FORECASTING AND INVENTORY CONTROL

FOR HOSPITAL MANAGEMENT

A Thesis submitted to the

Department of Statistics and Operational Research

Brunel University

in fulfillment of the requirements

for the degree of

Doctor of Philosophy

by

Walter Ramsey Crowe

Brunel University

1977

ABSTRACT

Economic stringencies have compelled Canadian hospitals to examine their administrative effectiveness critically.

Improved supplies and inventory procedures adopted by leading industrial corporations, suggest that hospitals might benefit from such systems. Lack of the profit incentive, and the high ratio of wages to total expenses in hospitals, have delayed adoption of modern inventory management techniques. This study examined the economic status of Canadian hospitals, and endeavoured to discover whether a computer-based inventory management system, incorporating short-term statistical demand forecasting, would be feasible and advantageous.

Scientific forecasting for inventory management is not used by hospitals. The writer considered which technique would be most suited to their needs, taking account of benefits claimed by industrial users. Samples of demand data were subjected to a variety of simple forecasting methods, including moving averages, exponentially smoothed averages and the Box-Jenkins method. Comparisons were made in terms of relative size of forecast errors; ease of data maintenance, and demands upon hospital clerical staffs. The computer system: BRUFICH facilitated scrutiny of the effect of each technique upon major components of the system.

It is concluded that either of two methods would be appropriate: moving averages and double exponential smoothing. The latter, when combined with adaptive control through tracking signals, is easily incorporated within the total inventory system. It requires only a short run of data, tracks trend satisfactorily, and demands little operator intervention.

The original system designed by this writer was adopted by the Hospital for Sick Children, Toronto, and has significantly improved their inventory management.

ACKNOWLEDGEMENTS

Generous assistance has been afforded me by administrators of hospitals and other health care institutions; members of faculty of several universities; and management staffs of corporations in Canada, U.S.A., and Great Britain.

Much of this research was undertaken during intervals between teaching and other professional duties. I am grateful to my colleagues at Lakehead University for their forebearance, and encouragement they extended to me.

My wife insisted that this thesis should be written, and firmly encouraged its completion. Her support and enthusiasm are warmly acknowledged.

It is a pleasure to express my gratitude to my supervisor, Professor Peter Macdonald, Head of the Department of Statistics and Operational Research at Brunel University. His guidance, suggestions, criticisms and advice were invaluable, and much appreciated.

Gratitude is expressed to these organizations for substantial financial assistance:

International Business Machines Limited, for an IBM Fellowship Award;

Lakehead University, for Chancellor's Fund Awards;

Ministry of Health, Government of Ontario, for Provincial Health Research Grants.

To the undermentioned persons my thanks are due, for permitting me to visit them and exchange ideas and experience:

J.H. Babson, School of Health Administration, University of Ottawa.

B. Barber, Operational Research Group, The London Hospital.

J.A. Bell, Laycock Engineering, Sheffield, Yorks.

A. Benson, McMaster University, Hamilton, Ont.

F.M. Black, General Motors of Canada, Oshawa, Ont.

J.L. Bogod, I.C.L. Medical Division, London.

E.G. Braithwaite, South-Western Metropolitan Regional Hospital Board, London.

J.S. Burnett, S. Smith and A. Nichol, Research and Intelligence Unit, Scottish Home and Health Department, Edinburgh.

D.A. Campana, Children's Hospital Medical Center, Boston, Mass.

C.A. Catassi, Alameda-Contra Costa Medical Association, Oakland, California.

N. Chaplin, The Institute of Hospital Administrators, London.

J.B. Cornish, J.M.G. Wilson and G. Madison, Hospital Supply Branch, Department of Health and Social Security, London.

E.A. Cross, South-Western Metropolitan Regional Hospital Board, Regional Pharmacy, London.

J.D. Croston, Management Services, Hoover, Perivale, London.

A. Crowe, Pharmacist, Port Arthur General Hospital, Ont.

W.S. Deyoe, New York University Medical Center, New York City.

D.E. Dowdell, Esso Petroleum, London.

A.J. Drdul, Education Center, I.B.M. Canada, Winnipeg, Man.

I.B. Duncan, Health Services Unit, University of Reading, Reading, Berks.

V. Eichmann, Associated Hospital Services, Milwaukee, Wis.

A.W. Engle, American Association of Hospital Accountants, Chicago, Illinois.

A.J. Enns, Monarch Machinery, Winnipeg, Manitoba.

J.R. Evans, The Queen Elizabeth Medical Centre, Birmingham.

F. Ford, The National Computing Centre, Manchester.

K. Free, The Pharmacy, Essex County Hospital, Colchester.

W.G. Gaman, Market Research, Wilmot Breeden, Birmingham.

M. Gibson, Management Services, Boots Pure Drug Company, Nottingham.

Sister L. Greco, W. Emack, P. Heney, Miss E. Taylor, St. Joseph's General Hospital, Thunder Bay, Ontario.

J. Griffith, Renold Limited, Wythenshawe, Manchester.

M. Hale, Ontario Hospital Association, Toronto.

J.M. Hayward, Pharmacist, Northwick Park Hospital, Harrow.

S. Heda, Bureau of Hospital Administration, University of Michigan, Ann Arbor, Mich.

W.M. Heller, American Society of Hospital Pharmacists, Washington, D.C.

L. Hernandez, H.D. Moyer, Strong Memorial Hospital, Rochester, New York.

B.A. Hodson, Institute for Computer Studies, University of Manitoba, Winnipeg, Man.

T. Hunt, C. Jones, Hillingdon Hospital, London.

J. Hutton and staff, Department of Industrial Engineering, Hospital for Sick Children, Toronto.

W. Jeffreys, Treasurer, Welsh Hospital Board, Cardiff.

J. Emlyn Jones, Regional Treasurer, Northwestern Regional Hospital Board, Manchester.

L.F. Jones, Area Supplies Officer, Severalls Hospital, Colchester, Essex.

C.L. Keehn, P. Splawski, General Hospital of Port Arthur, Ontario.

G.W. Kell, Herbert Small Tools & Equipment, Coventry, Warwick.

T. Kember, House Governor, The Westminster Hospital, London.

M. Kennedy and E. Hucks, Birmingham Regional Hospital Board, Birmingham.

G. King, Production Control, British Motor Corporation, Longbridge, Birmingham.

V.C. King, Advanced Devices Centre, Northern Electric, Ottawa, Ont.

R.L. Kraus, The New York Hospital, New York.

K.A. Kurbis, Willson Stationers, Winnipeg, Manitoba.

D. Linton, D.W. Carlson, Kimberley-Clark of Canada, Toronto, Ontario.

D. McDermott, Ottawa General Hospital, Ottawa, Ontario.

L. Marden, The Queen Elizabeth II Hospital, Welwyn Garden City, Herts.

E.A. Marostica, McKellar General Hospital, Thunder Bay, Ontario.

L.J. O'Riley, Atomic Energy of Canada, Ottawa, Ontario.

J.S. Parks, Pharmacist, Victoria Hospital, London, Ontario.

E.M. Partridge, The Plessey Company, Ilford, Essex.

W.E. Prichard, E.B. Eddy Company, Hull, Quebec.

H. Rapp, National Cash Register, Toronto, Ontario.

J. Robinson, Engineer, Wycombe General Hospital, High Wycombe, Bucks.

J.J. Rocchio, International Computing, Bethesda, Maryland.

E.J. Rooke-Matthews, Southampton University Hospitals Management Committee, Southampton, Hampshire.

B.A. Sammons, Purchasing Department, Winnipeg General Hospital, Winnipeg, Manitoba.

E.W. Seccombe, King's Fund Hospital Administrative Staff College, London.

C. Shanks, Systems Study Group, University of Saskatchewan, Saskatoon, Sask.

D. Shaw, Canadian Society of Hospital Pharmacists, Toronto, Ontario.

L.R. Shaw, The Proctor & Gamble Company, Toronto, Ontario.

R.F.A. Shegog, The Nuffield Provincial Hospitals Trust, London.

G.F. Shipway, Marketing Department, Joseph Lucas, Birmingham.

M.G. Simpson, Department of Operational Research, University of Lancaster, Lancs.

H.E. Smalley, Medical College of Georgia, Augusta, Ga.

Staff, Department of Health and Social Security, Computers and Research Branch, London.

Staff, Purchasing Department, Toronto General Hospital, Toronto, Ontario.

D.J. Stephenson, General Foods, Toronto, Ontario.

R.G. Storey, Planning & Development Branch, Greater London Council, London.

J. Stringer, J. Luckman, Institute for Operational Research, London.

I.R. Tomlinson, Supplies Officer, Sheffield Regional Hospitals Board, Sheffield, Yorks.

R.C. Tomlinson et alia, Operational Research Department, The National Coal Board, Harrow, Middlesex.

B.W. Turner, National Cash Register Co., London.

A.P. Voce, South Western Regional Hospital Board, Bristol.

E.G. Wallace, Burroughs Corporation, Detroit, Michigan.

E. Wilson, Henderson General Hospital, Hamilton, Ontario.

H. Wolfe, Department of Industrial Engineering, Univerity of Pittsburgh, Pittsburgh, Penn.

R.C. Wolfinden, Department of Public Health, University of Bristol, Bristol.

R.A. Wood, Canadian Tire Corporation, Toronto, Ontario.

D. Zilz, University of Wisconsin Hospitals, Madison, Wis.

S.W. Zimmermann, Graduate Program in Hospital Administration, University of Chicago, Chicago, Illinois.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

HOSPITAL SUPPLIES MANAGEMENT: INTRODUCTION

Since 1950, with the return to 'normal' conditions following a major war, interest in the scientific management of supplies and inventories has been growing. In recent years several important books have been published by Brown (1963), Hadley and Whitin (1963), Trux (1968) and Lewis (1970) among others, offering both theory and practical methods for use by manufacturers and commercial distributors. Computer systems designers have contributed actively to the improvement of inventory management, working either as consultants or within large organizations.

This literature is directed towards industry and commerce and much less has been published applicable to hospital inventory management. Most authors provide broad surveys, or concentrate on the bookkeeping aspects of supplies and store-keeping: for example McGibony (1969), Milne and Chaplin (1969), Robinson (1966) and Spencer (1967). Several theses and reports have discussed scientific inventory management for hospitals: Gandy (1971), Knopp (1971) and Labelle (1968) being of particular value. Some interest has been displayed by computer manufacturers expert in hospital management. It remains true, nonetheless, that hospital administrators must acquire their knowledge of modern techniques either from industrially oriented literature or from specialist journals which may not be easily obtainable by the manager.

Since most or all of the revenues of health care institutions are provided by government agencies, which in turn must account to their own senior departments or parliament, there is increasing pressure upon the institutions to function at an efficient level. Whether or not the general standard of health of the populations of developed nations has risen is debatable; it _is_ certain that the post-war introduction of national health services, improved diets, and medical treatment involving antibiotics have raised standards of treatment and the incidence of cures.

In common with industry, hospitals must hold stocks of supplies in order to match separate stages of activity. Whereas in industry supplies will be converted or assembled to form an identifiable 'product', health care institution supplies are required for the treatment and rehabilitation of the patient. Food, pharmaceuticals, laundry and cleaning materials, surgical and medical supplies are all inputs by which the goal of improved health care is attained.

This thesis does not claim that _all_ commercial activity is efficiently performed: bankruptcy statistics indicate that casualties are substantial. In 1974, for example, there were 2790 Canadian business failures, of which 857 were corporations. In trade and commerce alone, 1231 failures were reported with liabilities of $86 million (Canada: Report of the Superintendant of Bankruptcy, 1974).

The majority of commercial organizations make profits, and this is regarded as the most important criterion by stockholders; but how can the efficiency of hospital management be evaluated? Whereas most commercial products must be advertised to create or sustain demand, it is seldom necessary to persuade taxpayers to use hospital services. By the standard of high demand for the 'product', hospitals would therefore be accounted successful. It is not possible to measure efficiency by either absolute or marginal costs, since any hospital operating at half the per-diem cost of its neighbour would be regarded with great suspicion by the community.

This thesis is not written to investigate the wider question of efficiency, but to establish a model which will improve one sector of hospital management, i.e. supplies organization. It is the objective of the study to examine present hospital structures in Canada, the U.S.A. and the United Kingdom in broad outline, and then to describe the role played by supplies in the overall situation. The status of inventory control is compared with that in industry, and short term demand forecasting selected as an important component of inventory management.

Statistical demand forecasting is one method of determining likely future demand for each individual item stocked by the hospital. Examination of hospital accounts shows the relative importance of inventories as assets, but managers have indicated less concern for the development of suitable control methods than have their industrial counterparts. Given access to a computer, it is demonstrated that simple forecasting methods can be applied which will enable greater control over inventories to be exercised. This in turn will enable funds to be released for other important purposes.

Any of several forecasting techniques would be appropriate to a hospital, or small group of health care facilities. The writer examines these methods, with conclusions as to their suitability in terms of ease of application and adaptability: this examination is performed by computer simulation based upon actual historical data from Canadian hospitals.

Because short-term demand forecasting is undertaken as a means to the end of better inventory management, a computer-based total inventory management system has been developed incorporating several components: forecasting, a method to determine the economic order quantity, to maintain a reorder level, and to manage each item in stock on the principle of exceptions. This ensures that if the current status of an item in terms of the quantity available is sufficient to satisfy future demand (as indicated by the statistical forecast and any other information given to the computer), management need not be involved in the decision process.

The benefits of application of the methods recommended in this thesis include improved management of inventories, greater efficiency in the medical sectors due to scientific stock analysis, and the release of funds for use by other areas of the hospital.

CHAPTER TWO

HEALTH CARE SYSTEMS AND HOSPITAL ORGANIZATION

THE ENVIRONMENT

Canada is an independent nation within the British Commonwealth, being created by the British North America Act, 1867 which combined the advantages of a North-American based central government in Ottawa, with provincial autonomy. Despite the Act, Canada retains much of its earlier diversity due to the influences of geography - especially climate, language, and tradition.

The ten provinces are each responsible for major sectors of health care; the federal government controlling such activities as medical care for the native peoples and for the military. The population in general enjoys a high level of medical attention. The majority has also a high standard of living, due to the energy of the population, adequate mineral and other natural resources, access to world-wide markets, and an appalling climate which seems to encourage productive activity. These combine to create an appreciation of the benefits of good health, a determination to improve the well-being of coming generations, and willingness to finance and staff the modern health-care systems required.

The vast geographical spread of Canada causes inconveniencies. Careless (1965:3) explains:

> It is a vast land mass over three thousand miles wide, larger than the United States and Alaska put together, a little bigger than Europe, nearly a third larger than the island-continent of Australia. It extends from the temperate climate of the lower Great Lakes, from . . . grape vineyards to the coldest Arctic regions, where the granite-hard subsoil never thaws.

Minorities, particularly the 200,000 Indians and the 15,000 Inuit, have significantly lower health standards than other Canadians. Reasons are complex, but one is the unwillingness of health workers to be employed in difficult, isolated areas. Thus, within Ontario the availability of physicians for selected regions was reported in 1961 as:

York County (including Toronto	:	1 per 570 persons
District of Thunder Bay	:	1 per 1100 persons
Kenora, N.W. Ontario	:	1 per 1471 persons.

In terms of 'coverage' the discrepancy is more obvious: One doctor per 0.3, 420 and 4377 square miles respectively. The Canadian average (1973) is one active physician for 637 persons; by comparison the average was one for 2287 persons in England and Wales, or one per 27 square miles.

The size of the province of Ontario may be appreciated by study of figures I and II. North of the cities marked there are none of any size. By road from Toronto to Thunder Bay is 960 miles, approximately the same as from Calais to Rome. Most hospital accomodation is found in the concentrated area from Ottawa via Toronto to Windsor - near or along two of the five Great Lakes. Figure II shows the more scattered nature of settlement in Northern Ontario, with numbers of beds marked on the map.

Some are in Red Cross outposts and cannot be approached by road or rail.

Figure III covers Thunder Bay District, which contains the largest community in North-Western Ontario and several smaller towns. It is an important economic area - forestry, iron ore and other minerals, and cross-country transportation - but is isolated and rather depressed. The majority of visits were made to hospitals in Toronto and in Thunder Bay district, and most of the ideas and conclusions reached in this thesis derive from experience in these areas. Distance and access, scattered communities with poor levels of education and bad feeding habits, and extreme climatic conditions create health problems. Although every hospital can be in contact with a city, the logistics of patients, health workers and medical supplies is complex.

THE HEALTH CARE SYSTEM IN CANADA 1977

Post-War immigration from Europe, many countries of which administered health services, reinforced resident Canadian demand and caused an upsurge of planning. Federal and provincial governments cooperated to design a 'national' scheme to be administered provincially. This was made law by the Hospital Insurance and Diagnostic Services Act, 1957, permitting the federal Ministry of Health and Welfare to enter into agreements with provinces on a cost-sharing basis if guidelines were met. All provinces joined, the last being Quebec in 1961. Complementary legislation was

