the results under relatively high traffic intensities. The method of calculating pressures is discussed in section 7.5.4.1 on page 211.

Parcel No.	Pressure lbf/in^2	Parcel No.	Pressure lbf/in^2
1	1.98	32	1.72
2	1.15	33	1.12
3	0.58	34	0.44
4	0.03	35	0.0
5	1.94	36	1.62
6	0.45	37	0.38
7	1.76	38	1.59
8	0.87	39	0.81
9	0.18	40	0.09
10	0.18	41	0.06
11	0.42	42	0.38
12	0.15	43	0.13
13	2.73	44	2.37
14	0.27	45	0.25
15	0.58	46	0.50
16	0.25	47	0.22
17	0.51	48	0.44
18	0.49	49	0.44
19	0.34	50	0.28
20	1.52	51	1.31
21	0.22	52	0.16
22	0.48	53	0.41
23	0.06	54	0.03
24	0.37	55	0.28
25	0.22	56	0.19
26	0.60	57	0.50
27	1.69	58	1.50
28	0.03	59	0.0
29	0.09	60	0.03
30	0.28	61	0.22
31	0.28	62	0.25
Average			0.605

Table 7.52 Comparison of Loading Models and Contact Effects.

LOADING TYPE	PARCELS CONTACTS		NUMBER OF TESTS
	BASE	SIDEWALL	
RANDOM PLACEMENT Mean Average 63.8 S D parcels per loading	13.43 3.01	10.07 3.58	14
MOVING BELT Mean 59 parcels S D	16.89 3.95	8.67 3.00	9
DEGREES OF FREEDOM	21	21	
t-TEST ACTUAL VALUE	2.28 Just sig.	0.93 Not sig.	
CRITICAL VALUES OF t	1.72 at 95% level 3.53 at 99% level		
F-RATIO ACTUAL VALUE	1.80 Not sig.	1.36 Not Sig.	
DEGREES OF FREEDOM SIGNIFICANCE LEVEL CRITICAL VALUES OF F	8,13 95% 2.77	13,8 95% 3.27	

Table 7.53 Table of Loading effects versus Computer usage

COMPUTING EVALUATOR	MOVING		STATIC	
Programme	TL 201	TL 203	TL 202	TL 204
CORE USED Kwds	9.336	9.236	8.364	9.086
MILL TIME (mins/run)	1.11-1.59	1.09-1.17	1.13-1.47	1.12-1.19
RUN TIME (" ")	1.23-1.69	1.15-1.24	1.19-1.54	1.18-1.24
MILL TIME/PARCEL Minm	0.426	0.414	0.528	0.378
(seconds) Maxm	0.604	0.444	0.720	0.438
Average	0.515	0.429	0.624	0.408

Table 7.54 Table of variation of Evaluation Parameters with changes of Traffic Intensity, $x = 9$ to 97 parcels loaded in a conveyor 40 inches wide by 36 high with a section 72 inches long. The correlation is based on a linear relationship of $y = mx + c$ (See page 217)

EVALUATION PARAMETER y	EVALUATION PARAMETER CHANGE				
	Min	Max	Slope m	Intercept c	Correlation Coefficient r
PACKING					
Density %	5.54	47.32	0.468	0.60	0.999
Weight lbs	46.6	449.0	4.65	4.24	0.999
LOAD/PRESSURE					
Load lbs	14.4	121.0	1.019	27.836	0.782
Pressure lbf/in^2	0.32	11.42	0.014	1.809	0.137
SIDEWALL/BASE FORCE RATIO					
Max %	1.61	11.02	-0.056	7.385	-0.556
Average %	0.86	3.57	0.005	1.895	0.185
FORCES & CONTACTS					
Normal Base Forces lb	17.07	189.0	1.937	-1.316	0.997
Normal Sliding Forces Max	1.12	6.82	0.047	0.939	0.694
Normal Sliding Forces Ave:	0.37	6.28	0.053	-0.549	0.875
Contacts-Base	7.6	26.5	0.179	6.759	0.935
Contacts-Sidewall	1.4	2.1	0.232	-1.893	0.989

where the SIDEWALL/BASE FORCE RATIO is calculated as follows :-

$$S\ B\ F\ R = \frac{\text{Dragging Force on the Sidewalls}}{\text{Traction Force on the Moving Belt}} \times 100\%$$

Table 7.55 Comparison of Computer usage against traffic intensity for a conveyor section (40 in wide by 72 in long by 36 in high).