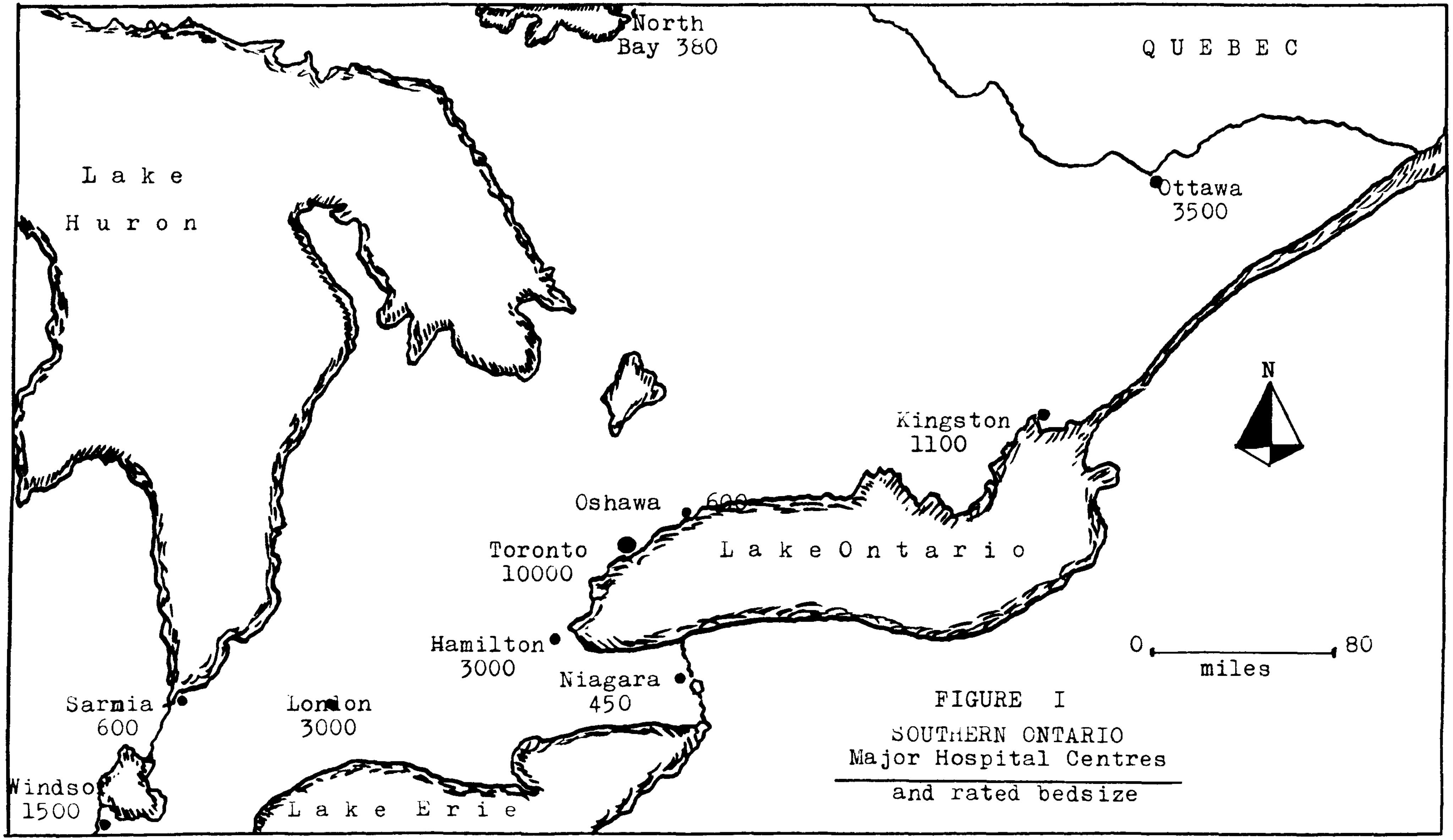


FIGURE I

SOUTHERN ONTARIO
Major Hospital Centres
and rated bedsize

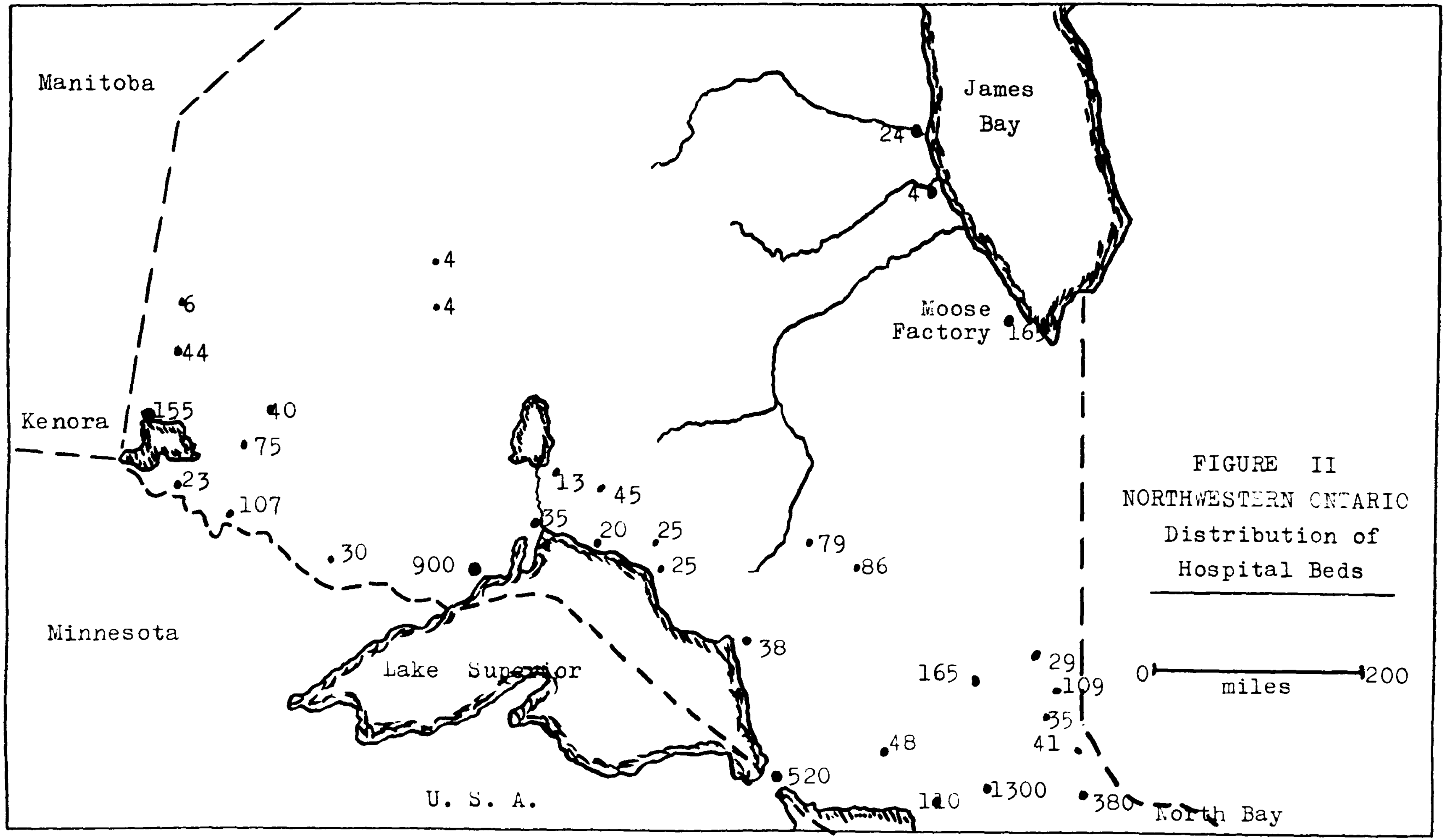


FIGURE II
NORTHWESTERN ONTARIO
Distribution of
Hospital Beds

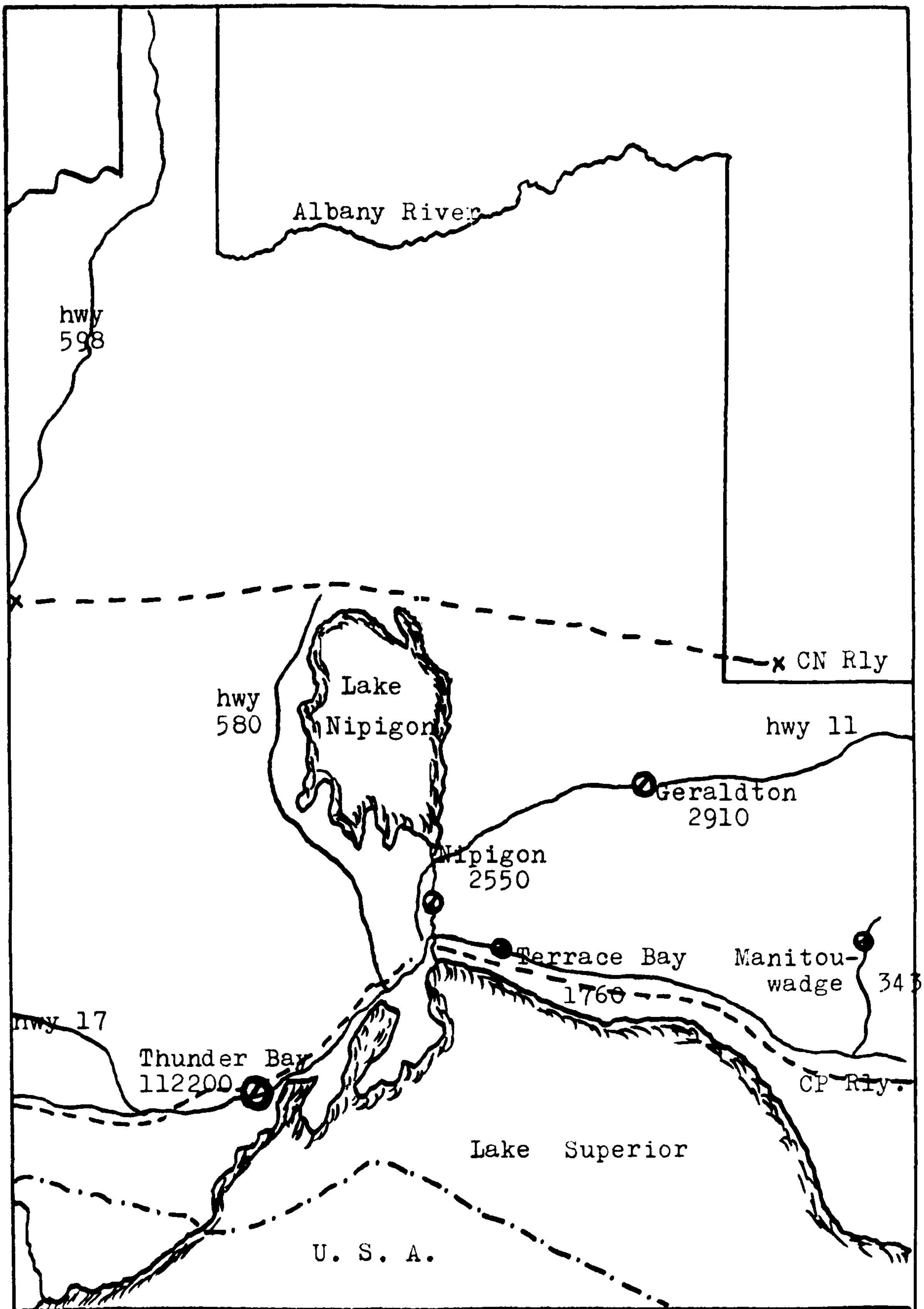


FIGURE III
THUNDER BAY DISTRICT
Hospital Centres
with populations

enacted to provide for ambulatory and medical services: the Medical Care Act, 1966.

Federal responsibilities include the health of native peoples, residents of the Yukon and the North West Territories; scientific and technical research into health services manpower, and into costs of delivery of health services; enforcement of quarantine regulations, and furnishing funds for approved provincial health care plans. Each plan must satisfy common stipulations such as provision for accomodation, meals, nursing services, diagnostic procedures, pharmacy, operating theatres and anaesthetic facilities.

The federal government contributes from the Consolidated Fund:

> 25 percent of the *per caput* cost of inpatient services in Canada plus 25 percent of the *per caput* cost of inpatient services in a specific province *times* the average number of insured persons in that province in a given year.

Table 1 shows the recent health care expenditure trend. It was calculated that if this continued, Canada's entire G.N.P. would be devoted to health care by the year 2000.

Provincial governments finance the health services from general revenues, sales taxes and health premiums. In Ontario, the federal government supports capital expenditures to a maximum of two-thirds of the cost. Current hospital expenditures are funded both by Ottawa and the province, the latter directed by the Ministry of Health and its agent, the Ontario Health Insurance Plan (OHIP). This latter is funded partly by subscription

Table 1

HEALTH CARE EXPENDITURE IN CANADA

	Expenditure $ million		Federal Contributions $ million
1969	5,100		
		1972-73	1,982 (+10% over 1971-2)
		1973-74	2,257 (+13.9%)
1974	8,000		
		1974-75	2,703 (+19.8%)
1975 (est.)	9,000		
		1975-76	3,189 (+18.0%)

Source: adapted from provincial and federal health statistics.

premiums ($192 per single person and $384 for family participation); and partly from federal Consolidated Fund. Little is paid directly by the 'consumer' except dental fees, drugs and a minor part of doctor's fees.

Table 2 shows health revenues and expenditure for the province within which most of this research was undertaken: Ontario.

53 percent of spending occurred in hospitals; 21 percent on OHIP; 19 percent on psychiatric services; two percent on extended care and rehabilitation but only one percent on public health. This low expenditure on 'preventive medicine' is causing concern; the federal government is taking active steps to encourage 'participation', or self-improvement of health levels.

Health insurance costs were rising at a rate approaching 20 percent each year, but ceilings have been imposed by Ottawa, of +13% (1976), +10.5% (1977) and +8.5% above 1975 levels. In Ontario attempts were made to reduce budgeted spending from $2580 millions to $2530 in 1976 by closing hospitals and releasing staffs. Despite these

Table 2

MINISTRY OF HEALTH, ONTARIO: REVENUE AND EXPENDITURE, 1975

REVENUE	$(000)	EXPENDITURE		$(000)
Contributions, Federal	951,469	Administration: Ministry of Health		70,467
O.H.I.P. Premiums	548,095	Programmes to encourage and to protect health		66,142
Miscellaneous	10,390	Treatment and rehabilitation:		
	1,509,954	Health Insurance	649,811	
		General Hospitals	1,399,582	
		Capital Grants, Loans	69,876	
		Extended Care, Rehabilitation	119,243	
		Psychiatric	182,854	
		Alcohol and Drug Abuse	9,875	
		Laboratory	10,300	
Excess of Expenditure over Revenue	1,068,196			2,441,541
	$2,578,150 (000)			$2,578,150 (000)

Source: adapted from Ministry of Health, Ontario, Annual Report, 1975.

attempts, the outcome was a rise of 11 percent in 1976 above 1975. Proposals were made in an Ontario Ministry of Health Report (1972:2) whereby a single, comprehensive health programme should be created. Responsibilities should be divided between the Ministry and new District Health Councils, with greater community involvement. The Health Councils are now in operation and are emphasizing the need for preventive medicine, to accompany their liaison work with other health institutions.

HOSPITAL ORGANIZATION

Table 3 shows the organization of Canadian hospitals by classification and bedsize, giving a clear indication of the preponderance of provincial public hospitals.

Table 4 gives a breakdown of public general hospitals, to distinguish particularly between the bedsize figures of teaching and non-teaching hospitals. Expenses of teaching hospitals are, on average, far higher than those in other institutions, due to their more complex structure and nature of work performed.

Hospitals receive income from the province based on a per-diem rate:

$$\text{P.D.R.} = \frac{\text{Total Approved Expenses Budget} - \text{Cash Revenues}}{\text{Estimated Patient Days}} + \text{Standard Ward Level Costs}$$

The latter costs are reimbursed on an interim bulk payment basis, with year end adjustment. There is difficulty in administering the individual hospital due to the lag between expenditures and much of the provincial repayment.

Table 3

CANADIAN HOSPITALS

TYPE AND BED RATING

1974

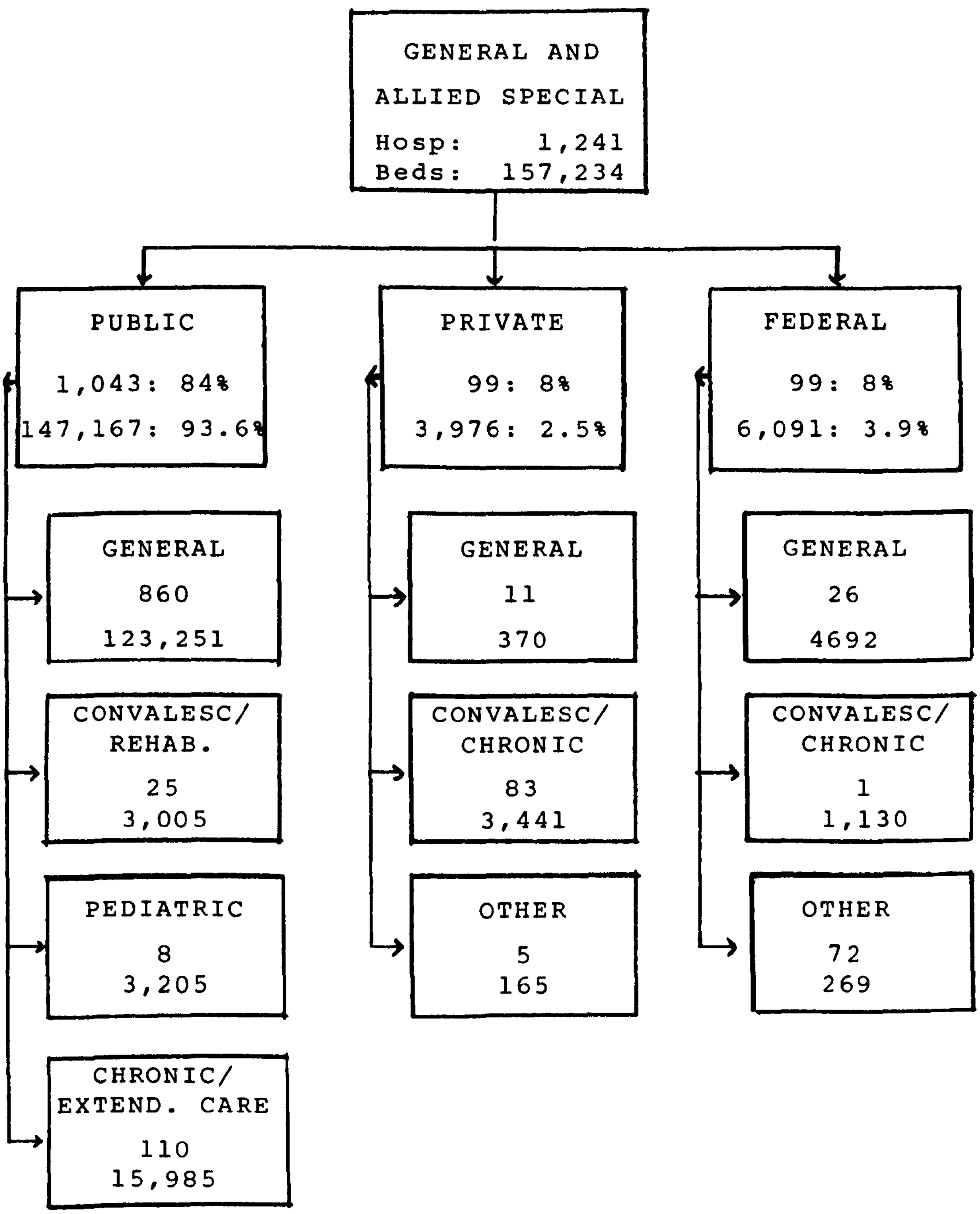
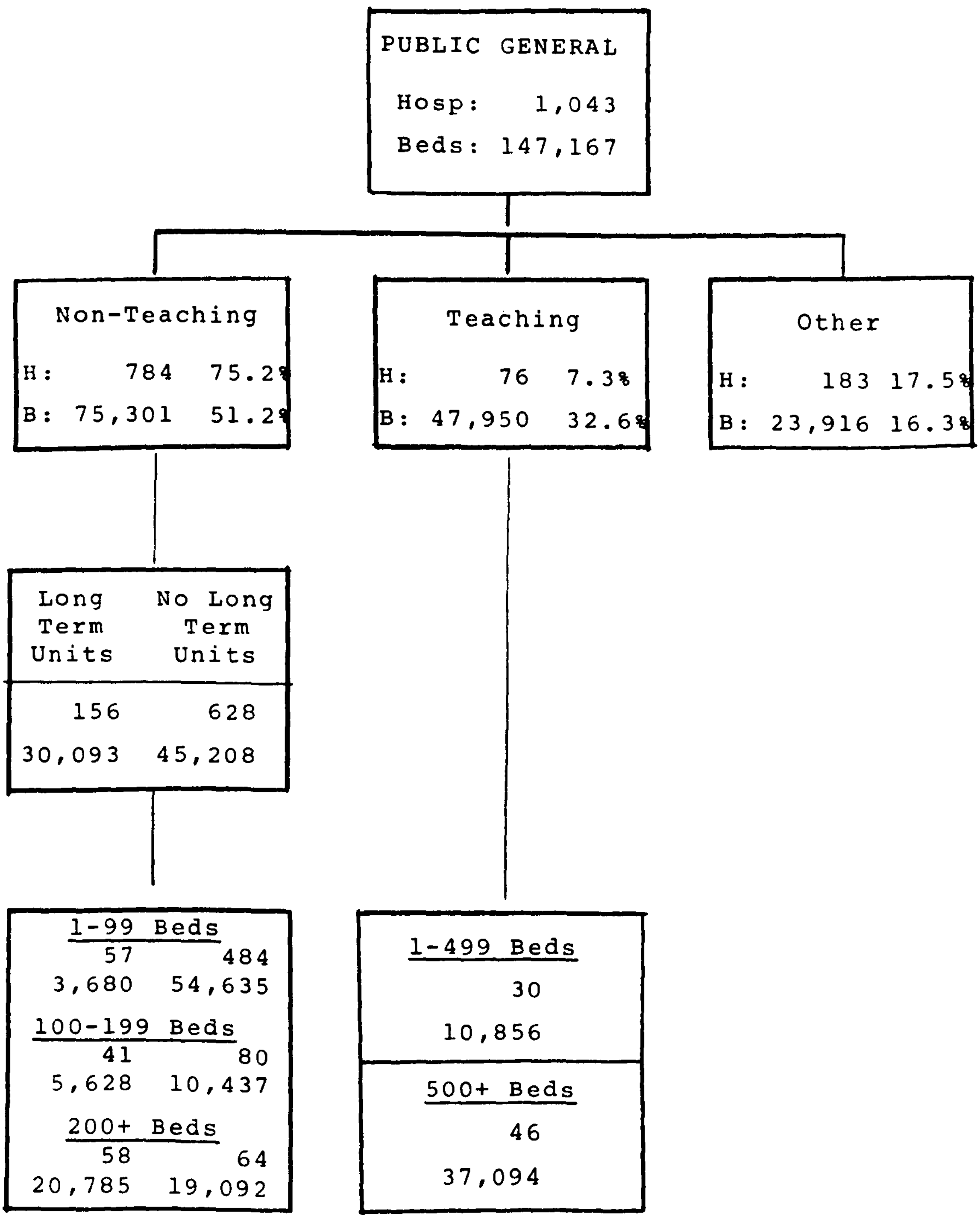


Table 4

CANADIAN PUBLIC GENERAL HOSPITALS

TYPE AND BED RATING

1974



Three methods of income classification are:

1. Operating income by type - consisting of net income from patients, grants for special research projects and other grants, and other income. Approximately 86 percent of net income relates to inpatients and nine percent to outpatients.
2. Income per rated bed. By province the sum ranged from $13546 in Prince Edward Island to $26212 in Quebec (1974 statistics) with Ontario income of $23153. By type of hospital the range was from $17127 for non-teaching general, to $42413 for pediatric hospitals; and by size of hospital the range was from $13844 for the 1-24 bed general to $35882 to the 1-499 bed full teaching hospital.
3. Per patient day - this refers to the period of service to an inpatient between census-taking hours on two successive days. The mean rate was $96 for all public hospitals in Ontario in 1974, 33 percent over 1972 figures.

In 1975 the sources of revenue for Ontario hospitals were:

	$000	Percentage
Ministry of Health	1,410,007	96.3
Federal Government	1,442	0.1
Workmen's Compensation Bd.	18,406	1.3
Non-residents of Ontario	30,008	2.0
Other	808	0.3
Total	$1,463,770	100.0

Hospital expenses are usually reported in terms of per-diem costs. 1975 Ontario statistics are classified in table 5.

Table 5

ONTARIO PER-DIEM HOSPITAL EXPENSES:

OVERALL AND SELECTED HOSPITALS, 1975

Location	Total Days of Care '000	Gross Operating Costs $	Wages $	Drugs, Medical, Surgical Supplies $	Admin. $	Food $	Housekeep. Laundry Linen $	Physical Plant $
All	14,687	120.48	84.20	6.47	9.77	2.95	2.66	3.99
Toronto General	339	196.40	134.56	16.22	15.90	3.28	3.52	5.41
Toronto Sick Children's	212	268.03	154.53	16.09	28.04	3.70	4.84	9.79
Thunder Bay McKellar	115	112.71	80.03	6.72	8.30	2.58	1.08	3.42
Sault Ste. Marie General	90	104.39	75.53	6.61	7.95	3.17	0.81	2.40

Source: adapted from Ontario Government statistics and annual reports.

The substantial differences between teaching and specialized hospitals, and general hospitals in terms of expenses can easily be seen in the table.

Table 6 shows expenses of all Canadian public hospitals over several years, to highlight changes in proportions through the past decade.

Table 6

CURRENT EXPENDITURE OF

CANADIAN PUBLIC HOSPITALS

	PERCENTAGES			
	1965	1970	1973	1974
Salaries and Benefits	65.1*	76.7	76.9	78.0
Medical and Surgical Supplies	3.1	3.1	3.1	3.1
Pharmaceuticals	3.8	3.0	2.6	2.4
Food	4.9	3.5	2.0	2.7
Linen	0.5	0.3	0.3	0.2
Fuel, Electricity and Water	2.1	1.6	1.4	1.5
	79.5*	88.2	86.3	87.9

'Other expenses' include repairs and maintenance, travel, insurance and depreciation.
*excluded benefits to employees.

Source: adapted from Canada: Department of Health and Welfare. Hospital Statistics. Ottawa, 1976.

Distribution of hospitals of Ontario is in similar proportion to those of Canada, shown in tables 3 and 4. The 236 public hospitals contained 51,490 rated beds in 1975 (i.e. those the hospital is designed to accomodate on the basis of established standards of floor area, as at December 31, 1974), and served 11.7 million active, 2.85 million chronic and 0.8 million newborn patient days. Gross operating expenses were $1,770 million, offset by revenues of $223 million (15.5 percent) and Ministry financing of $1,410 million (80 percent).

Admissions to public hospitals rose from 1.24 million in 1970 to 1.42 million in 1975, an increase of 14 percent, but patient-days of care were steady at 14.6 million due to a compensating reduction in the average length of stay in active wards - from 9.8 to 8.4. Table 7 gives operating and financial statistics for selected Ontario hospitals, once again emphasizing the diversity of these institutions.

Table 7

SIZE, ADMISSIONS AND BUDGETS,

SELECTED ONTARIO HOSPITALS

1975

	Staff	Active Bed Rating	Admissions	Average Stay	Gross Operating Costs $000
Toronto General	3960	1383	37,283	9.8	66,650
Ottawa Civic	2780	1103	29,198	10.9	47,720
London Victoria	2350	849	28,749	8.5	41,990
Toronto Children's	3105	787	26,627	8.2	56,970
Scarboro General	1321	639	23,096	7.9	23,960
Kingston General	1630	562	20,476	7.9	28,570
Thunder Bay McKellar	800	390	12,600	9.1	12,960
Kenora	311	159	3,729	11.2	4,910
Toronto Baycrest*	267	154	453	98.3	4,230
Sioux Lookout+	63	42	928	10.6	1,140
Thessalon+	26	17	519	8.8	n.a.

Source: Annual Reports for 1975.

*Chronic long stay hospital.

+Red Cross hospital.

It is a recurrent theme in this thesis, that there are major differences between hospitals and commercial enterprise which give rise to different needs and varied emphases. Table 8 is designed to compare and contrast expenses distribution, and shows data for two hospitals and a large Canadian corporation.

Table 8

DISTRIBUTION OF EXPENSES

HOSPITAL AND CORPORATE

	Canadian Gen. Electric $mill.	%	Brandon Hospital $000	%	Scarborough Hospital $000	%
Salaries and Wages	288	35	5,794	67	14,497	78
Materials and Supplies	520	62	669	8	2,130	11
Depreciation	16	2	411	5	575	3
Taxes*	8	1	--	--	--	--
Interest Charges	--	--	504	6	47	--
Other Administration	--	--	1,253	14	1,423	8
	$832 mill.		$8,631,000		$18,672,000	

*hospitals are tax exempt.

C.G.E. makes all possible efforts to attain a high level of materials and supplies control. Hospitals have concentrated to a larger extent on manpower efficiencies since their materials and supplies expenses are, by comparison, less significant. Whereas 78 percent of revenues of Honeywell Inc. arise from sales of products and 20 percent from computer rentals and service, 94 percent of the revenues of the Toronto General Hospital arise as reimbursement for services rendered to patients, from the provincial government.

Table 9 shows clearly the concentration of hospital assets in fixed items: property, plant and equipment. Total liabilities in 1970 were $1,028 million.

Table 9

ASSETS & LIABILITIES: CANADIAN PUBLIC HOSPITALS

AT END 1970

ASSETS			% of Total Assets	LIABILITIES		% of Total Liabilities
Current Assets				Current Liabilities		
Accounts Receivable:				Trade & Accounts Payable	10.7	
Blue Cross, Workmen's C.B.	1.6			Bank Loans, Overdrafts	4.2	
Provincial Plan	2.8			Accounts Payable	3.9	
Year end Adjustments	0.4	4.8		Accrued Liabilities	3.5	27.9
Inventory of Supplies ($414 per rated bed)		1.8				
Cash on hand & in Bank		1.2				
Investments		1.2	10.2			
Capital Assets				Capital, Short Term Liabilities		
Investments		2.8		Bank Loans	3.5	
Capital Grants		2.0		Accounts Payable	3.4	9.9
Cash on hand & in bank		0.7	6.2			
Property, Plant, Equipment				Long Term Liabilities		
Buildings & Service Equipment ($17,000 per Bed)		57.7		Bonds & Debentures: Hospital		
				Hospital	35.7	
Major Equipment		10.9		Municipal	4.7	
Construction in Progress		8.3		Other	2.0	
Land		2.4	81.1	Advances from Provinces	7.1	
				Notes Payable	1.9	
				Bank Loan	1.6	62.6

Source: Hospital Statistics, Vol. IV, Statistics Canada, 1970.

INTERNATIONAL COMPARISONS

In most 'developed' countries, the proportion of the Gross National Product spent on health care has risen steadily or rapidly from a typical 3.5 percent in 1950, to as much as 7 or 8 percent today (Sweden, U.S.A.). Canada managed to peak at 7 percent and has now lowered this marginally.

The United States has, as yet, no national health insurance scheme in operation. Most users are assisted by private insurance, and the 1970 data of fund origins were:

Private Sector	63%
Federal Government	25
State and Local Authorities	12
	100%

The most important carrier is Blue Cross. By 1968 60 million persons were enrolled, over 80 percent being in approved groups. These relieve the sometimes massive burdens of hospitalization upon workers and their families. Significant assistance to other citizens has come through the Social Security Act, 1966 which authorised the introduction of Medicaid giving medical protection to the poor and needy, and Medicare, assisting those over 65 years with hospital and other medical care. By 1977 91 percent of persons under 65 years were covered by health insurance; of the 18 millions not covered, half are excluded due to inadequate provision by the States.

National health systems are being extensively debated. In the 1977 Congress eighteen national health bills were introduced, the most forceful being that of Senator Edward M. Kennedy - vesting complete control of health care in the federal government. At present the nearest to a national health system is that being developed by authority of the National Health Planning and Resources Development Act, 1974. Each State has created a Health Coordinating Council and a Development Agency, responsible to the U.S. Department of Health. At local level 200 Health Systems Agencies are being formed to coordinate planning in areas with populations varying from 1/2 to three millions; at present great difficulties are being experienced with boundaries and defining agencies powers.

As in Canada health care costs have risen greatly. In 1946 average hospital costs per patient day were $9.39 and in 1976 $158.00, an increase of 1680 percent! At present, pressures are being experienced to increase national plans and expand coverage to working people; but less funds will be available to undertake these tasks. Total cost of medical care has soared from $42 billion to $140 billion in less than ten years, yet many are not receiving adequate care.

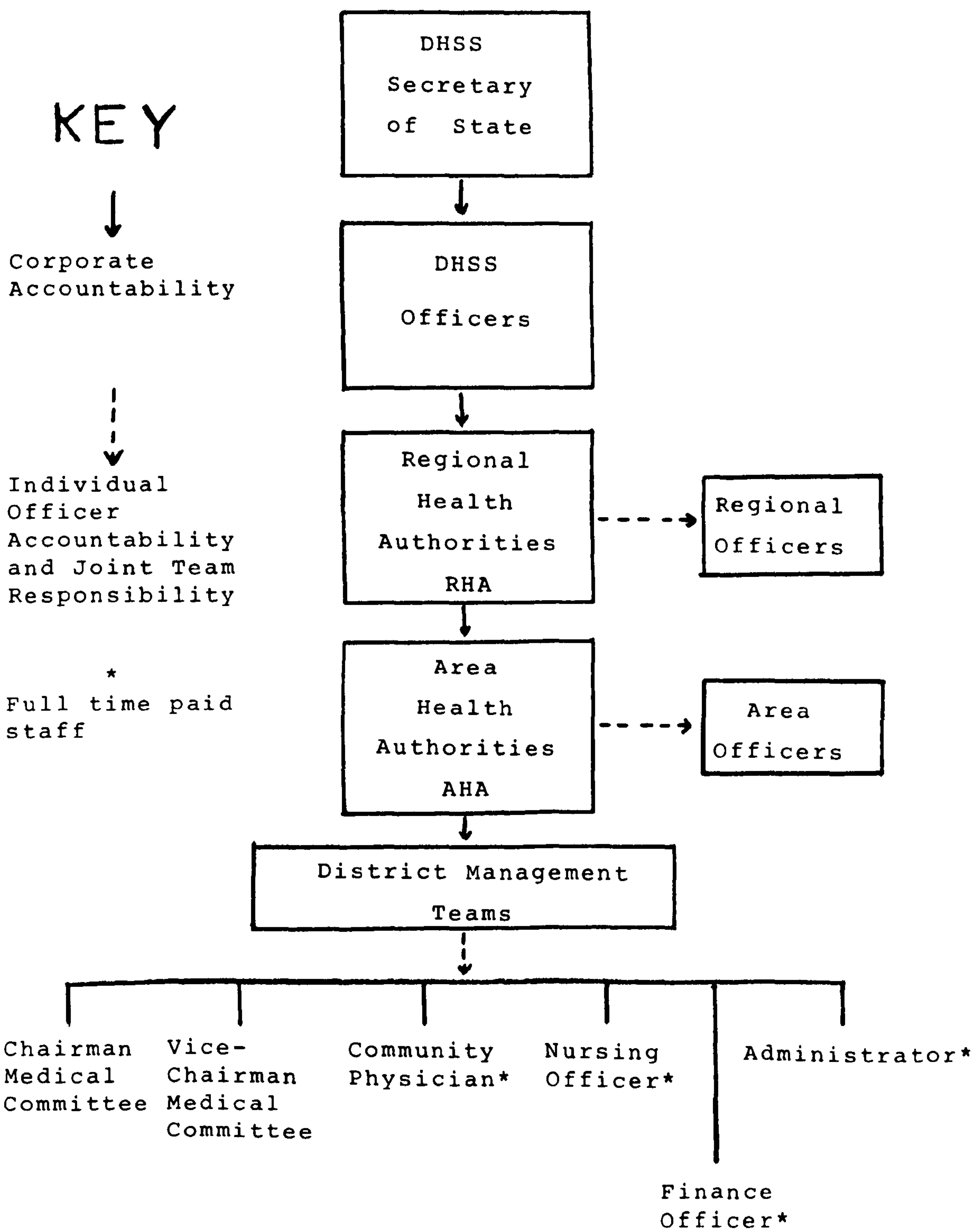
The United Kingdom has had a national health service since 1948, under the authority of the National Health Service Act, 1946. Three decades later a total reorganization was introduced, shown in modified form in table 10.

The Department is responsible to the Secretary of State and Parliament for the efficient running of the NHS. Regional Health Authorities participate in key planning and major works, and provide central services such as

Table 10

U.K. NATIONAL HEALTH SERVICE

1974 REORGANIZATION



computing. There are fourteen RHA's each with one or more medical schools.

The third level consists of ninety Area Health Authorities, forming the operating level for assessing health needs, and administration of plans to meet those needs.

At fourth level are Health Districts, each covering a population of 100-500,000; one to six Districts to an AHA. The teams are multi-disciplinary and the intention is for each member to become involved in all sectors of health.

The service has moved away from hospital centered care, in recognition of the fact that more than 95 percent of those needing care are treated in primary units; much more emphasis is now placed on general or family medicine. This shift in emphasis is causing problems - for example there were 300,000 hospital nurses and only 10,000 community nurses in 1974. This ratio will need to alter fairly rapidly.

It would seem that the creation of cohesive Districts will give opportunity for management systems which require involvement beyond the individual hospital, yet ideally are applicable best at a scale smaller than national. Inventory systems would appear most suited to the Area level.

Table 11 may be compared with table 1 which shows Canadian expenditure.

In 1974, 63 percent of current and 87 percent of capital expenditure were on hospital services. Length of stay and occupancy rates are of the same order of size as those in North America.

Table 11

U.K. NATIONAL HEALTH SERVICE

EXPENDITURE

	1954	1961	1972
	£ million		
Current Expenditure	576	1028	3048
Capital Expenditure	28	62	310
	604	1090	3358

Table 12

OCCUPANCY: ENGLAND & WALES (31 Dec. 19--)

	1966	1971	1973	1974
In-Patient Staffed Beds	468	450	437	427
Average Daily Occupancy	393	368	348	342

Table 13

N.H.S.: LENGTH OF STAY (days)

	1954	1961	1972
All Institutions	42.8	34.5	24.2
Short Stay	--	14.5	10.2

Source: Central Office of Information. Annual Abstract of Statistics. London, 1974.

Table 14 presents statistics comparable with table 3 above. Reduction of available beds will continue, with emphasis on ambulatory care, and modern attitudes to psychiatric care and treatment.

Table 14

HOSPITAL BED ALLOCATION, GREAT BRITAIN

(Beds: add '00)

ALL HOSPITALS

1963	1973
Hosp: 2953	Hosp: 2724
Beds: 5334	Beds: 5056

LESS THAN 250 BEDS		250 TO 499 BEDS		500 TO 999 BEDS		1000 TO 1999 BEDS		2000+ BEDS	
1963	1974	1963	1974	1963	1974	1963	1974	1963	1974
2409	2161	292	309	158	206	72	62	22	--
452	1590	103	1119	1120	1398	980	857	490	--

Source: Central Office of Information. Annual Abstract of Statistics. London, 1975.

Finally, table 15 shows (for England alone), total national health services costs for 1974-75; those for the following year are estimated to have been eleven percent higher.

Table 15

N.H.S. GROSS COSTS

ENGLAND 1974-75

(£000)

Item	Gross Costs	%
Hospital and Community Health Services	2,584,147	78.3
Family Physician	641,400	19.4
Departmental Hospitals	8,214	0.2
Training	17,447	0.5
National Administration and Common Services	11,350	0.3
Other Items	35,899	1.1
	3,298,457	

Source: Central Office of Information. Annual Abstract of Statistics. London, 1974.

Each country has reached, or is moving toward a national health service. Economic difficulties have created problems, and the responses by each country seem similar: reduce the rate of cost increase, and de-emphasize hospital services. This thesis is designed to show that some assistance to these ends can be given by improvements to hospital supply systems.

CHAPTER THREE

THE MANAGEMENT OF HOSPITAL SUPPLIES

INTRODUCTION

World interest in supplies is stronger than for many years, rising and diminishing in response to specific crises. The long era of low cost materials and low-wage processing has now ended.

Health care institutions are major consumers of resources. Planners must expect increasing problems in the coming decade including:

1. Increasing scarcity of certain raw materials, particularly timber, natural gas and petroleum. The seven fold increase in use of plastics from 1962 to 1972 in the U.S.A. has been checked due to materials shortages and health legislation covering PVC workers. Managers are revising plans which called for increased usage of disposable syringes, intravenous tubing etc.
2. Changes in political structures. Investment in capital development of health care facilities is essential for all countries; oil nations funds are assisting Canada in the creation of new buildings and other fixed investments. There are dangers that too-ready access to investment monies may strain the sense of financial and fiscal responsibility.

3. Rising labour costs. Until recent government restraints, maintenance workers were receiving increases in excess of 20 percent annually. Small hospitals that contract out for electrical, plumbing and other repairs incur heavy costs that are often saved by larger institutions using their own staffs.
4. In Canada the inclement climate, high fuel costs and indifferent road and rail services combine to raise prices of materials and fuel to hospitals, and render deliveries uncertain. Some improvements may be made within cities with cooperation: central laundries, computers, warehousing, purchasing and central sterilization of supplies.

A careful study by A. Burt Kline (1975) of American hospital supplies, showed concern that increased competition for scarce resources would divert health workers from their humanitarian goals, influencing their actions to obtain their share of raw materials. A substantial part of hospital spending is controlled or influenced by the medical staff, and in the past there has been a divergence of views between those who requisition supplies only as a means of treating patients more effectively, and those who are directly concerned with business efficiency and are controlling purchasing and storage. Now, due to economic realities, these two sides are being forced together.

Baer (1967) investigated the experience of New York hospitals a decade ago. In twenty years (1947-67) U.S. hospital costs rose 720 percent. Payroll rises outran others (840 percent) but supplies increased in price many times. His estimate of reasons for these rising costs include: the three shift system; greater paramedical care; emphasis on research; more consumers demanding higher quality service, and updated physical plant. To aggravate the situation, he observes: "in most hospitals, the requisitioning, purchasing and accounting procedures are cumbersome and inefficient."

McNerney and Study Staff (1962) stressed the complexities of modern hospital procurement, and the problem caused by the service role of hospitals. Since 'profits' cannot easily be measured it is important to avoid waste and obsolescence and to control supplies tightly. They quoted from the King Edward Hospital Fund (1952:24): "the main principle . . . is that everyone concerned should be given to understand that supplies are cash in another form and that they must be guarded just as carefully".

By 1973, the disposable market, very small in 1960, had reached $600 million in U.S.A. and Canada, and is estimated to reach $1000 million by 1980. Benefits to busy institutions include greater availability, no need for expensive sterilization, safer packages and elimination of cross infection. A study by Frost and Sullivan (1973) on "Hospital Medical Supplies", stressed the importance of hospitals as consumers of certain products. Disposables are now well established in: Blood administration set accessories, intravenous fluids, surgical blades, hypodermics (syringes and needles), surgical gloves, sutures, scalpels, underpads, X-ray films. In 1973 these were rapidly increasing in use: gloves for examination and non-surgical use, hand scrub products, hot/cold pads, medical/surgical clothing, plastic tubing, catheters, prepacked drapes and components, prepacked trays, kits and packs.

The diversity of supplies is illustrated by the Catalogue of one Ontario hospital: table 16. It should be noted that many inventoried items do not appear on the list. These are large numbers of food items, usually the responsibility of the dietician, and at least 3000 items of drugs, in the care of the pharmacist.

Table 17 shows the wide variety of 'customers' for hospital supplies. Some appear only once (Medical/ surgical wards) but are major consumers of the entire range of medical, dietary, pharmaceutical and other supplies. Other areas have highly specialized but equally important needs, (EEG, Laboratory). One major U.S. distributor, American Hospital Supply, Inc., has catalogues totalling 3000 pages, listing 60,000 items. These include dental equipment, surgical instruments, dressings, needles and syringes, medical furniture for wards, operating rooms, office and other departments, sutures, X-ray equipment and a vast array of electronic equipment. Drugs, every kind of food and beverage (except alcoholic), massive choices among medicines and drugs, linens, clothing: all these are required by the hospital, many daily. Expensive items have proliferated, all subject to rapid obsolescence: computer equipment, patient monitors, blood analysers and others. The Computerized Axial Tomography Scanner (CAT) is ardently desired by many Canadian hospitals. Ministries are reluctant to finance the cost of $250,000 and annual

Table 16

SUPPLIES CLASSIFICATION, HOSPITAL LEVEL

CLASS	SELECTED ITEMS
1	Compressed Gases: cylinders (oxygen, CO_2).
2	Chemicals and Reagents: Acetone, ether, nitric acid, alcohol, propanol.
3	Medications and Solutions: Sulfadiazine, Isuprel, Mysoline, Penicillins, dextrose.
4	Dyes, Indicators and Tests: Hema-combistix, hypaque cont media, sterilometers.
5	Cleaners and Antiseptic Compounds: deodorants, floor wax, phisoHex, washing powder.
6	Toiletries: mouthwash, toothpaste, shampoo, combs.
7	Housekeeping: towels, paper rolls, water softeners light bulbs, ash trays, steel wool.
8	Linen and Bedding: bed pads, pillows, sheeting.
9	Bandages and Adhesives.
10	Dressings: Gauze and sponges.
11	Gas Administration and Infusion Equipment: filters, infusion sets, transfer packs, etc.
12	Medical/Surgical Instruments and Accessories: bulbs, blades, lancets, toothpicks.
13	Protective Surgical Gear: gloves, masks, boots, drapes.
14	Plaster and Orthopaedic Supplies: bandages, crutches, splints.
15	Sutures.
16	Syringes and Needles (often disposable).
17	Catheters and Tubing, e.g., nasal, endotracheal, feeding.
18	Containers: basins, bottles, caps, flasks, jars.
19	Laboratory Glassware: slides, tubes.
20	Tapes: adding machine, sticky, measuring.
21	Bags and Envelopes.
22	Office Supplies, filing accessories.
23	Forms.
24	Paper.
25	Miscellaneous: batteries, hot water bottles, padlocks, cotton.
26	Animal Food.

Source: The Hospital for Sick Children. Catalogue, Toronto.

Table 17

USER CLASSIFICATION, HOSPITAL LEVEL

MAJOR DEPARTMENTS

MEDICAL	LABORATORIES	OFFICES	BUILDINGS
Wards	Genetics	Accounts	Engineer
O.R.	Haematology	Personnel	Carpenters
C.S.R.	Bacteriology	Printing	Painters
O.P.D.	Neurology	Computer	Machine Shop
Intensive Care	Pathology	Purchasing	Transport
E.N.T.	Blood	Stores	Linens
Paediatrics	Biochemistry	Finance	Serving Room
Anaesthetics	Virus	Med. Records	Cafeterias
Radiology	Dental	Indust. Eng.	Cold Stores
Opthalmology	E.E.G.	Security	Gardeners
Psychiatry	RH Lab	Housekeeping	
Physiotherapy	Lab Tech.	Chapel.	

upkeep of $200,000, particularly if purchase of other needed equipment were to be neglected.

COOPERATIVE PURCHASING

Publication of the Canadian Ministry of National Health and Welfare Task Force Reports on the Cost of Health Services in Canada (1970) gave the message that larger health units must be developed, with a strong trend to regionalization to avoid duplication. The report encouraged the formation of larger health service bases to serve as supply centres using transport from the centre to smaller users. For example, the city of Thunder Bay, Ontario, with 100,000 persons, has three short stay general hospitals each with overlapping facilities, three purchasing departments, three stores, etc.