TRAFFIC INTENSITY	MILL TIME	MILL TIME/PARCEL	DIFFERENCE x 10^{-4}
9	0.021	0.0023	
			2
19	0.048	0.0025	
			0
29	0.072	0.0025	
			3
39	0.110	0.0028	
			28
49	0.275	0.0056	
			4
59	0.354	0.0060	
			6
69	0.458	0.0066	
			13
79	0.627	0.0079	
			27
89	0.939	0.0106	
			32
97	1.340	0.0138	

Table 7.56 Table of Packing Intensity,(No. of Parcels, Packing Density & Weight of Parcels loaded into a constant area of conveyor of 2880 square inches) as a function of the Width of the Conveyor. The parcel data was from Croydon Office, and the model was the Random Placement or Static loading.

WIDTH OF CONVEYOR (inches)	NO OF PARCELS	PACKING DENSITY (%)	WEIGHT (lbs)
32	72	35.4	349
36	63.7	30.7	294
40	76.5	37.5	367
44	72.3	35.7	348
48	69.3	33.6	323
52	74.3	37.2	348
56	63	30.7	290
60	68.7	32.9	315
64	69.3	33.7	323
68	64.33	31.4	294
72	63	30.1	287

NOTE :-

1) That PACKING DENSITY $= \dfrac{\text{Volume of Parcels in Section}}{\text{Volume of Conveyor}} \times 100\%$

2) That all of the above runs used a conveyor of constant height of 36 in. For the conveyor lengths appropriate to the widths, see Table 7.58.

Table 7.57 Table of Maximum Loads & Pressures on parcels in a Conveyor Section of constant area of 2880 square inches in plan view, which are shown against varying widths of conveyor section. Samples for both Random Placement (R P) and Moving Belt (M B) models are given, using parcel data from Croydon Office. The respective values of maximum load and of maximum pressure are not necessarily on the same parcel, or even on the same run in that sample.

WIDTH OF CONVEYOR (inches)	MAXIMUM LOAD (pounds force)		MAXIMUM PRESSURE (pounds force/in^2)	
Model No of runs/sample	RP 3	MB 4	RP 3	MB 4
32	114	97	5.15	1.21
36	101	123	1.54	1.83
40	118	137	1.96	11.42
44	160	122	1.98	2.91
48	104	85	2.60	2.76
52	152	129	2.17	14.4
56	140	80	1.40	2.23
60	95	92	1.57	4.68
64	115	97	1.89	4.26
68	100	92	1.87	4.70
72	111	119	2.17	4.29

Table 7.58 Table of Number of Contacts of Parcels with the sidewall and base of a Conveyor Section of constant area of 2880 square inches, shown against varying widths of conveyor section. Random Placement (RP) models have a sample size of 4 runs, and Moving Belt Models (MB) have a sample size of 3 runs.