Until recently each hospital was responsible for its own purchasing, but now there is the quite rapid spread of group purchasing schemes in Ontario, including Hospital Purchasing Inc. representing 35 Toronto hospitals. However, many hospitals are not covered, and those that are may select or reject agreements at will. Letouzé and Sutherland (1974:8) explain that at least $50-100 million of Ontario health supplies could be handled through regional or provincial group purchasing, with savings of 5 to 10 percent. One reason for the comparatively slow movement towards modern purchasing methods is, as in Britain, that a relatively small proportion of the current revenue budget is allocated to supplies. The Task Force reported that only five percent of the non-capital budget is spent by the Purchasing Agent, compared with 70 percent spent on wages and salaries; 23 to 25 percent is expended on food and drugs, but much of that is in the hands of the Dietician and the Pharmacist. Supplies are more important than the dollar expenditure would indicate, since a substantial amount of salary expenditure should be added. This comprises not only the direct expense of the Purchasing and Stores, but the indirect costs of the time of all those personnel who are concerned with requisitions, transport and accounting. The Task Force states: "There is no doubt that the computer will play an important role in hospitals in the future", but it modifies this on the same page: "When a computer is acquired as the solution to poor management and ineffective manual systems the problems are compounded". The Task Force favours a strong Purchasing Manager, who is to be part of the administration team, to cooperate with the director of finance and departmental heads, to examine and assess the "end-use-cost" of supplies and equipment as distinct from the "landed cost concept". End-use-cost takes into consideration such factors as price, quality, quantity, standardization, storage and distribution, the cost of processing the orders and holding the stock, maintenance, effectiveness in practical application, hazards, complexity . . . This is vastly more challenging than just finding out the name of a supplier and mailing an order.

In Britain the Hunt Committee on Hospital Supplies Organization (1966) conducted an investigation into the central supply policies of large organizations. It discovered that Butlin's, Marks & Spencers and ICI purchased most of their supplies centrally; the Greater London Council (GLC) bought 97 percent and the Central Electricity Generating Board 93 percent centrally. Central Storage policies varied: Marks & Spencers and Butlin's did not store centrally; NCB, ICI and GLC had extensive central stores.

FINANCIAL ASPECTS

Tables 5, 6, 8 and 9 above show the relationship of supplies expense to overall Canadian hospital expenditure. Statistics from Canada Health Division (1976) show that inventories of supplies average two percent of the total assets of public hospitals. There is a substantial range, from 4.7 percent in very small non-teaching, acute general hospitals to a low of 1.2 percent in 1-499 bed full-teaching general hospitals. Inventories per rated bed rose from $454 in 1972 to $644 in 1974. Regional differences are emphasized by the range from $483 in Alberta to $1160 in Newfoundland, with Ontario at $612.

Nothing has been written in Canada concerning national or provincial supplies and inventory management, other than short references in reports such as that mentioned above. In Great Britain the Central Health Services Council (Messer) Report (1954) estimated that 25 percent of a hospital's total spending was on consumable goods. A study in 1969 by one Regional Board reported expenses on salaries and wages of 61 percent and provisions and supplies of 21 percent. Table 18 gives official figures for England and Wales.

Table 18

REVENUE ACCOUNT EXPENDITURE, HOSPITALS

ENGLAND AND WALES, 1969-70

		£ Million	
Total Expenditure		868	
Supplies, goods, equipment:		242	28.0%
of which total:	£m.		
Salaries and Wages	586		67.5%
Admin., Blood Transfusion and mass radiography	40		4.6%

	£mil.	% Total	% Supplies
Med./Surg. Appliances & Equipment	40	4.6	17
Pharmaceuticals	26	2.9	11
Dressings	6	0.7	2
Provisions	46	5.2	19
Power, Light, Heat, Water, Laundry	40	4.6	17
Building, Plant, Ground Maintenance	25	2.9	10
Staff Uniforms; clothing	6	0.7	2
Other Maintenance	42	4.8	17

Source: Central Statistical Office. <u>Digest of Health Statistics</u>. London, 1971, analysed in Office of Health Economics. <u>Hospital Purchasing</u>. London, 1972.

BRITISH EXPERIENCE AND POLICIES

Although recent studies have revealed differences in supply situations between hospitals in Canada and the U.S.A., there is agreement that most are overstocked. This thesis has as a major objective, investigation of this proposal:

> that hospital inventories can be reduced 10 to 20 percent through scientific methods, using models at present adopted by progressive industrialists.

Since little of value has been undertaken in Canada, it is necessary to examine one major concentrated hospital service. In England and Wales the <u>National Health Service Act, 1946</u>, and the <u>National Health Service (Functions of Regional Hospital Boards, etc.) Act, 1948</u> gave individual management committees and teaching hospital Board of Governors, powers to acquire and maintain supplies and equipment of all kinds, subject to the ultimate central influence of the Ministry of Health. It was envisaged that supplies officers would be appointed: in only 44 percent of the Regions had this been done by 1974. At intervals the Ministry spoke in favour of central purchase contracts (1949, 1953) but became more interested in encouraging local joint contracting.

By 1965 hospital spending on goods and services had reached £14.5 million (current) and £7 million (capital). Of this, central contracting accounted for only 10.6 percent. Joint purchasing at a more local level absorbed 23 percent of the total, though regional patterns varied, spending ranging from 10 through 75 percent.

Reasons were offered at that time by the Committee on Hospital Supplies Organization (Hunt). One was that there were seldom adequate centrally located stores; a second reason was that daily operation of the hospital vested in the local Hospital Management Committee. This had separate corporate existence and substantial rights to conduct its own affairs. The Ministry had major overall powers but did not use these to enforce more rational supply activities.

The Office of Health Economics (1972) discussed the outcome of the Hunt Report. Recommendations for a separate Hospital Supply Board (to deal with specifications, rationalization of storage methods and development of a national vocabulary), were rejected, and a less powerful Supply Branch established. The recommendations that Regional Supplies Officers should be appointed, to coordinate the work of Area Supplies Officers - including group purchasing - were not evenly implemented. This led to poor communications, high prices and small scale and inefficient purchasing.

Whether the 1974 reorganization will cause a shift towards centralization is as yet unclear. Mr. A. Campbell, then Chief Supplies Officer for the Welsh R.H.B. commented in 1973: "It would be hard to imagine any industrial or commercial enterprise with a £250 million budget, 70 percent of which is common to all their users, having anything other than a centralized control!"

An independent investigation was conducted by Hyman and Day (1970). Having visited several hospitals and conversed with suppliers, the authors observed that (as stated above) supplies were still managed by largely autonomous units within N.H.S. A more rational system could no doubt be devised with emphasis on central contracting and national deliveries; advantages could be lost owing to increased costs of warehousing and transport.

The authors' recommended fewer purchasers - at present there are supplies officers, pharmacists, dieticians and engineers conducting the procurement function. The size and location of stores should also be investigated.

In 1973 this writer visited the D.H.S.S. Supplies team led by Mr. J. E. Postles, at which time ideas were exchanged concerning likely 1974 changes. Supplies before 1945 were disorganized and the 1948 N.H.S. had the effect of creating a more unified service, assisted by the Supplies Division of the Ministry. It was thought that the 1974 changes should create stronger Area supplies organization. Mr. Postles could not predict the influence at Regional level, but considered that the Regional Supplies Officer might be made responsible for contracting. The team were interested in improved technology and explained that each region will have the services of a powerful computer in due course (ICL 1900E): in theory this should greatly simplify overall co-operation.

Another study group was to be established to investigate Stock Control and Stores Accounting. One section was already at work on a National Stores Vocabulary, which could be completed by 1976. There have been no reports in the Journals concerning results of the Working Party's operations.

It is however believed that work is well advanced on the creation of the unique coding for all items within 26 divisions. The Office of Health Economics described benefits of the catalogue for stock control, ordering and distribution, with the warning that there is a danger of "over zealous coding and recording of products at every stage of their progress to the final user, and unproductive . . . processing and analysis of information."

Martin (1965:8) estimated that 400 authorities in England and Wales were purchasing supplies. The Hunt committee had admitted that little progress to rationalization had been made, but emphasized that: "since it seems that the needs of the hospital service will always be greater than the resources which can be devoted to them, it is essential to make the maximum use of the resources . . . since every penny saved by efficiency in organizing supply, and by reducing the range of items and spares, can be devoted to more and better treatment for the patient".

Pearce (1976) has stressed the difficulties he anticipates at administrative levels below the most senior, caused by increasing centralization of long-term purchasing contracts. The end-products of central purchasing have satisfied the majority of consumers and: "criticism has tended to centre on the relative narrowness of the area of consultation which has taken place". At local levels, little expertise is now required, other than an ability to distinguish the required item from masses of information on contracts, and a talent to identify national vocabulary numbers when these are introduced. Pearce also noted that: "at the stores level of the organization there is a monotonous degree of uniformity from store to store regarding the range of items kept in stock".

At present, the supplies system is still fragmented; and simple, basic inventory control methods may be recommended to improve the economics and level of service. Policies and high quality organization are required to control current complexities, even at the individual hospital level. A supplies policy manual is seldom available, and in Canada, U.S.A. and Britain we are at some distance from local or national policies. Recommendations of Hyman and Day (1970), the Office of Health Economics (1972) are now consolidated:

1. There is urgent need for a data base as part of a Management Information System. No plans have been published in Canada for such a data base or M.I.S. Once sufficient data on item demand is available, forecasting techniques could be applied to improve order point and order quantity systems. Bodenham and Wellman (1972:41) observed: "it is unlikely that less than two years accumulated data will be sufficient as a basis for forecasting, hence the need to make use of any current data from stores accounting procedures to build up the data base as soon as possible."
2. There must be regular direct contact between users, health boards, or councils and the central procurement agency. Major retail chains have highly structured systems, to connect those requiring replenishment with the warehouse or purchasing office. No such facilities are yet generally available for hospitals. Work on optimal stores locations has been performed in Britain, but the problems of logistics are enormous. It has

been shown earlier that geographical distances in Canada preclude enthusiastic investigation into centralized stores.

3. One factor causing increased costs of operating the health care facility, is the ever rising level of expectation of patients. Stringencies since 1970 have now reversed some earlier trends, and hospital average lengths of stay and admission are falling. Since the environment surrounding hospitals may be unsettled and dynamic, it is difficult to use some statistics. For example, the data below, of a large Ontario metropolitan hospital, is shown for three years, but the Administrator commented in his annual report (Scarborough General Hospital:1974):

> Each year has brought needs for expanded, updated or additional services and 1974 was no exception. The challenge of anticipating and meeting these demands, while maintaining the quality and quantity of existing services was not new to us.
>
> It was much greater in 1974 . . . because of rapid inflation coming together with further financial constraints by government. The Ministry of Health . . . tightened its purse strings and its initial guidelines allowed a net increase of less than six percent over the previous year.
>
> Hospitals were not sheltered from or immune to inflationary forces and by mid-year arbitrators under hospital collective bargaining had awarded rate increases for one year of 20 to 30 percent for service employees, and of over 30 percent for registered nurses . . .
>
> In-patient admissions increased by over three percent, emergency visits by almost seven percent and mental health clinics, with some 43,000 visits, were up by 49 percent. New born admissions, down by nine percent, were an exception.
>
> Our total operating expense at $18,672,379, was up by 21 percent, but this included operating expense of $185,000, for chronic care in 1974, which was not applicable in 1973.
>
> Our major expense is in wages and benefits. This item, totalling over $14,000,000 was up by almost 23 percent. The benefits portion increased at an even greater rate and a significant factor

in this was Unemployment Insurance, which was up by 119 percent.

Total non-wage expense, excluding depreciation, was up 19 percent. Higher prices were the major factor. Our fuel oil expense at $115,595 was up by 63 percent over 1973.

	1972	1973	1974	% to 1972
In-Patient Admissions	21,782	22,363	23,164	106
Patient Days	192,878	186,130	188,681	98
Emergency treatments	82,846	88,024	93,986	113
Laboratory Tests, Units (000)	9,589	9,210	8,552	89
Standard Ward Allowable Cost	$ 62.91	$ 68.12	$ 81.41	129
Rated Active Bed Capacity	641	641	641	---

4. Broad scope exists for the techniques and ideas of management scientists. Bodenham and Wellman (1972:41) state: "Demand, prices and the range of goods available change quickly, and the system of control must be sensitive to such changes in costs if they are to be minimized". This usually assumes that records will be centrally available. The Office of Health Economics (1972:14) comments: "Hospital authorities are often incapable of forecasting their own take-up of many products within a reasonable margin of error. In part this may be due to uncertainties inherent in the pattern of hospital consumptions but to a considerable extent it also reflects a lack of even the most basic information". There is no available data on transport and distribution costs, storage costs (national, provincial or local level) to allow policy makers to forecast the effects of one parameter change on others.

This chapter has examined hospital supplies organization in broad terms. It is obvious that much progress needs to be made before any system can be implemented in Canada at provincial levels. Management Scientists are attracted to the challenges, but the Office of Health Economics (1972:18-19) warns that:

> Although operational research is likely to be more fruitful in the supplies field than in most others (providing resources for implementation are made available), the use of sophisticated O.R. techniques brings with it the danger of uncritical acceptance of pseudo-scientific results. Probably the path towards an optimum supplies policy lies in progressively reducing the area of uncertainty through specific studies, instead of an impossible attempt to bring all the costs and benefits of all alternative policies into one comprehensive evaluative model.

CHAPTER FOUR

MANAGEMENT OF INVENTORIES IN HOSPITALS AND INDUSTRY

As health services progress toward larger and more regional groupings, inventory management systems become ever more relevant. In the single hospital centered organization at present predominant in Canada, the U.S.A. and (to a lesser extent) in Great Britain, there is still potential for system development. The ideas in this thesis, based upon progressive elements in industry, are ahead of the necessary organizational framework to allow of general implementation by hospitals.

McNerney et al. (1962) found that ordering and other aspects of materials management in hospitals, varied particularly with bed ratings. In his Michigan survey he noted that few small or medium size hospitals (250 or fewer beds) used stock classification; less than half of these maintained permanent stock records, and two-thirds of very small hospitals (50 or fewer beds) carried out no systematic annual physical inventory record taking. Even today, writers claim that scientific inventory methods are superfluous. Gue and Freeman (1975:247) wrote that: "the cost of conducting the requisite studies in the hospital environment where good usage data are scarce and certain costs difficult to measure, is rarely justified by the return. An experienced purchasing agent, a good stock-keeping system that is coupled with sufficient foresight to avoid being caught with a large supply of obsolescent items, and continuous attempts to standardize can often save considerably more than scientifically derived E.O.Q.'s and reorder points". There is little evidence to justify their optimism.

ACCOUNTING FOR INVENTORIES

An examination of the accounting reports of eight North American corporations was undertaken. Table 19 illustrates selected features for comparison with hospital accounts, of which a selection is shown in table 20. These tables show:

1. The ratio of inventories to current assets in industry ranges from 35 to 90 percent. Hospital inventory to current asset ratios also range widely but are usually in the 5 to 30 percent region. This difference may explain why less attention has been paid to this sector of materials management by health services managers.
2. Current assets: total assets ratio is substantially less in hospitals than in industry. Hospitals are land and buildings intensive, and carry supplies more for direct consumption than for conversion through the manufacturing process.
3. In many hospital reports it is not possible to identify the material value of inventories, since they are recorded inclusive of material components, plus labour and other expenses. For the present purpose the

Table 19

CORPORATE ACCOUNTS, 1976

	Total Assets $M.	Current Assets $M.	CA/TA %	Inventories $M.	Inv./CA %	Working Capital $M.	Acs Payable /Inventory %
ACKLANDS Winnipeg	180	147	82	92	63	46	42
CANADIAN GENERAL ELECTRIC Toronto	571	407	71	198	49	168	25
CANADIAN TIRE Toronto	427	244	57	100	41	112	51
EMCO London, Ontario	99	77	78	51	66	48	27
HONEYWELL Minneapolis	2204	1046	47	364	35	535	38
METROPOLITAN STORES Winnipeg	68	34	50	30	90	9	34
REYNOLDS ALUMINUM Quebec*	56	35	62	26	73	15	26
WABASSO Montreal	65	45	69	33	74	15	18

Source: 1976 Published Accounts.
* = 1974.

Table 20

HOSPITAL ACCOUNTS, 1974

	Rated Bedsize	Total Assets $000	Current Assets $000	CA/TA %	Inventories $000	Inv/CA %	Working Capital $000	A/Cs Payable/ Inven. %	Supplies expenditure, annual, itemized $000		
BRANDON Manitoba	433	10,283	627	6	152	24	144	267*	Drugs	204	
									Dietary	175	
									Laundry, linen	25	
									Housekeeping	15	
									Med/Surg	250	669
SCARBOROUGH Ontario	641	17,602	3352	19	222	6.6	917	873*	Med/Surg	688	
									Drugs	350	
									Dietary	652	
									Laundry, linen	172	
									Housekeeping	25	
									Laboratory	100	
									Nuclear, Med.	29	
									Radiology	114	2130
WINNIPEG Health Centre	1378	43,830	6538	15	1778	27.2	700	324	n.a.		
THUNDER BAY Ontario	265	12,340	2609	21	186	7.1	1641	246	Med/Surg	323	
									Drugs	278	
									Others not identifiable		
DRYDEN Ontario	75	1,057	301	28	Med/Surg 27	31	116	4.6	Medical/Drugs	91	
					Drugs 21				Dietary	57	
					Other 45				Ambulance	6	
					93				Plant	35	
									Others (1/2)	49	238

* includes other accrued expenses.

assumption has been made that cost of materials is the proportion P of the total cost in the report, where P is the value:

Medical/Surgical supplies	1.0
Pharmaceuticals	1.0
Laundry and linens	0.5
Foodstuffs	0.5
Housekeeping	0.5

4. Working capital, or current assets minus current liabilities, shows the current wealth of the organization after creditors claims have been satisfied. Industrial ratios range from 26 to 62 percent of current assets; hospital ratios are much lower, from ten to 24 percent, indicating a closer relationship between short term items than would be tolerated by industry.
5. The ratio of accounts payable to inventories indicates the relative importance of unpaid creditors to purchased supplies. Industrialists maintain tight control over this, witness the small range from 18 to 51 percent. Hospitals are funded in a 'global' manner and this may explain the great variation in the ratio.
6. Hospitals do not report 'turnover' details, the ratio of sales to inventory. Industry varies in its criteria - retailers report values of six times per year; manufacturers ratios are lower. With improved inventory systems, hospitals would be able to concentrate on this important ratio. For individual stock items the speed of turnover is important, but it is doubtful whether an average from several thousand items has any

meaning. Most managers specify a high level of 'minimum' stocks, and this masks the rate of stock turn. Duke (1973) stressed the influence of location: a Toronto hospital could expect a one-hour delivery of needed items; in remote areas several days would be required.

THE BERMAN APPROXIMATE STANDARD

Berman and Weeks (1971:chapter 15) examined ratios of importance to hospitals in the U.S.A. and used comparisons established by Berman during an earlier investigation (1968). Five ratios are given in table 21. Industrial comparisons are provided by Acklands, an automotive equipment distributor, and Canadian Tire, a major retailer of hardware with 303 branches in eastern Canada.

It seems that the Berman Standard is not applicable to Canadian hospitals. Divergence between Canadian and U.S. hospitals reflects different concerns and financial responsibilities which, in turn, relate to different autonomies. The current ratio (current assets: current liabilities) should demonstrate high liquidity. Canadian hospitals' debts are in fact guaranteed by municipal, provincial or federal governments, and the need for high liquidity is less than that required by the more independent, autonomous U.S. hospitals.

The acid test ratio (liquid assets to current liabilities) is the most stringent evaluator of ability to meet immediate commitments. Although Canadian hospitals have low values, they are close to the 1:1 proportion often

Table 21

ACCOUNTING RATIOS OF

HOSPITALS AND CORPORATIONS

Ratio	Berman Standard*	Brandon	Kenora	Scarboro	New York U.S.A.	Acklands Ltd.	Canadian Tire
Current	5 : 1	1.3	1.3	1.4	4.0	1.5	1.6
Acid Test	4 : 1	1.0	0.9	1.3	3.8	0.6	0.8
Cash/Total Assets	1.3%	1.9%	0.2%	6.2%	3.4%	5.3%	2.4%
Inventory/ Total Assets	1.7%	1.5%	1.6%	1.2%	4.0%	49.0%	26.0%

* based on a sample of operating parameters from representative U.S. hospitals.

recommended by commercial accountants. The Cash to total assets ratio has limited value due to fluctuations in cash held by hospitals. For example, the Regina (Saskatchewan) hospital had $1,102,000 in cash and term deposits at the end of 1973, and $527,500 in 1974. The ratios were 16.8% and 8.3% respectively.

Berman used an Inventory to total assets ratio of 1.7 percent, and this is approached by Canadian hospitals. The value is influenced by a hospital's situation regarding stores space; also the tendency in an inflationary era to overstock will alter the ratio upwards.

A BASIC INVENTORY MODEL

Before an order can be mailed to a supplier, a series of decision-making processes are undertaken, which may vary from utmost simplicity to mathematical complexity. Inventory management is one sector of the entire supply process; the effect of poor inventory management and control is to reduce the effective utilization of capital; to increase risks of obsolescence, deterioration and pilferage; to hold excessive quantities of items not in demand and suffer shortages of those in high demand; to waste space, and to pay for goods whose return in utility will be lower than the outlay.

The quantity to order may be decided in an arbitrary fashion; in a probabilistic manner with estimates of lead time and anticipated demand; or by using a deterministic method, with constant demand, lead time and reorder quantity. The intricacies of order point determination will depend upon the seriousness of being out of stock, the cost of maintaining safety stocks, the historical pattern of demand, and of lead time distribution. Methods are: fixed order quantity with fixed order times — an idealistic state; fixed order quantity with varying order periods - presupposing a carefully determined order point, certain demand and well-known lead times: fixed order period and varying order quantity, which is neat and useful for tidy production scheduling; and varying order quantity and order times. This latter situation is common, and demand forecasting is a vital component. It is unfortunate that four variables are evaluated by four different persons: the demand forecast; required service level; order quantity, and reorder point. It is the objective of the system designed by this writer to reduce this inefficiency.

A simple re-order point model is used:

$$R.O.P. = L\bar{D} + K\sigma\bar{D}\sqrt{L} \quad \ldots (1)$$

where $\bar{D}$ is the average of recent demands.

K the service level factor.

L the average lead time.

σ dispersion of demand around the mean.

The basic economic order quantity model is thought to have been introduced by Harris (1915):

$$E.O.Q. = Q^* = \sqrt{\frac{2DA}{IP}} \quad \ldots (2)$$

where D is the latest demand forecast.

A the estimated ordering cost.

I the holding cost, one unit per year as a percentage of the item's value.

P the purchase price per unit.

D is an important variable used by both (1) and (2). The assumption made is that demands occur at a constant rate and a reasonable forecast of annual requirements is feasible. Snyder (1973) showed that the assumption can be relaxed to allow for erratic demands; and for price/quantity discounts.

Ordering cost comprises marginal costs incurred from the time need for the item is recognized by the user or stores, through ordering, receipt and delivery to the stores or user. Holding costs include administrative expenses, interest on capital tied-up in the stores; and (of particular importance to hospitals) costs of obsolescence. The algorithm begins with the overall cost of acquiring the economic order quantity, and proceeds to examine each discount price/quantity division in turn. The selected combination will be that which has the lowest overall cost. The assumption made is that sufficient funds are available to pay additional invoice charges, and that storage space is sufficient.

It is desirable that the entire inventory be classified according to ABC analysis: Dickie (1951). High value items (A) receive direct, frequent management attention; (C) items may amount to 60 percent of the total number but perhaps only 5 percent of turnover value, and may be maintained on a "topping up" basis, with reduced management involvement. Contained in the (B) group are those items which cannot be classified as critical (A), but are not of such low annual usage value as (C). These items will be considered as part of the computer-controlled system, but will receive less direct management scrutiny.

A method of determining the reorder quantity that has received attention in journals is the Wagner-Whitin algorithm (1958:89). The authors' wrote that: "allowing the possibility of demands for a single item, inventory holding charges and set-up costs to vary over N periods, we desire a minimum total cost inventory management scheme which satisfies known demand in every period. Disjoint planning horizons are shown to be possible which eliminate the necessity of having data for the full N periods". Kaimann (1968a, 1968b, 1969, 1970) has demonstrated that since economic order quantities are established <u>once</u> in the year or in the horizon time, and not altered until the subsequent forecast period, dynamic demand conditions cannot be compensated. He includes substantial trends and seasonal fluctuations in his comments, and welcomes the Wagner-Whitin algorithm as a means of overcoming this problem. The technique recognizes that for each period, one of two situations will occur. Production will take place either in that period, or will have taken place in an earlier period, with holding cost penalties. The algorithm assists in the choice of which alternative to select, and is recommended to replace the E.O.Q. where high fluctuations are experienced. Gleason (1971) indicates that in steady state demand conditions the algorithm yields the same order policy as E.O.Q., but also recommends Wagner-Whitin for the reasons given above. Philippakis (1970) provided carefully worked illustrations to quantify the savings due to this algorithm, but Tuite and Anderson (1968:23), although recognising these advantages, observed: "the familiarity and simplicity of the E.O.Q. approach are such that it is unlikely to be replaced by dynamic programming in normal applications. There are, however, operating conditions under which savings available by Wagner-Whitin warrant a change in the method."

Kaimann (1974a, 1974b) incorporated a safety stock allowance to cover uncertain demand and variable lead times, but using the basic model.

Lowerre (1975:41) criticized the new algorithms, declaring that: "the dynamic lot sizing algorithms are considerably less cost effective than the E.O.Q. in minimizing total order and carrying costs, when lot size ordering and unit carrying costs are relatively low and average unit demand is relatively high, given the same coefficient of variation. Any policy that orders in excess of total planned requirements to the forseeable horizon will be excessively expensive almost by definition." By case study Lowerre displayed his claim that previous examples produced savings due to the assumption of relatively high order and holding costs with relatively low average demands. Using a lower unit price resulted in a cost penalty which would be acceptable to managers wishing to continue to use E.O.Q. Three major weaknesses of published models are, the need to assume that demand is known several weeks ahead; ignoring costs of computer time when recommending dynamic models; and differing lot sizes be ordered or run: this could be disruptive. For any inventory system intended to be simple, the degree of decision-making required makes the Wagner-Whitin algorithm unsuitable, at least until a researcher with practical experience publishes a more widely acceptable method. It is believed that an effective forecasting method can reduce uncertainties in demand, and make the E.O.Q. Method as suitable as the Wagner-Whitin Method.

HOSPITAL INVENTORY REQUIREMENTS

In theory, hospital inventory management is solicitous, based on the premise that supplies are vital and must always be available. In practice it often seems indifferent, due to the much smaller burden that supplies bear upon hospital expenses than salaries and wages. Neither attitude is helpful and new approaches are needed to improve the situation.

Certain items are requisitioned regularly, and demand can be predicted: most dietary items, routinely prescribed pharmaceuticals and common household products, for example. Other items (such as expiry-dated pharmaceuticals, and fresh foods) cause storage difficulties, and forecasting is influenced by those considerations. Many items are used throughout the hospital, and fluctuations in usage tend to even out, permitting analysis of demand. The fact that some items are directly related to the quality of health, and there is a tendency to hold substantial safety stocks to ensure continuous service, causes problems when the same high stocking routine is followed for the many non-critical items such as office supplies, cleaning powders and most dietary items.

The objectives of hospital inventory management are similar to those accepted by industry. At priority level is the provision of appropriate quality of service to patients and employees. Optimum service will be that given in response to intelligent, cooperative demand. The risk of stock-out must be at the level specified by management. The true cost of a stock-out cannot be measured, and safety stocks are held as an insurance; the implied stock-out cost must not be over-estimated. The economics of inventory management must also be considered. Industrial purchasing management has the profit incentive to encourage sensible budgeting; the hospital motive should be to maximize 'satisfaction' for each dollar spent.

Supply and inventory management is affected by major changes influencing the entire hospital. Thus in Canada, hospital workers are rapidly becoming unionized, implying the possibility of disputes and more stringent working agreements. The technology of the catering department is changing, particularly in the area of pre-packaged foods, and rapid heating systems. The pharmacy is becoming more centrally involved in health care, and less an auxiliary of the health team. Rapid expansion of use of plastics and disposables took place until the crises of 1974 and 1975 made disposables more luxurious. Inflation has affected manufacturers' willingness to sign firm contracts, and price rises are common at every ordering interval. It may be expected that these events will increase demand for improved scientific methods.

Gandy (1971) reviewed the literature and found no theoretical concepts that have been specifically developed for hospital inventory management. Modern and progressive managers adapt well-tried industrial techniques, though with the risk of sub-optimization. Knopp (1971) examined reasons why inventory managers tend to perform below maximum efficiency. Each manager views his particular situation as unique, and structured methods leading to R.O.P. and E.O.Q. appear to him as restraints upon his freedom. Staff levels would be disturbed if an influx of scientifically oriented systems analysts were experienced; the accounting function also would be upset in the search for data to create values for holding and order costs. Records may be scarce and hinder the needs of forecasting, especially for demand data covering two or more past years. The most difficult discipline would probably be the requirement to allow the scientific system to take control. For example, if the manager maintains a rule of "two months supply on hand at all times", it is a serious step to take to allow a system to override this, should it be considered necessary.

Modern systems are computer-based. Schulz (1969: 23) remarked that: "computer systems are only aids to the manager. The fact remains that the inventory manager basing his judgment on sound management decision-making techniques, must still set objectives and determine what goals are to be attained."

A survey by the International Data Corporation in 1969 indicated that 1383 computers were in use by 894 U.S. health facilities, 41 percent being in hospitals. Of 1079 relevant applications, 61 percent concerned office accounting, 15 percent were 'general applications', five percent 'supply inventory and accounting', and only 2 1/2 percent 'inventory control'. Shepley (1972:21) wrote that: "health care institutions are still using completely manual methods for 55 percent of all hospital information processing . . . the only areas in which E.D.P. is gaining broad acceptance are payroll, personnel management, accounts receivable and patient accounting."

In Britain the Department of Health and Social Security maintains strong policy control over all N.H.S. computing. The D.H.S.S. has envisaged much increased use of data processing, especially in view of the transfer of local authority health functions in the 1974 reorganization. Progress is hindered by inflation which is affecting costs of medical computer systems. By 1976 most regions were to have a standard computer configuration, consisting of at least an ICL 1903T, with 64K storage. In 1973, there were only nine off-line batch systems, and one on-line, using terminal interaction for a central sterile supply department. Twelve applications were planned for introduction by 1976, plus several drug record and stock control applications.

In Ontario, the Ministry of Health has no plans for a provincial computer-based inventory management system.

To study the extent of modern scientific inventory management practices in industry, the American Production and Inventory Control Society carried out a survey of American business (APICS:1974). Fearon (1969) had earlier examined American hospitals and concluded that most showed little appreciation of scientific management; and two hospital inventory surveys were conducted by the writer to examine both U.S. and Canadian attitudes (Crowe:1973; Crowe:1976). Analyses of the results are now given, and a fuller description is contained in the appendix. The 1972 survey went to 140 hospitals, with 46 percent response; the 1975 survey to 100 hospitals with 30 percent response - the samples being independently selected. Table 22 shows characteristics of respondents.

Table 22

MAIN CHARACTERISTICS

OF HOSPITAL RESPONDENTS

MEASURE	STATISTICS	1972 SURVEY	1975 SURVEY
	Mean	642	508
Rated	S.D.	220	140
Bedsize	C.V.	34	28
	Median	600	490
	Mean	2960	1776
Number of	S.D.	2443	1082
Stores Items	C.V.	83	61
	Median	2000	1900
	Mean	236	181
$000 Value of	S.D.	177	215
Stores	C.V.	75	119
	Median	185	177
	Mean	353	381
$ Value, Stores	S.D.	217	274
per bed	C.V.	61	72
	Median	280	345

Source: Crowe (1973; 1976).

Histograms of replies showed that distributions of all except 'rated bedsize' were skewed. Both years data appeared to give similar patterns and it is believed that the two groups can be reasonably compared.

It would seem that economic stringencies are causing hospitals to reduce inventories. The mean number of items fell from 2960 to 1776 (-40 percent); the value invested fell by 23 percent, indicating the off-setting effect of rising prices.

The two surveys showed that the main use for computers in hospital inventory management, is for production of the stock status report (27% and 37% respectively). The APICS survey (1974) indicated that 88 percent of reporting industrialists use computers for this purpose. Sixteen percent of hospitals (Crowe, 1975) use computers to prepare purchasing documents; in industry, 75 percent. Sixteen percent of hospitals claimed that no computer service was available; it is more likely that no budgetary allowance is made for this purpose.

Table 23 is a combination of APICS and hospital survey responses to questions concerning methods of calculating basic inventory statistics; it is a useful indicator of the likelihood that modern methods will be adopted in the near future.

Since the same hospitals were not surveyed twice, trends cannot be deduced with confidence; it does appear however that neither industry nor hospitals have reached the limits of modern inventory management.

The E.O.Q. formula requires estimates of holding and ordering costs. Many hospitals had computed no values for these. The mean order cost was said to be $11 in 1972 and $16 in 1975, but with a substantial range of opinions. Questions concerning stock holding costs resulted in these percentages: 17 (1972), 15 (1975) and 20 (APICS), again with ranges of substantial width. From direct examination of many hospital records, the writer concludes that the

Table 23

METHODS TO DETERMINE EOQ AND ROP

ORDER QUANTITY	Crowe 1972	Crowe 1975	APICS
	%	%	%
Estimate by Purchasing Manager	38	28	39
Estimate by using department	2	20.5	-
Slide Rule or Nomograph	15	20.5	-
Computer Programme	18	15	49
Release under contract	5	10	18
Dataphone	4	2.5	-
Several Methods	16	2.5	Yes
None Reported	2	0	-
	100%	99%	
REORDER POINT			
Use of ROP Formula	20	52	36
Refer to low shelf stocks or card balances	50	29	21
Periodic Review	13	3	N.A.
Normal Use estimate plus added safety stocks	N.A.	16	N.A.
More than one method	11	N.A.	43*
	94	100	100

* Materials Requirements Planning

most common inventory method used, is to calculate minimum and maximum levels for each item based on past experience and economic stringencies, and to permit an order to be placed when the predetermined minimum level is approached. This takes no account of dynamic demand conditions, trends, variable lead times, nor of rapid changes in costs of holding stock. Although the E.O.Q. formulas are used quite commonly by industry, none of those responding to the APICS survey made use of the Wagner-Whitin algorithm.

Since most hospital administrators have no understanding of inventory management as a dynamic force, it is necessary to consider opinions of industrialists for ideas as to improvements. APICS reported that half of the companies would wish for an improved data base, and almost half required more accurate and dependable forecasts of demand. One third realised that computers could be more efficiently used, and 30 percent wished for greater management support. Hospital administrators in 1975 did have strong views on problem areas affecting supplies generally. Top concerns were about inflation; staff shortages; supply shortages with erratic delivery times; storage space limitations; lack of firm quotations, and labour disputes.

STORES LOCATION RATIONALIZATION

Every large corporation with multiple locations has considered the question of central or local stores and purchasing offices. Ontario has a hospital service with more than 300 branches, yet no policy has emerged concerning centralization other than group purchasing. Benefits could be gained from physical central location of stores, especially in cities with two or more hospitals and other health centres. Deliveries would be simple, allowing hospitals to maintain only a working and emergency stock. The problem of obtaining agreement between authorities is great, and most stores are in separate institutions.

Within the hospital the question of one central location for purchasing may arise. A recent survey by Hospital Administration in Canada (1975) showed that the larger the hospital (rated beds) the greater the impact of central purchasing. More than 80 percent of large hospitals used a central purchasing system for major items; only 41 percent of small hospitals used a central purchasing point; 64 percent of medium sized hospitals (101-499 beds) did so. Certain items are more commonly purchased centrally than others. Table 24 is adapted from this 1975 survey, and shows which departments are most often centrally located.

Table 24

CENTRAL STORES LOCATION

WITHIN A HOSPITAL

	By Size		By Type	
	Small	100 Beds	Acute Care	Other
Pharmacy	58%	27%	41%	63%
Food Services	58	41	49	63
Physical Plant	61	68	62	74
Laboratory	63	83	74	63
Operating Room	74	93	82	79
General	88	90	90	95

Source: Hospital Administration in Canada (1975).

Edmands, Schutta and Daly (1976) published a study of the Fairview organization in Minneapolis, comprising three privately owned hospitals and nine other medical institutions serving 2800 beds. Great expansion has taken place since 1965, and today the corporation supplies materials and procedures to many other hospitals.

A study began in 1971 to rationalize materials management, since space was badly used and there were no real policies as to internal or external location of stores and services. It was decided to retain two major hospital central supply departments, improving layouts and locations and switching between CSD and other departments as was seen to be economic. Thus, for Fairview, such departments as Laboratory, Surgery and OB retained their supply functions. Space at one hospital was released to enlarge outpatient facilities.

The economic impact included net staff savings of $31,000 annually, and revenue increases of $35,000. The authors claim that the central supply operation has become more effective; space made available for other purposes, and existing equipment better utilized.

No mention is made of improved inventory management beyond that claimed above; but it would seem that the new procedures could be amended to incorporate a sophisticated inventory management system.

PHARMACY INVENTORY MANAGEMENT

Regulations regarding supply and inventory of drugs and chemicals are strict, particularly for narcotics. Many drugs must be held at a low and stable temperature, and the expiry date must be carefully regarded. Maintenance of inventories and possibly even record keeping, may be beyond the capacity of general store-keepers. Large hospitals usually have a separate pharmacy, which cannot be afforded by smaller institutions. In earlier years, laboratory and operating room supplies would have been in specialized areas, but increasing adoption of ready-for-use sets has led to these being in general stores.

Demand for drugs is very individualistic; a doctor may have emphatic preferences, or a patient may require special medication; these will reflect on the complexity of storekeeping. Even indirect situations can pose complications. Thus, a strike in a major glass manufacturing establishment in Ontario in early 1976 caused serious problems, since the firm was the only convenient supplier of the special glass used by pharmacists.

Garrett (1973:22,24) recommends a central system for medical/surgical, food and sterile supplies but a separate organization for the pharmacy (other than accounts payable). His idea of a coordinated supply system matches closely with this thesis. Data should be recorded directly from the order processing system and on-hand stocks updated directly. Each month a forecasting programme will examine every stock item and prepare a forecast for the next and subsequent months. These will be based on past activity plus growth trend data, and incorporate seasonal phenomena and any management input. A separate programme will calculate up-dated major values of R.O.P., E.O.Q. and safety stocks.

Major changes in drug distribution methods are occurring which affect inventory management. One is the unit dose concept. Traditionally, hospitals have used the floor stock-prescription order system to supply medications for the wards. Other drugs were issued on patient prescription and sent in a batch sufficient for several days, for administration by the nursing staff. The unit-dose system centralizes this operation; all doses are packages, dispensed and checked in the pharmacy, although if they can be purchased in unit-dose format, time will be saved. Although unit-dose systems are used in many hospitals, they are still regarded as experimental.

A second development is the clinical pharmacy. The qualified pharmacist is closely involved with the medical staff, accompanying them on their rounds, giving advice on all aspects of drug therapy. It is still experimental, and sufficient staff will not be available in many areas for years. Indeed in 1974 only 62 percent of American hospitals had any full-time pharmacists.

Despite the specialized developments above, the main features of inventories are true of the pharmacy. Studies have shown the validity of the ABC phenomenon, and such concerns as costs of holding and purchase are important. Since 3000 or more stock units may easily be held, minimum quantities ordered may well depend upon discount offers by suppliers. For example, a local hospital has a specialist in dermatology; his patients use much steroid ointment which normally is $48.00 per kilo, but can be purchased for $37.00 per kilo in five kilo units.

Many systems have been designed, and this writer has investigated several. Inventory management is a common component, although he has discovered very little of an innovative nature. A resumé of the objective of a system has been described by the Birmingham Regional Hospital Board in 1970:

> To make more effective use of financial resources by optimising both the amount of capital tied up with stock holding and the cost of purchasing. It will provide pharmacy management with a means of controlling usage, expiration, and wastage of drugs. It will make available data on the different methods of dispensing drugs so that comparisons

can be made, perhaps resulting in the transfer of some drugs at present being requisitioned, to a more automatic method of stock replenishment.

The complex nature of pharmacy stocks has led to the use of mini-computers in many cases, rather than incorporation within a main configuration. The Hospital Systems Study Group has developed inventory and unit dose systems through collaboration between the University of Saskatchewan in Canada, the University Hospitals of the University of Wisconsin and the University of Kentucky, and a computer manufacturer, B-D Spear Medical Systems. It covers all aspects including admitting and discharge of patients, medical order entry and reviews, scheduled and non-scheduled medications and control of restricted drugs. Another major hospital that has developed the use of a mini-computer is Strong Memorial Hospital, University of Rochester (New York). The pharmacy, with 16 professional pharmacists, dispenses from a stock of 2000 items and has developed a complete but not innovative inventory system. In Ottawa an area grouping of ten hospitals have negotiated for IBM equipment and should have an inventory/group purchasing system in operation in 1977. The thrust was provided by the Riverside Hospital, using a previously designed stores and pharmacy stores system, but substantial problems were encountered when the single hospital attempted to establish a separate pharmacy system.

MICRO-ANALYSIS: INDIVIDUAL HOSPITALS

When annual reports are examined, certain facts emerge:

1. The outstanding expense of any hospital is wages. This charge averages 72 percent of total expenses; industrial proportions vary with the nature of the enterprise, but 30 percent would be typical in manufacturing.
2. Supplies expenses are on average eight percent of total expenses; industrial supplies form a much greater proportion: 60 percent for one home appliance manufacturer, for example.
3. Inventories as a proportion of total assets are low in hospitals - often below two percent, whereas industrial values range from 25 to above 40 percent. However, as a percentage of current assets the value of inventories is appreciable - as high as 40 percent and is leading to pressure upon controllers to keep this investment within bounds.

Typical of the larger hospital is one health centre of a large mid-western U.S. university, visited in 1976. There are 650 rated beds, and medical care is innovative and consequently expensive. Of total expenses of $15 million, 61 percent is incurred to pay the 1850 employees. The average level of inventory was valued at $610,000 and its distribution is shown in table 25.

The value of inventories per rated bed was $937, a high figure in comparison with most hospitals visited: a value of $400 would be nearer the average. Given the inventory below, holding costs per year would amount to $182,000, or the salaries of ten middle level managers.

Table 25

HOSPITAL INVENTORY OF SUPPLIES

20 MAY 1976

Food	$ 78,667
Pharmaceuticals	28,033
Medical Gases	1,363
I.V.'s and Sets	49,788
AK Supplies	15,002
Sutures	28,464
Medical and Surgical	165,880
Printed Forms	78,256
Office Supplies	12,106
Laboratory Supplies	32,832
X-Ray Supplies	29,048
Surgical Instruments and Appliances	7,730
Dietary Supplies	36,369
Housekeeping Supplies	38,232
Linen Disposables	7,295
	$609,065

It has been shown that a scientific approach to inventory management by hospitals is uncommon. As society becomes more demanding and medical technology more complex; as health services costs threaten to absorb the national product, and claims for increased spending are resisted, operations researchers are compelled to become increasingly interested in systems for inventory management. There are potential benefits to be gained, if only because current procedures are so inefficient.

CHAPTER FIVE

THE DEMAND FORECASTING COMPONENT OF HOSPITAL INVENTORY MANAGEMENT

Information concerning the use of scientific inventory methods by hospitals is meagre; details of applications of statistical short-term forecasting routines are equally scanty. This thesis attempts to show that a system combining inventory management and forecasting can be designed and implemented; that management of hospital supplies will thereby be improved; and that the system will remain practical, given the quality of equipment and manpower available in Canadian hospitals. Inventory methods must be linked to policies established by the hospital, and this restraint might suggest that upgrading should await the development of a comprehensive management information system (M.I.S.). It is unlikely that such a structure will be available for many years, and any sub-optimization resulting from a total inventory package will not be serious nor damaging to the general interests of the hospital.