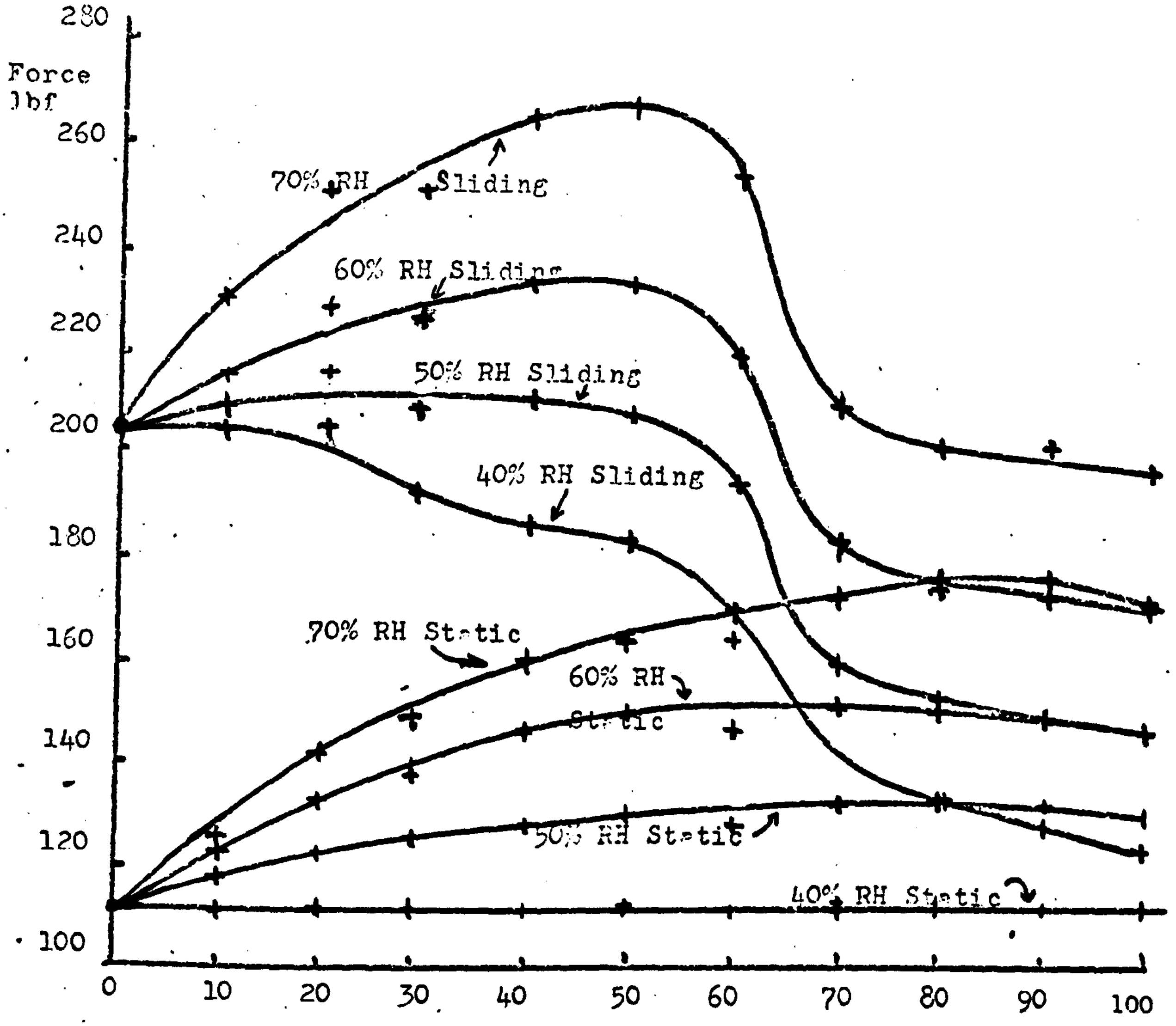
CONVEYOR		BASE CONTACTS		SIDEWALL CONTACTS	
WIDTH (in)	LENGTH (in)	RP (no)	MB (no)	RP (no)	MB (no)
32	90	15.75	15.67	9.75	18.00
36	80	17.00	17.67	8.75	12.00
40	72	12.25	14.00	8.00	10.50
44	65	13.50	16.00	6.00	10.00
48	60	16.50	16.00	6.75	9.33
52	55	17.00	15.67	5.50	7.67
56	51	16.75	17.33	4.75	6.67
60	48	16.50	17.33	3.50	6.33
64	45	18.00	16.33	5.00	6.33
68	42	15.25	14.33	3.25	5.00
72	40	17.25	15.67	2.25	3.33

Table 7.59 Table of Forces on the Base and Sidewalls of a Conveyor Section of constant area of 2880 square inches, shown against varying widths of conveyor section. The conditions for testing are as for tables 7.57 & 7.58.

CONVEYOR WIDTH (in)	BASE FORCE STATIC (lbf)		SIDEWALL FORCE SLIDING (lbf)		SIDEWALL/BASE FORCE RATIO (%)	
	RP	MB	RP	MB	RP	MB
32	125	89	3.25	2.61	2.59	2.94
36	114	88	1.06	2.29	0.92	2.61
40	152	90	1.05	0.78	0.69	0.86
44	141	89	1.17	2.22	0.83	2.49
48	129	95	1.18	1.93	0.92	2.03
52	148	90	2.10	1.55	1.42	1.73
56	119	89	0.44	2.30	0.37	2.59
60	133	95	0.78	0.50	0.59	0.53
64	131	93	2.49	2.03	1.89	2.19
68	123	90	0.74	1.34	0.60	1.48
72	118	95	0.89	0.45	0.75	0.47

Table 7.60 Linear Regression of Evaluation Parameters, (See Section 7.5.3, page 201) against the change in width, which is the independent variable, x = 32 to 72 inches. The correlation is based upon the relation y = mx + c

EVALUATION PARAMETER y	EVALUATION PARAMETER CHANGE				
	Sample		Slope	Intercept	Correlation Coefficient
	Min	Max	m	c	r
LOADING (Packing Intensity)					
Number of pcls	63	74.3	-0.17	77.9	-0.492
Packing Density %	30.1	37.5	-0.10	38.75	-0.500
Weight lbs	287	365	-1.216	384.68	-0.578
LOAD/PRESSURE					
Max Load lbf	73.1	124.5	-0.364	116.29	-0.264
Pressure lbf/in^2	1.23	3.51	-0.023	3.04	-0.556
FORCES & CONTACTS					
Random Placement lbf	114.3	152.5	0.105	127.6	0.213
Base Force					
Moving Belt lbf	87.5	95.3	0.115	88.3	0.107
Random Placement lbf	0.44	3.25	0.097	2.31	0.162
Sliding Force					
Moving Belt lbf	0.45	2.61	0.003	1.7	0.127
Contacts - Base Number	14.0	17.66	-0.009	16.47	-0.111
Contacts - Sidewall Number	3.3	18.0	-0.004	15.95	-0.140
SIDEWALL/BASE FORCE RATIO					
Random Placement %	0.40	9.2	-0.036	3.67	-0.188
Average					
Moving Belt %	0.47	2.94	-0.037	3.70	-0.560



% age of Plastic Wrapped Parcels in the sample loadings.

Fig. 7.61 The effect of varying percentages of Plastic Wrapped Parcels in the sample loadings, upon the Traction Force exerted upon the Conveyor Belt. The parcel data is that from Croydon Office, the model is the Moving Belt (MB) and the belt material is rubberised cotton. It is assumed that the belt surface remains at ambient temperature, and the friction data used,is that found from the test rig shown in fig 7.27.