Management requires prediction of short-run future demand to provide adequate service to the user departments, and to optimize inventory investment. Decisions may be based on quantification to some extent, but there are complexities which are not amenable to quantitative definition, nor algorithmic solutions. Wagle (1965:195) emphasized that the aim of mathematical models is not to supplant judgement and experience, but to enable managers to gain greater insight into the nature of complex problems, and to reduce uncertainty. This thesis relies on simple models, since there is no experience available upon which to build anything complex. Knopp (1971:2) declared that: "scientific inventory management has become a fairly common term in hospitals; particularly those where computers are used." It is true that some claims have been made at conferences, but it is contended that true scientific management, using techniques such as statistical fore-casting, is rare. Writers have been emphasizing the advant-ages for some years. Labelle (1968:103) contrasted the need to control investments in supplies, due to scarcity of capital resources, with the humanitarian objectives of patient care and safety, and Ammer (1975:4) noted that the recent economic pressures upon hospitals will cause them to reconsider the efficiency of their decision-making procedures, including inventory management.

Inventory demand forecasting also assumes increas-ing importance due to the rising costs of non-labour components. Ammer (Ibid., p. 1-2) notes that (in the U.S.A.) every ten percent increase in salaries is accom-panied by a 15 percent increase in non-personnel costs. Duncan and Norwich (1973:154-5) refer to U.K. health studies to support their contention that a sophisticated stock control policy is not viable for such items as pro-visions, dressings, cleaning materials, bedding, linen and clothing. These studies recommended the use of a simple reorder policy. Each item's safety stock would be determined by agreement between the hospital and supplies officer concerned; the quantity to be ordered would be determined by use of the classical E.O.Q. formula. Gandy (1971) and Raitz (1964) draw attention to problems of forecasting and inventory management, when translated from an industrial to the hospital setting. One is the difficulty of classifying medical supply items into basic demand patterns. These items often display more serious fluctuations than would industrial items, "partly caused by the stochastic nature of the demand, as well as the practice of infrequent withdrawals of rather large quantities from stock . . . this non-uniform demand rate adds to the variability of demand already present in the time series" wrote Adam (1972:4). Another is the absence of a strong profit motive closely associated with inventories, leading to a lack of commitment to sophisticated methods since payoffs cannot be measured as they may be in industry. Adam (Ibid.) and Konnersman (1969) relate forecasting to daily administrative decisions, including food requirements which depend on the daily patient census, numbers of staff and visitors, incidence of special diets, and food preferences. These exogenous or subjective elements could be programmed into the system either through provision for management intervention or else as data became available.

FORECASTING AND HOSPITAL ACTIVITY INDICATORS

Examination of the hospital shows that it has the characteristics of an open system with respect to its general environment, but that the system becomes closed with respect to diagnosis and treatment. It should be possible, therefore, to quantify activities within the system with a view to correlating patient treatment with use of supplies.

This writer examined several attempts to create performance indicators, with the objective of using the most suitable as a guide to demand upon supplies. It was discovered that none has reached the stage of useful applicability. Grogono and Woodgate (1971:1024) have written:

> Despite the size of the (health care) industry we have as yet no rational basis upon which to organize and distribute our resources. This must in part be attributed to the absence of any method of measuring efficiency; we have no method of measuring a patient's health before and after treatment. If we had, we might be able to allocate limited treatment resources to areas where they would be most beneficial . . . and we could also apply cost-effectiveness calculations to much medical work.

Rosser and Watts (1972) explained that measurement problems are hampered by the lack of definition of the term "improvement", and the classification difficulties which follow.

Kourie (1976) analysed a pilot study of general surgery specialities in relation to efficiency of service to patients. He identified two major variables affecting efficiency; the time spent waiting before admission to hospital, and the length of stay in the hospital. What would be the effect on costs if the length of stay could be reduced? The study was conducted for the British NHS, and allowed participating doctors to develop their own length of stay indicators. It was discovered that there are great variations in most specialities between hospitals, and that the average stay per specialty cannot be used with confidence as a measure of primary efficiency. The Hospital Activity Index uses some seventy patient groupings, and the difficulties of creating an agreed indicator from these is substantial. The author refers to Revans (1964) for the view that the hospital tends to act as a 'single organism' tending to perform wholly efficiently, or not.

Chen et al. (1974) criticize 'utilization' as the basis for measuring effectiveness since this may not necessarily correlate positively with the effectiveness of a service, and may even be inversely related. Highly effective therapies - such as appendectomy - involve no further expense; chronic disease therapy will not cure but results in high utilization. Again, inefficient therapy leads to long hospital stay.

Chen and Bush (1976) recognize the need for a composite index derived from measurements on several dimensions. The first is the level of function (disability): this widely varies between populations and needs classifying by demographic characteristics into modules, whose function level expectancies are homogenous. The second dimension involves expected transitions to other function levels at subsequent points in time. These are transition probabilities, or prognoses, and expected durations have been under study by the Chen team and others for several years. Efforts may be made to obtain medical consensus as to a set of function levels for most conditions in the population.

Attempts to obtain a valid health indicator are continuing but seem far from solved. The possibility of using an indicator to measure demand upon the health directed supplies used by a hospital, is remote.

CRITERIA FOR OBJECTIVE DEMAND FORECASTING

Chase and Aquilano (1973:182) identify two approaches to forecast development. The first is based upon the premise that what happened in the recent past will be indicative of future expectations; statistical techniques are used to produce the forecasts. The second is more subjective, relying on customer opinion and intentions; surveys; salesmen's estimates; use of indicators, and technological forecasting. In practice, both methods are used.

This research concentrates upon objective forecasting methods and attempts to take into consideration stochastic properties of the system. IBM (1967:36) suggested that a systematic balancing of the conflicting factors: stability and responsiveness, would achieve superior results over intuitive forecasting, because of a human tendency to overcompensate. The degree of confidence placed by a manager upon any method is in direct relationship to his degree of comprehension, plus his knowledge that it is within the competence of his employees. As Craddock (1967:260-1) observed: "A complicated formula has to perform a good deal better than a simple one, and has to pass a rather vague criterion of being inherently reasonable, before we should prefer to rely on it."

Formulas should include allowance for trends and seasonal variability, and sudden changes such as steps; there should be some test of significance to isolate both trends and seasonals to check that they are truly representative of these patterns.

Most models are vulnerable to misleading inputs. Exceptionally high or low values will occur which can confuse an automatic system, and provision should be made to evaluate these outliers to discover whether the likelihood of their occurrence is within probability bounds. It may be that true outliers could be processed out of the data string and replaced by expected demand.

Inventory demand forecasting uses a short time horizon, to the exclusion of techniques involving, for example, the leading index, or econometric multiple regressions. The model that is established will facilitate routine, repetitious application appropriate to the type of data anticipated, and will probably involve the services of a local or centrally based computer. Experimental development of the thesis system frequently demanded capacity in excess of 300 K (300,000 bytes of available storage) on the Lakehead University machine. The system has the acronym: BRUFICH, from Brunel University Forecasting and Inventory Control for Hospitals. It incorporates accepted requirements of an inventory management forecasting model, namely:

1. Inclusion of forecasting procedures within the overall inventory model.
2. Input and processing of essential decision variables: demand data, trends and seasonal adjustments, without excessive runs of past data.
3. Selection, quantification and testing of parameters, such as the weights used for averaging.
4. Recognition of changing demand patterns, using adaptive mechanisms and exceptions reporting.
5. Provision to forecast through one period and variable lead time, with regular updating capability.
6. Design of appropriate tabulations and graphical presentation of actual data and forecast values, together with measurement of errors.

A hospital forecasting system is affected by stringencies which must be accomodated. Access to certain medical and pharmaceutical products may be restricted for security reasons, causing expensive record keeping and the need for separate stores. Many drugs cannot be recycled after expiry date, and the loss must be borne by the hospital or supplier. Medical staffs emphasize the essential or critical nature of many products whose variety, fragility and scarcity cause difficulties for the purchasing manager, who attempts to rationalize demands and create true priorities.

An efficient inventory system will improve management performance. Incorporation of the BRUFICH system is possible without risk of sub-optimization, since there is at present little likelihood of a comprehensive hospital management information system being implemented in the near future.

Many visits have been made to hospitals in Great Britain, Canada and the U.S.A., with the object of studying needs of inventory and supply managers. Their prominent concerns are that:

1. Any system should reduce the level of inventories without harming the quality of services rendered;
2. The forecasting routines should be incorporated within any system without disruption;
3. The demands of any procedures should not be excessive, and beyond the capacities and capabilities of staff and equipment. Intuitive methods are popular since stores employees are not likely to have knowledge of mathematics, statistical ideas nor concepts of systems analysis;
4. Sufficient data and secure parameters should be available, to avoid confusion as to the effectiveness of statistical analysis.

Record keeping and inventory methods in hospitals visited by the writer, were such as to demand the simplest, most robust system. Hospital executives query the need for scientific management unless it can be introduced and maintained at a reasonable cost, and without substantial increases in staff or effort. The only guarantee that this writer could give, was that efficiency and control would be enhanced, but that overall monetary contribution could not easily be deduced.

BRUFICH was designed with academic and practical objectives in view. The simulation aspect is the one usually emphasized in the remainder of this thesis, but the diagrams and descriptions in this chapter are also applications-oriented. It was used as a testing mechanism at Brunel and Lakehead Universities, with data obtained from several hospitals, to show:

1. Procedures to forecast demand by several methods used by industry, including simple averages, Box-Jenkins and Exponential Smoothing.
2. The effects of different parameters on forecast results.
3. The reaction of forecasts to a variety of holding and ordering costs, and quantity discounts.
4. Methods of evaluating errors in the forecasts.

THE BRUFICH INVENTORY SYSTEM

Any inventory system should include:

1. A current catalogue of each individual stockkeeping unit (item) with an identifying number.
2. A properly considered planning period, with which the demand forecast will coincide. Normally, one month will be appropriate, unless lead times, accounting requirements or other planning considerations require a different length of time.
3. Classification of the entire inventory by ABC method, whereby A items can be guaranteed the priority attention their utilization demands. The label A may be given for expenditure reasons alone, or include critical items with low annual utilization.
4. A data base, including at least two years item

requisition information.

5. An appropriate forecasting system.
6. Methods to permit management override and inclusion of pertinent information.
7. A fully tested control system, with forecasting error evaluation, computations of economic order quantity, reorder point, discount price/quantity selection and reports indicating performance of the entire system compared with the established standard.

Several considerations have been taken into account. One is the erratic nature of demand data; this may be caused by the several groups that requisition supplies, each with its own plans and motivations - doctors, nurses, laboratory technicians, and physiotherapists, for example. Second, the small annual usage of many items. Industrial managers might discard them but there is a strong instinct in the health service to hold onto stocks. Third, the smaller pressure of economics in hospitals can cause greater stocks. The bill is paid by an amorphous entity - the taxpayer - whereas the private sector must account to the share-holder. Fourth, hospitals are autonomous; the scattered nature of their institutions makes central control difficult, and renders the development of a large-scale, efficient system, difficult.

The system is computer-based, with input by means of punch cards; records are kept on and off-line on magnetic tape.

The six main record files are:

1. SRIM: Stock Record Inventory Master, which controls the entire system and holds basic records.

2. DHI: Demand History and Identification, which prepares input data leading up to the first regular forecast run; and which assembles preliminary months' data for new items.
3. AFM: Adaptive Forecasting Master, the controller of regular forecasting routines.
4. ROP: Reorder Point, which contains all values upon which the reordering decision is based. It is involved with forecasting, ordering and issuing of stock, and ensures that a safety allowance is kept.
5. EOQD: Economic Order Quantity Data, controls the half year updating of EOQ, and maintains EOQ values for all items.
6. DISCO: Discounts, maintains the values of discounts with quantities offered by suppliers, and enables correct decisions to be made regarding the level of discount to accept.

Outline flowcharts show major relationships.

Figure IV indicates daily routines: special documents are needed to input purchases, receipts, requisitions, returns and other regular matters. When SRIM is completely updated, a daily test of the level of stocks is made, and reordering considered if necessary.

Monthly routines are mainly concerned with demand forecasting, as shown in figure V. Any selected forecasting method can be incorporated into the procedure.

Three files are used directly. SRIM contains up-to-date information on every item in stock. DHI is used to identify new items, and compute the initial values needed by forecasts. The forecasting routines are

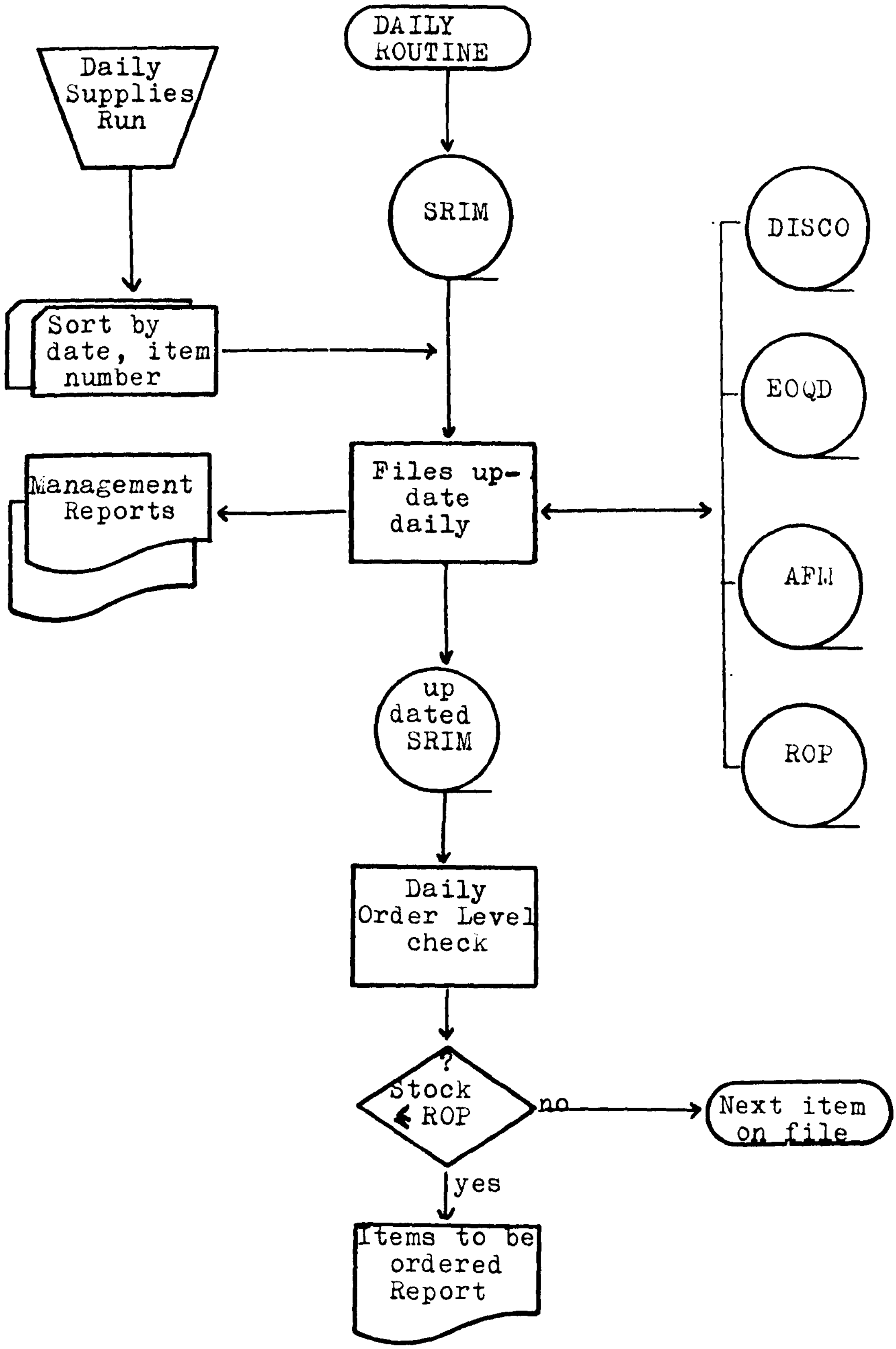


FIGURE IV

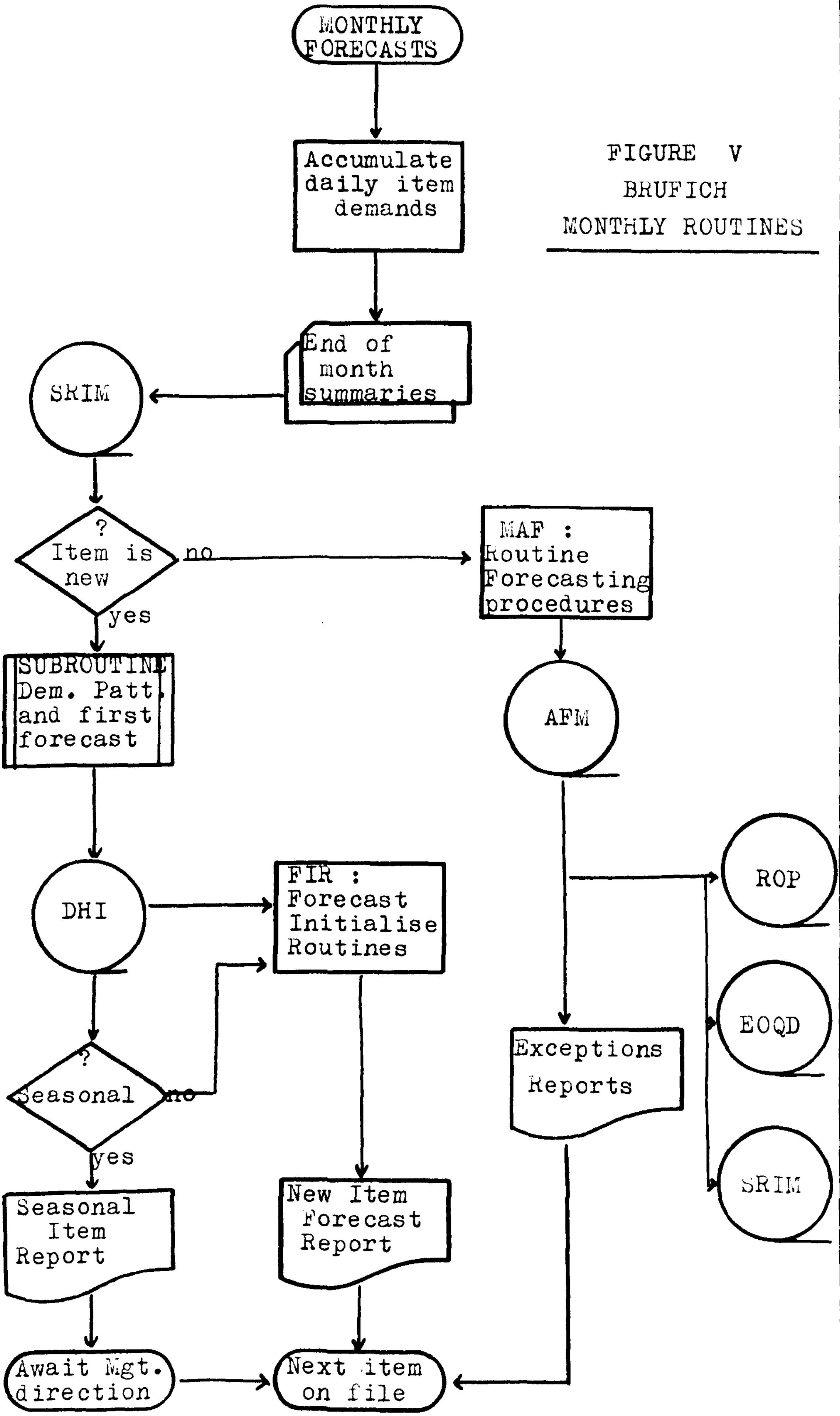
BRUFICH

DAILY PROCEDURES

FIGURE V

BRUFICH

MONTHLY ROUTINES



contained in the AFM file, together with appropriate parameters.

Figure VI shows quarterly procedures mainly concerned with updating reorder points, including those of newly acquired items. The Reorder Point file - ROP - receives information from AFM and SRIM, concerning forecasts, lead times and ABC classification. Provision is made for information to be given to the system about service level changes and unusual demand conditions. The updated ROP file is then available for monthly forecasting, and for daily order quantity decisions.

Figure VII demonstrates the half-yearly analysis-by-value process, although it may be run at any desired frequency. Margins of value are decided by management, and items classified according to the desired divisions.

The writer analyzed the inventory of a large hospital prior to the introduction of a modified BRUFICH system. Values used were $2000+ for A, and $100+ for B. Table 26 shows the results, which closely matched the Parêto curve, as explained by Dickie (1951).

The recommended interval for updating the economic order quantity is six months. Should less than twelve months history be available of an item, management will decide the E.O.Q. value: figure VIII. Forecasting for new items is performed by an 'extended forecast routine' for stable and trendy items; there is a special procedure if seasonal regularity is anticipated.

Since many EOQ methods are available, the computer programme permits exchange of the subprogramme for any other desired by the manager.

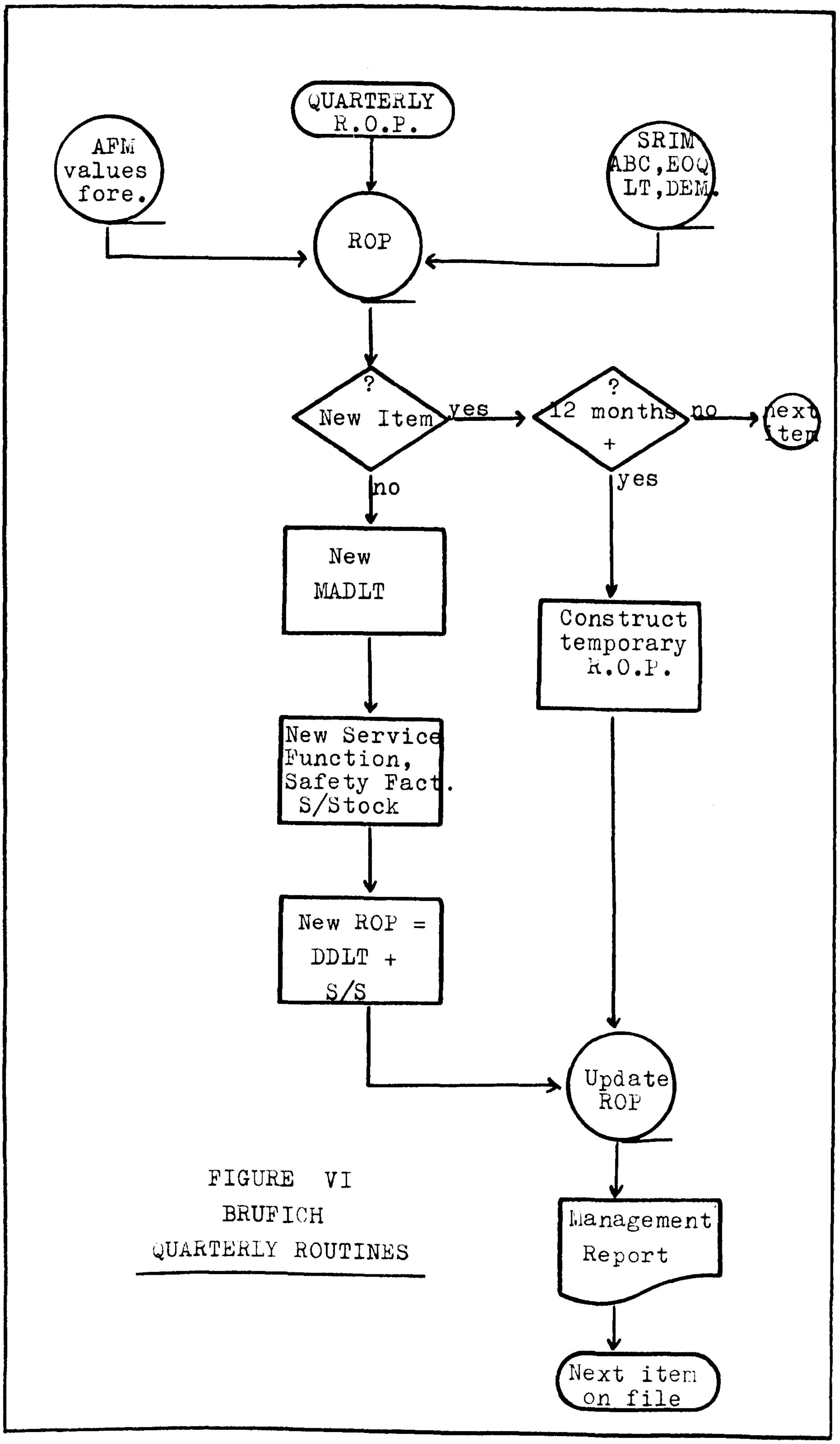


FIGURE VI
BRUFICH
QUARTERLY ROUTINES

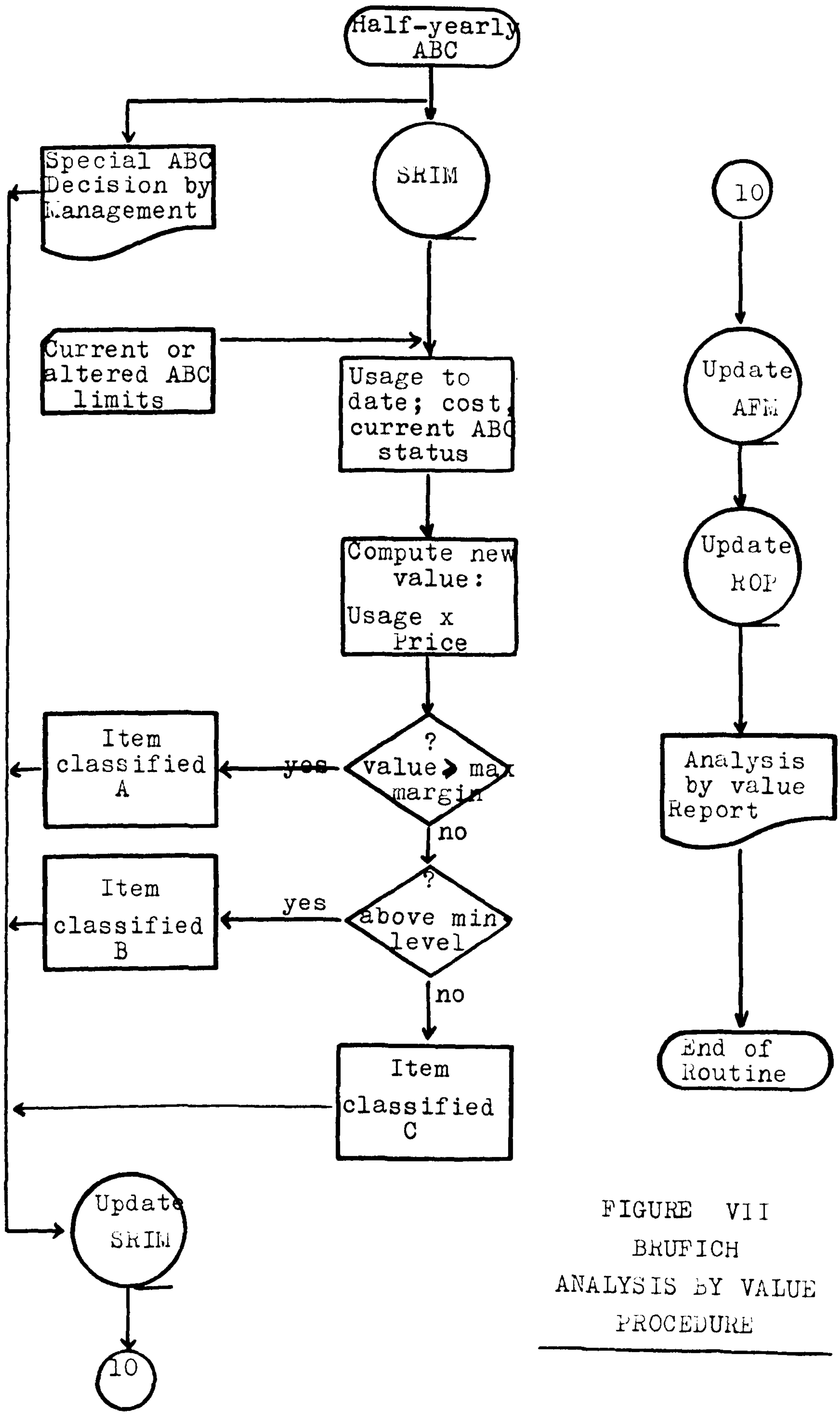


FIGURE VII
BRUFICH
ANALYSIS BY VALUE
PROCEDURE

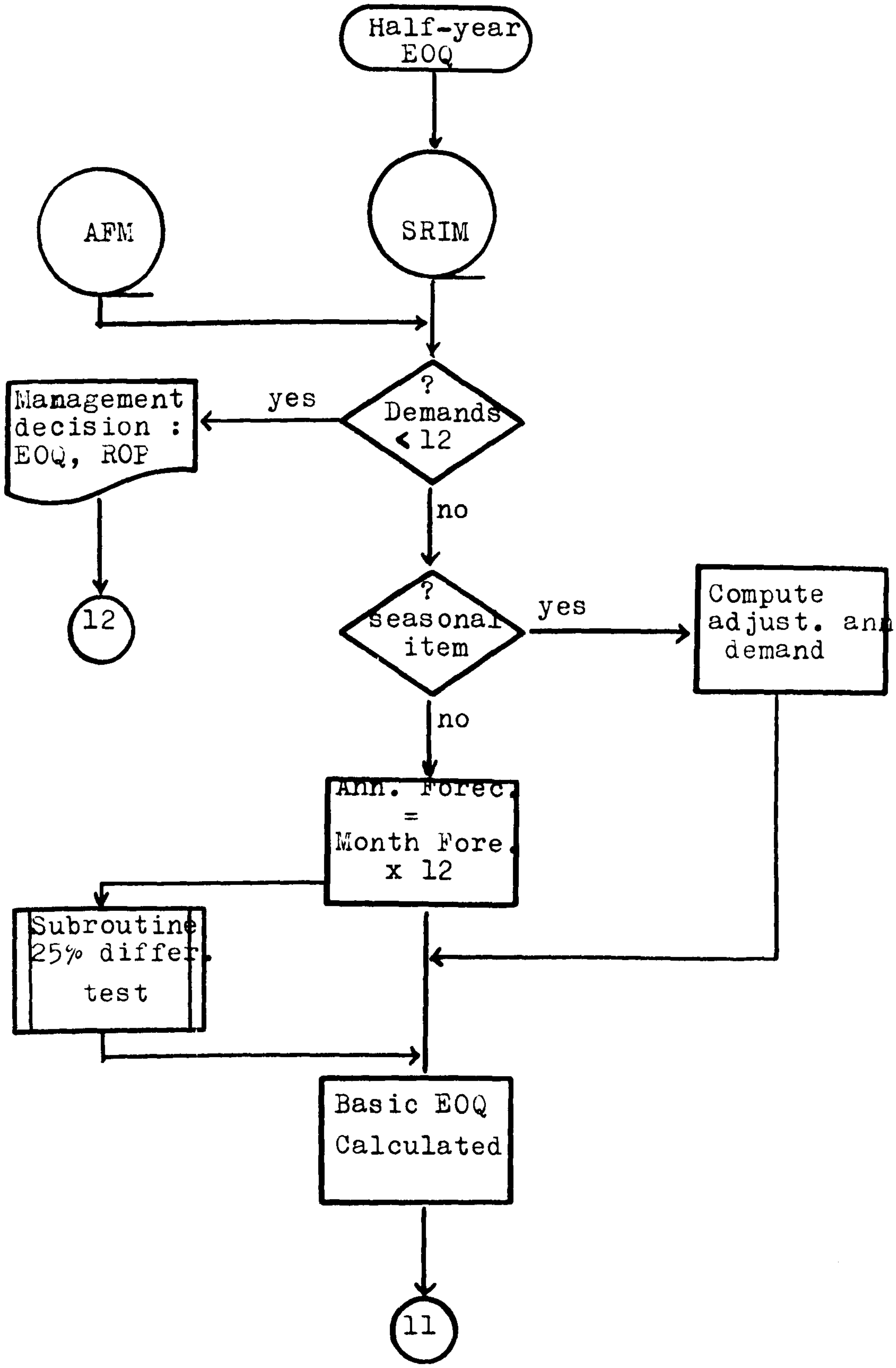


FIGURE VIII (1)
Brufich
EOQ PROCEDURE

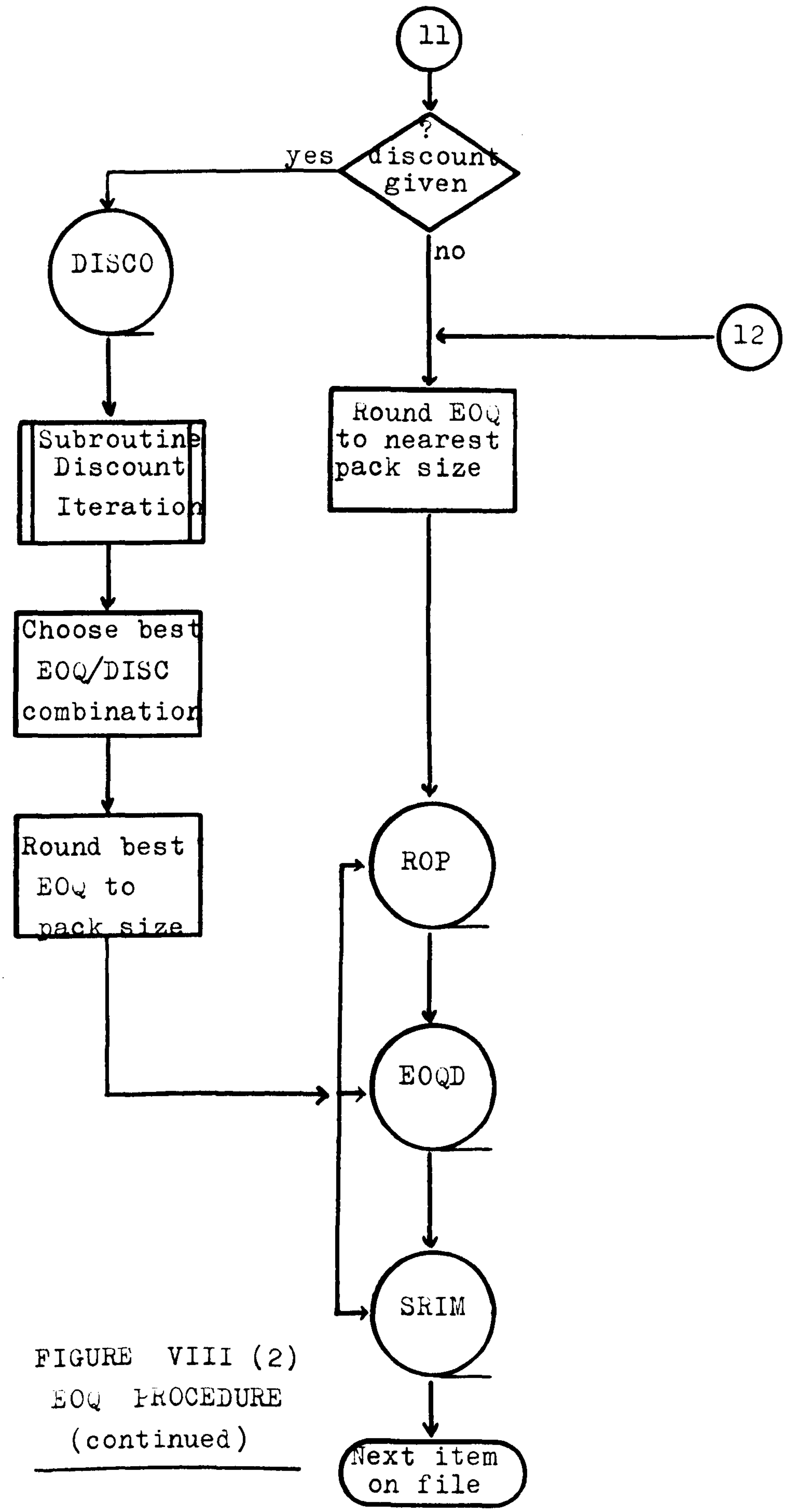


FIGURE VIII (2)
EOQ PROCEDURE
(continued)

Table 26

ANNUAL USAGE BY VALUE

HOSPITAL FOR SICK CHILDREN, TORONTO

Annual Issue Value	Number of Items	Percentage of Total	Cost of Issues	Percentage of Total Cost of Issues
$ Above 10,000	12	1%	$ 229,538	19%
5000 - 10,000	17	1	110,057	9
2000 - 5,000	83	5	270,765	23
A Total	112	7%	$ 610,360	51%
B Items:				
$100 - 2,000	880	53%	$ 540,975	45.5%
C Items:				
$0 - 100	654	40%	$ 40,000	3.5%
All Items	1,646	100%	$1191,335	100%

Many items will be purchased on an annual contract. For those having discounts an iterative routine has been devised (not shown in the charts).

In order to extend the monthly forecast to an annual basis for the EOQ procedure, a comparison is made between the latest forecast at an annual rate, and the actual demand experienced in the past year. If the difference is large, a special report is created requesting management advice as to which value is to be used.

Once a year a major report will be issued: figure IX shows the flow-chart. Every computer file is required, and the design of the report is sufficiently comprehensive to enable budget planning to be efficiently conducted.

For thesis purposes, the main importance is the selection and incorporation of an appropriate method of

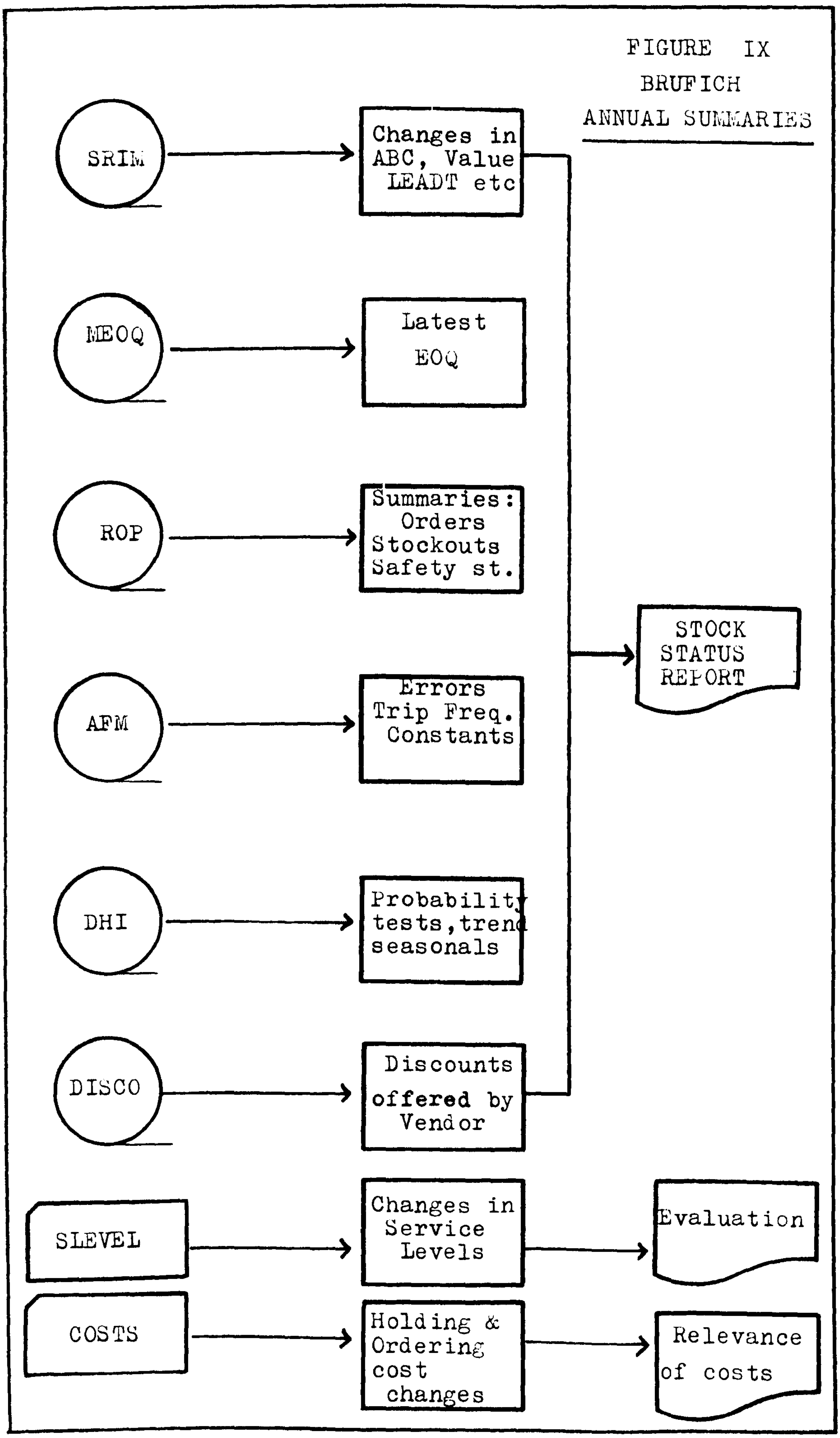


FIGURE IX
BRUFICH
ANNUAL SUMMARIES
SRIM
Changes in ABC, Value LEADT etc
MEOQ
Latest EOQ
ROP
Summaries: Orders Stockouts Safety st.
AFM
Errors Trip Freq. Constants
DHI
Probability tests, trend seasonals
DISCO
Discounts offered by Vendor
STOCK STATUS REPORT
SLEVEL
Changes in Service Levels
Evaluation
COSTS
Holding & Ordering cost changes
Relevance of costs

demand forecasting. An examination of potentially satisfactory methods is conducted in the following chapters, with evaluations.

FORECASTING APPLICATIONS IN HOSPITALS

Since forecasting demand is a vital component of inventory computations, questions were asked in the 1972 and 1975 hospital surveys and the industrial survey of the American Production and Inventory Control Society (1974). Results indicate that industrialists rely heavily on executive judgement. Hospital administrators favour simple statistical averaging, in addition to past experience. Sixteen percent of respondents to the 1975 survey claimed the use of moving average estimates, but none used exponential smoothing. Both A.P.I.C.S. (1974) and Crowe (1975) mentioned the Box-Jenkins methods, but no claim for use was made by industry or hospitals.

It is interesting that Exponential Smoothing is used by 30 percent of the industrial respondents, although there is no indication at what level. Some hospitals are planning to attempt forecasting by this means, but few are yet really involved. Recommendations were made by Raitz (1964) who conducted a limited experiment using one category of hospital supplies. A more recent thesis, by Ingrando (1972) comments that there is ample literature concerning E.O.Q. in hospitals, but almost nothing about forecasting with exponential smoothing; he discovered only three references including Raitz. One application (Sposato and Spinner, 1970) referred to independent health insurance plans, to forecast their number and the number of subscribers in the future; another by Ulrich and Noart (1971) described an application in the dietary department, to forecast meal demand for both patients and cafeteria customers. Raitz (1964) made the only references concerning the use of the technique to forecast future inventory requirements.

The 1972 responses indicated that 78 percent of hospitals attempt to forecast at least through lead time. Since, however, two-thirds of hospital purchasing staffs had limited or no access to computing equipment, it is not surprising that modern statistical techniques were not used. This is unfortunate, since modern adaptive smoothed average forecasting methods are fast, simple, effective and cheap.

Several respondents forecast by use of simple averaging of recent requisitions. Given a product whose demand pattern is stable this method gives adequate results. It is usually the case that hospital requistion patterns are <u>not</u> stable.

Many correspondents claimed to use trend and seasonal adaptations. The writer has the impression that this is mainly subjectively performed and results could be inaccurate. Recognition and elimination of noise in the stochastic pattern of hospital demand requires special statistical techniques. These are not likely to be performed without the facilities of modern computing equipment.