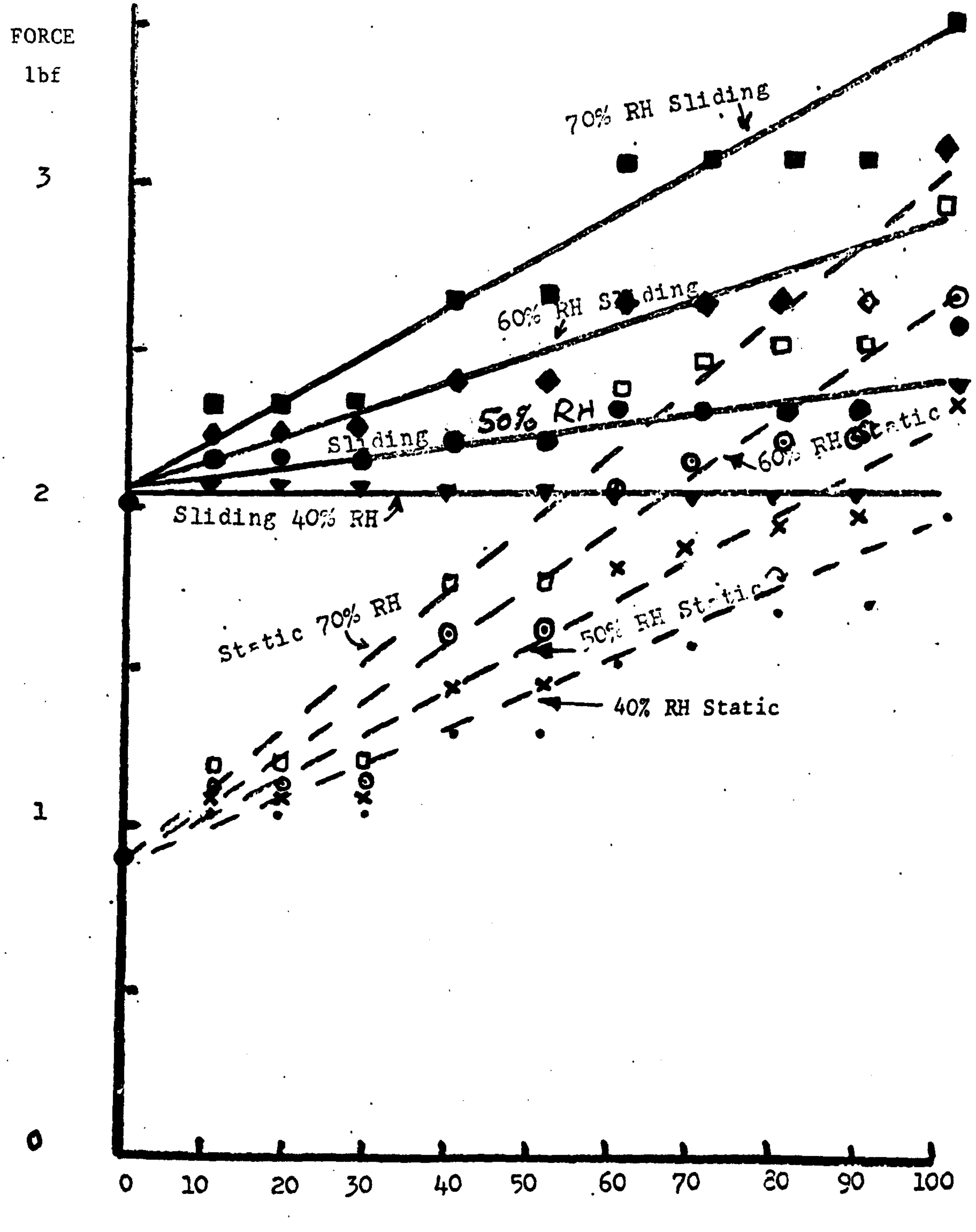


Fig. 7.62 The effect of varying percentages of Plastic Wrapped Parcels in the sample loadings, upon the Frictional Forces exerted upon the Sidewalls of the Conveyor Section, which is that considered in Fig. 7.61. The sidewall material is steel, and the assumptions and conditions are unchanged.

Table 7.63 The Packing Intensity given by the Computer Simulation, using the Parcel Data for the six offices of Castellano, Clinch & Vick (1971). This is compared to the Packing Intensity obtained when using the Parcel Data for the sample of live mail from the Validation Tests at WDPO.

PACKING INTENSITY GIVEN BY THE COMPUTER SIMULATION				
OFFICE	NUMBER OF PARCELS		PACKING DENSITY %	
	Mean	Standard Deviation	Mean	Standard Deviation
Birmingham	73.5	14.53	46.3	5.88
Brighton	57.8	11.63	38.2	11.02
Croydon	63.0	15.92	31.1	2.66
Liverpool	60.7	9.97	32.8	4.92
Manchester	63.2	13.73	37.4	7.76
NWPO	61.7	13.05	38.4	8.43
WDPO	68.3	12.37	49.1	7.26

Table 7.64 Table of Packing Intensity resulting from the Validation Tests carried out at WDPO. A stationary conveyor of similar cross-section to the computer simulation, was packed by hand with samples of live mail.

PACKING INTENSITY RESULTING FROM HAND PACKING LIVE MAIL		
DESCRIPTION in	NUMBER OF PARCELS	PACKING DENSITY %
Approx. 40 wide by 36 high by 72 long	74	50.51
Approx 40 wide by 36 high by 108 long	126	54.90
108 long results scaled down to 72 long	84	54.90

$$\text{where PACKING INTENSITY} = \frac{\text{Volume of Parcels loaded}}{\text{Volume of Conveyor Section}} \times 100\%$$

Table 7.65 Table of results from the statistical analysis using the SPSS computer programme.

	Number of Parcels	Length		Breadth		Height		Weight	
		M	σ	M	σ	M	σ	M	σ
Birmingham	330	14.202	5.413	9.073	3.785	4.781	2.642	5.79	4.392
Brighton	382	15.156	5.231	9.793	3.255	4.977	2.702	5.692	4.179
Croydon	302	14.35	6.474	8.616	3.562	4.455	2.694	4.462	3.828
Liverpool	403	14.746	6.139	9.623	3.360	4.248	3.050	5.022	4.259
Manchester	419	15.004	5.683	9.766	3.687	4.500	2.363	4.889	3.392
NWPO	241	15.144	6.484	8.917	3.510	4.713	2.610	5.482	4.245
All parcels	2075	14.809	5.848	9.389	3.532	4.610	2.691	5.222	4.060
WDO Pkts	337	10.024	5.012	5.844	4.413	1.119	.697	.624	.455

where M = Mean dimension in inches of sample of stated number
σ = Standard Deviation " " " " " "

Table 7.66 An analysis of the Parameters given by the SPSS programme given in Table 7.65, to compare Packet & Parcel characteristics.

PARAMETER	$\bar{L}$	$\bar{B}$	$\bar{H}$	$\bar{W}$	$\bar{V}$
Packet	10.024	5.844	1.119	0.624	65.551
Parcel	14.809	9.389	4.610	5.222	640.982
Comparison Ratio CR	0.677	0.622	0.243	0.119	0.102

APPENDIX X

BIBLIOGRAPHY

BIBLIOGRAPHY

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