TESTING DATA FOR GOODNESS OF FIT

To forecast demand during the lead time, and to establish safety stock levels, it is desirable that the pattern of distribution of the data be studied. It is likely that if the data can be shown to fit a known probability model sufficiently well, this could be used as a substitute for the actual statistics: King (1968:299), Phillips (1972:1), and Holt et al. (1960:281). Although demand data is discrete, several continuous distributions have been examined for goodness of fit. If a reasonable approximation could be obtained, it would be convenient to acquire the advantages of - for example - the well tabulated normal distribution. Phillips (1972:19) wrote: "Such assumptions can often lead to highly erroneous results, and hopefully the programme GOF will eliminate some of those flagrant errors."

To compute probability densities for every item in stock at frequent intervals would be an expensive, major undertaking. Yet to compute likely lead time demand implies some knowledge of any underlying probability distribution, and this suggests that study of families of items to determine common patterns would be beneficial. Thereafter, inventory control procedures could be performed routinely:

1. Test a set of data for goodness of fit and select the closest theoretical probability distribution.
2. Establish a suitable service level, depending upon the opinions of management and the item's A, B, or C status.
3. Using appropriate statistical tables, define maximum

demand during lead time, and, thence, the required safety stock.

Thirteen items of the entire 68 item sample of hospital demand data were selected to ascertain whether patterns of demand approximate to known theoretical distributions. The programme devised by Phillips at Purdue University: GOF has been adapted, and exponential, normal, uniform, poisson and lognormal testing subroutines performed using - as appropriate - Chi-square, Kolmogorov-Smirnov and Cramér-von Mises goodness of fit tests.

Demand data is discrete, and the length of histories available was sometimes insufficient to allow all tests to be performed. This inhibited the use of Chi-square since cell sizes would be too small in many cases. The Phillips programme (GOF) uses equal cell sizes with a default of a maximum of fifteen cells. GOF adopts the common method of amalgamating neighbouring cells to ensure that both observed and expected values are equal to or greater than five units. Gibbons (1971:72) urged that this rule should not be applied inflexibly; the Chi-square approximation is often reasonably accurate for expected cell frequencies as small as 1.5. In the experiment, Chi-squares has been mainly used for items with N above 35, though it proved useful in other cases when testing for Poisson.

The Kolmogorov-Smirnov test was run for all 13 items. It involves comparison of the sample cumulative distribution function with the theoretical equivalent at each sample observation. The sample test statistic is the maximum deviation between the two functions at any point in the sample, this value being compared with a tabular critical value at a variety of significance levels:

$$D_n = \max \left| F_n(X) - F_o(X) \right|$$

The method is displayed in figures X and XI, testing an item for normal and exponential fit. We accept the hypothesis that there is no significant difference between the data and a normal distribution; there is a significant difference between the data and the exponential distribution.

Although data should be continuous for exact results, O'Toole (1964) and others state that the test can be applied to discrete data. If the test is applied to the distribution of a discrete variable in a sample, and the decision is reached to reject the hypothesis concerning the distribution in the population, the decision to reject is satisfactory and as safe as it would be if the underlying variable were continuous. Gibbons (1971:84) noted that the same procedure for discrete values as for continuous can be used though the test is now conservative.

The second consideration is that of grouped data, to which the method can also be conservatively applied.

Hospital sample data has been analyzed in both the grouped and ungrouped mode. Massey (1951:72) stated: "grouping observations into intervals tends to lower the value of D. For grouped data, therefore, the appropriate significance levels are lower than the regular table. For large samples, grouping will cause little change in appropriate significance levels. However, grouping into a small number of categories can cause important changes for any sample size."

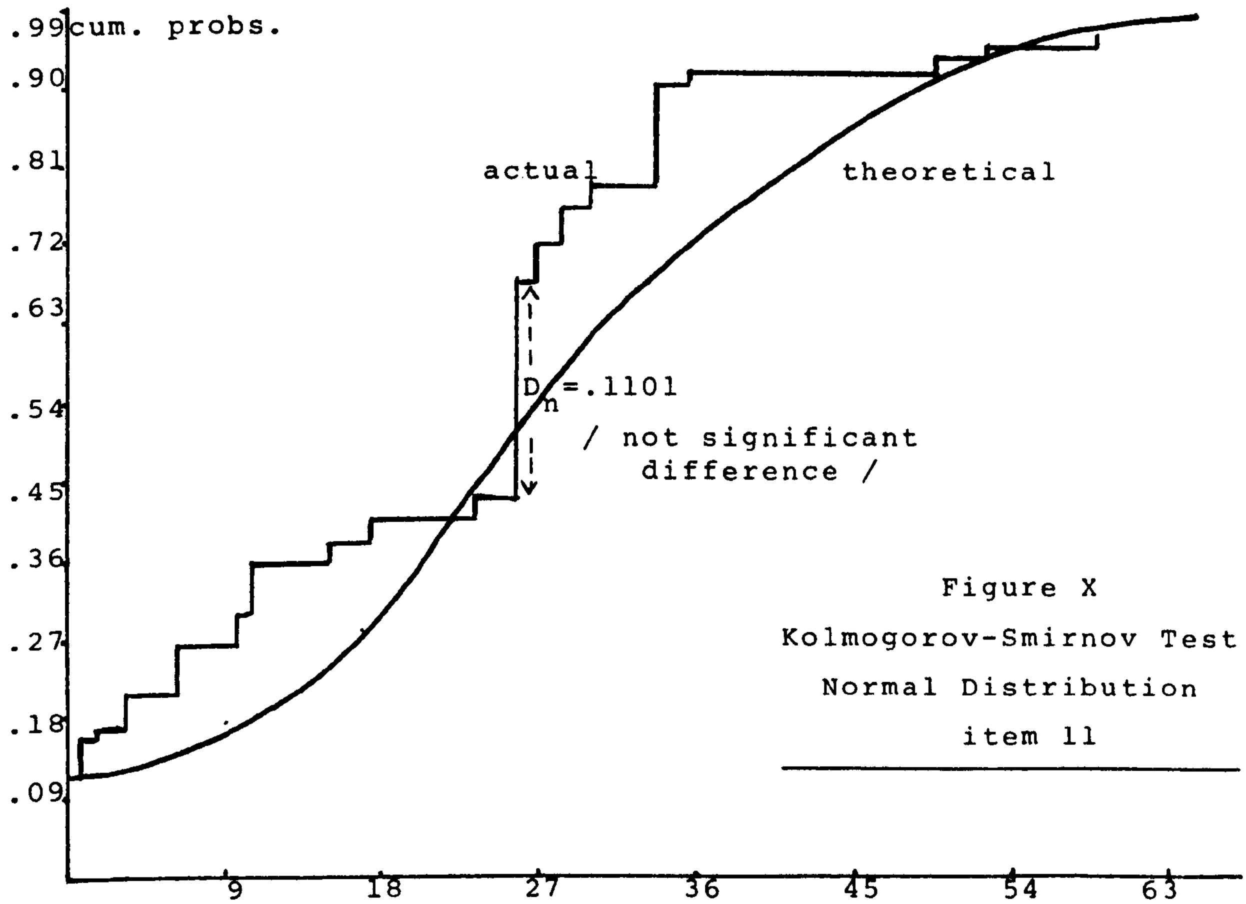


Figure X
Kolmogorov-Smirnov Test
Normal Distribution
item 11

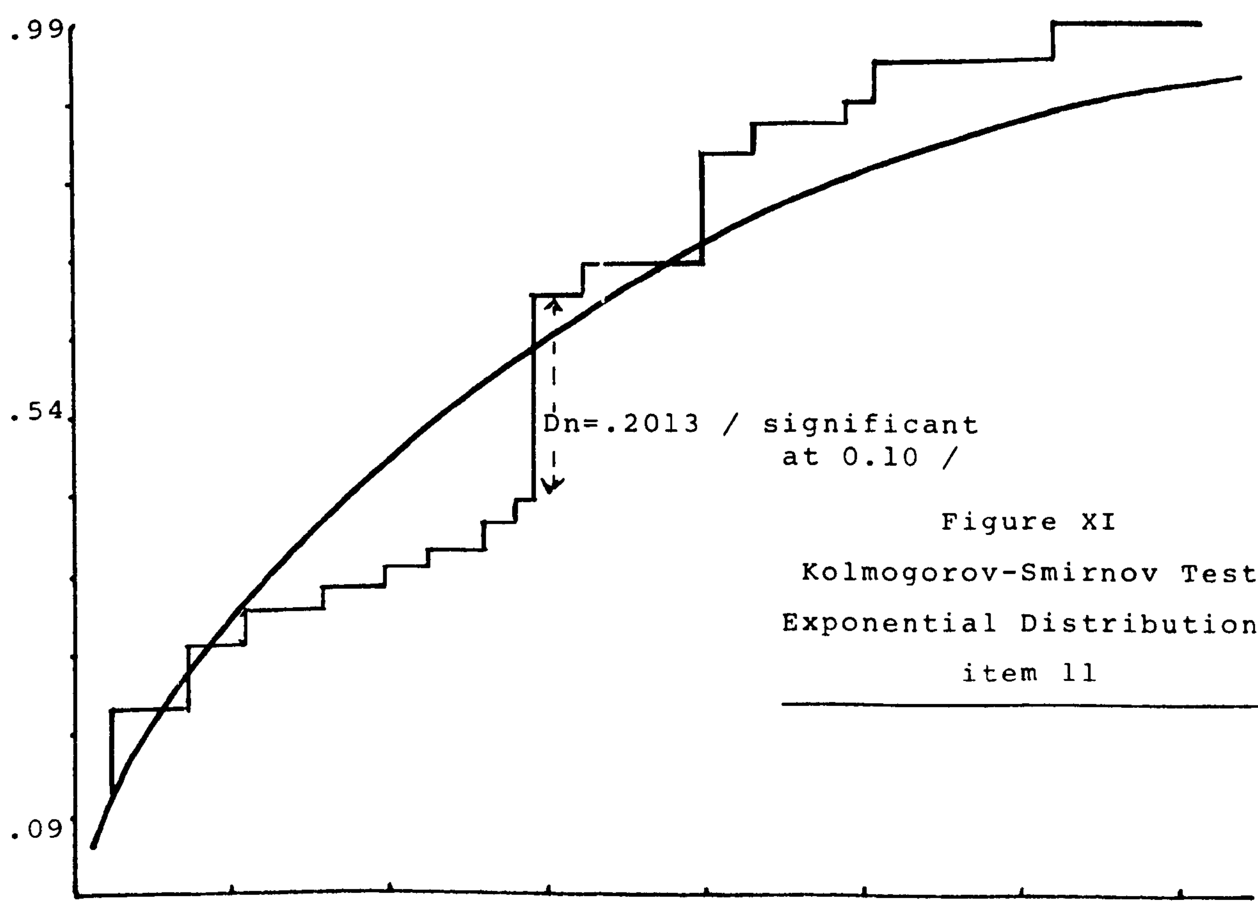


Figure XI
Kolmogorov-Smirnov Test
Exponential Distribution
item 11

As an illustration of the effect of grouping, one item (number 43) was tested against the Poisson distribution, with lambda = 6.40.

(1) Grouped Distribution

Range	Frequency	prob.	cum p.	Theoretical Poisson	Smirnov Statistic
0-4	20	.3333	.3333	.2350	.0983*
5-9	30	.5000	.8333	.8858	.0525
10-14	7	.1167	.9500	.9975	.0475
15-19	3	.0500	1.0000	1.0000	.0000
	60				

* this largest D value is compared with the table of critical values, with four cells (4 d.F.). The range is from .4940 (alpha = .20) through to .7330 (at alpha = .01) and therefore the null hypothesis is accepted that there is no significant difference between the data and a Poisson distribution.

(2) Unit Cell Distribution (abbreviated table)

Units	Frequency	Cumulated Prob.	Theoretical Poisson	Smirnov Statistic
0	6	.100	.0017	.0983
1	0	.100	.0123	.0877
2	5	.183	.0463	.1367
3	1	.200	.1189	.0811
4	8	.333	.2350	.0980
⋮	⋮	⋮	⋮	⋮
18	0	.983	.9972	.0142
19	1	1.000	.9972	.0028

There are now 20 degrees of freedom, and the critical values range from .231 through to .356. Again, the difference is not significant, but there is a greater likelihood that it could approach the critical region, since the variability of each demand is now considered.

The final experiment was to take each month's demand separately, with 60 months data for this item, in arrayed form for convenience.

There are 60 degrees of freedom, and tabular values range from 0.1381 (alpha = 0.20) to 0.2104 (0.01). Once again the difference is not significant, but closer.

(3) Individual Month Distribution (abbreviated table)

Demand	Cumulated Prob.	Theoretical Poisson	Smirnov Statistic
1	.0167	.0123	.0044
1	.0333	.0123	.0210
1	.0500	.0123	.0377
1	.0667	.0123	.0544
1	.0833	.0123	.0710
1	.1000	.0123	.0877
2	.1167	.0463	.0704
⋮	⋮	⋮	⋮
4	.2171	.2350	.0179
4	.2338	.2350	.0012
⋮	⋮	⋮	⋮
4	.3338	.2350	.0988*
⋮	⋮	⋮	⋮
16	.9686	.9997	.0311
17	.9853	.9999	.0146
19	1.0000	1.0000	--

The Kolmogorov-Smirnov method assumes that population parameters are known. Should only sample statistics $\bar{X}$ and S be available a modification may be preferred, the <u>Lilliefors Test</u> (Lilliefors, 1967).

It follows the same method but requires that the sample values be 'normalized' to Z values for normal distribution testing: the Z's are used in the computation instead of the random sample data.

Conover (1971:305) stated: "the Lilliefors test is designed specifically to test only the composite null hypothesis of normality. While this is probably the null hypothesis most frequently tested, general all-purpose goodness of fit tests such as Kolmogorov are still indispensable because of their versatility."

Although the GOF computer programme does not include the Lilliefors test, table 27 shows results of the computation for comparison with figure X (item 11).

The sample statistics are $\bar{X}$ = 25.6, S.D. = 17.55 with n = 45.

Using: $$T_2 = \sup_x \left| F^*(x) - S(x) \right|$$

the value is .094. Referring to a table adapted from Lilliefors (1967:399-402), the reading is smaller than all alpha values given, between .01 and .20: the null hypothesis is accepted.

The fourth test, Cramér-Von Mises is used when sample sizes are small. The test specifies a continuous distribution, but with cautious analysis it can reinforce the Kolmogorov-Smirnov, particularly since Chi-square is inappropriate for small samples. Sample data is arrayed and data points treated separately, with no cell grouping. The table of critical values used by Phillips (1972:34) derived from Anderson and Darling (1952) is:

Critical Value	.90	.80	.70	.40	.30	.20	.15	.10	.05	.01
Z :	.046	.062	.079	.147	.184	.241	.284	.347	.461	.743

Table 27

GOODNESS OF FIT

NORMAL DISTRIBUTION

LILLIEFORS TEST: ITEM 11

Normalized Z values	Cumulative Empirical function	Hypothesized Distribution function	Lilliefors Statistic T_1
-1.4	0.1111	0.080	.031
-1.34	.1777	.090	.088
-1.12	.2000	.130	.070
-0.89	.2667	.185	.082
-0.83	.2889	.230	.086
-0.72	.3111	.232	.079
-0.43	.8556	.333	.023
-0.83	.3778	.350	.028
-0.32	.4000	.373	.027
-0.09	.4222	.462	.040
+0.02	.4444	.508	.064
0.08	.4667	.534	.067
0.25	.6889	.600	.089
0.36	.7111	.642	.069
0.48	.7333	.685	.048
0.54	.7556	.707	.049
0.59	.7778	.723	.055
0.82	.8888	.795	.094*
1.39	.9111	.918	.007
1.50	.9333	.934	.001
1.96	.9778	.975	.003
2.53	1.0000	.994	.006

If the computed value exceeds Z we conclude that the true distribution function differs from the hypothesized function.

The Cramér-Von Mises test resembles the Kolmogorov-Smirnov in that it is a function of the vertical distance D_n: as in figure X; but instead of incorporating a single maximum difference, the Cramér test uses n differences between the curves of the hypothesized and observed distribution functions. Conover (1971:306) wrote that: "intuitively it appears that the Cramér-Von Mises test statistic makes more complete use of the data and therefore should be more effective than the Kolmogorov statistic, but the facts fail either to prove or disprove such intuition."

The computer programme GOF uses:

$$Z = \frac{1}{12n} + \sum_{i=1}^{n} [F^*(X^{(i)}) - \frac{2i-1}{2n}]^2$$

where n is the observed sample size and $F^*(X^{(i)})$ the value of the hypothesized distribution function $F^*(x)$ at the i^{th} smallest number observed in the random sample, for i = 1, 2, . . ., n, the sample data being arranged in ascending order.

A fifth test is available - the Moments test - based upon the null hypothesis of Normality. The programme includes measures of skewness and kurtosis which may be compared with tables of critical values developed by Jones (1969) for n between 10 and 125. The main importance of the GOF Moments test is to reinforce impression that the data is (or is not) normal, by study of the skewness of the data.

Table 28 lists thirteen items from the entire sample, which have been analysed using the GOF programme.

Table 28

THIRTEEN ITEM GOF SAMPLE

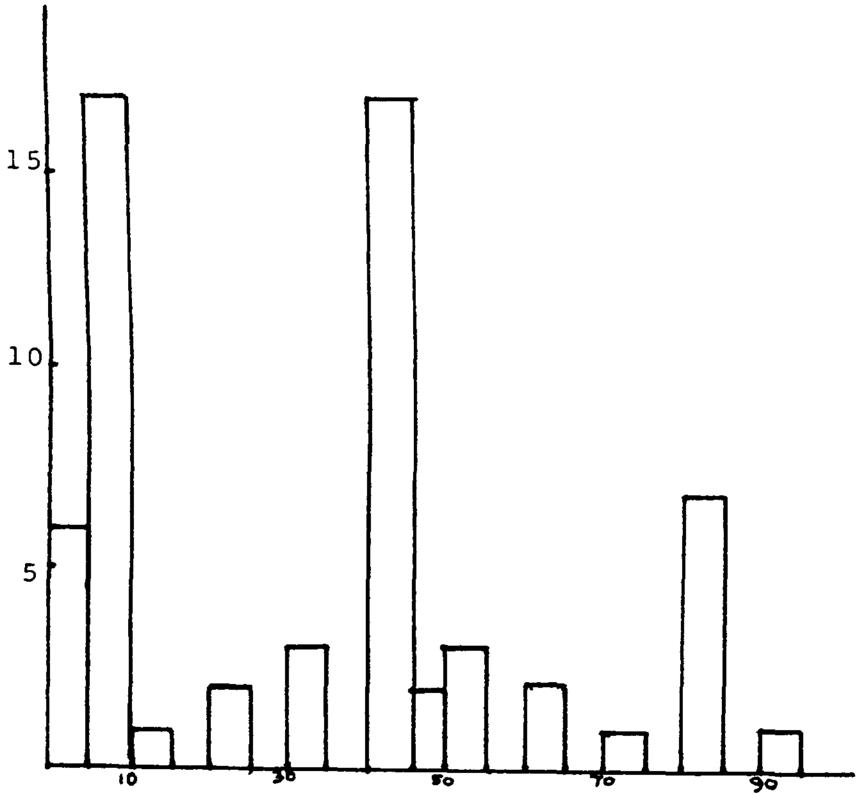
Sequence	Item Number	Description	N.
5	82100010	Paper E. E. G.	62
6	88100010	Face Tissue	62
7	07100010	Apple Juice	62
11	25213050	Ether Anaesthetic	45
15	34100020	Elastic Bandage	29
16	09110020	Baking Powder	32
17	08120020	Jelly Powder	32
23	43100020	Culture Bottle	34
43	59100040	Gypsona Bandage	60
44	83100010	Ball Pen	62
45	82210010	Copier Paper	62
60	16100010	Cotton Sheeting	62
65	26210050	Fusidate	17

Histograms of these thirteen items are presented in figures XII to XV.

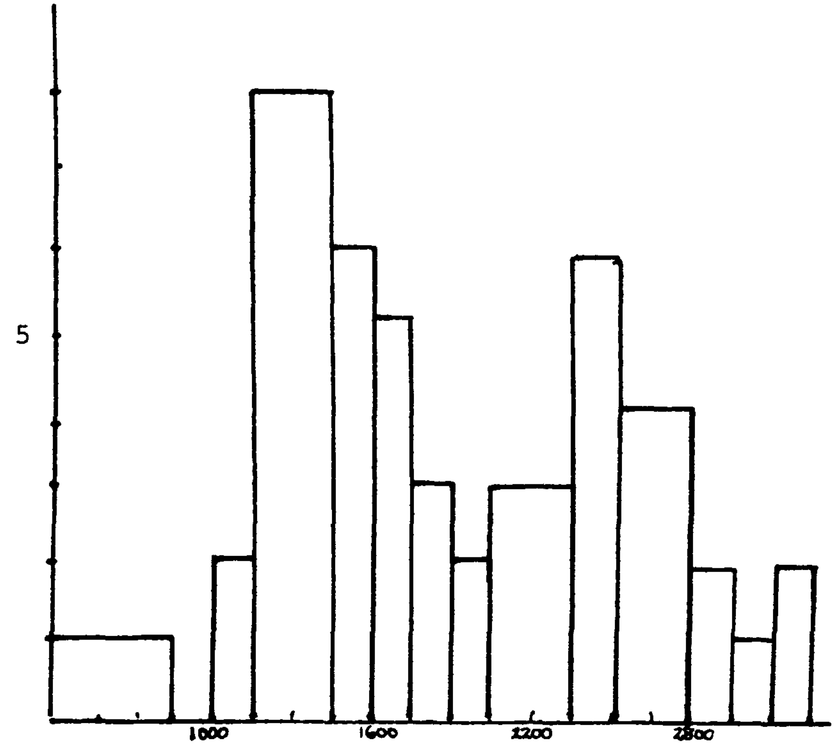
Tests were performed to discover whether the data conformed to these theoretical distributions:

1. Continuous Uniform

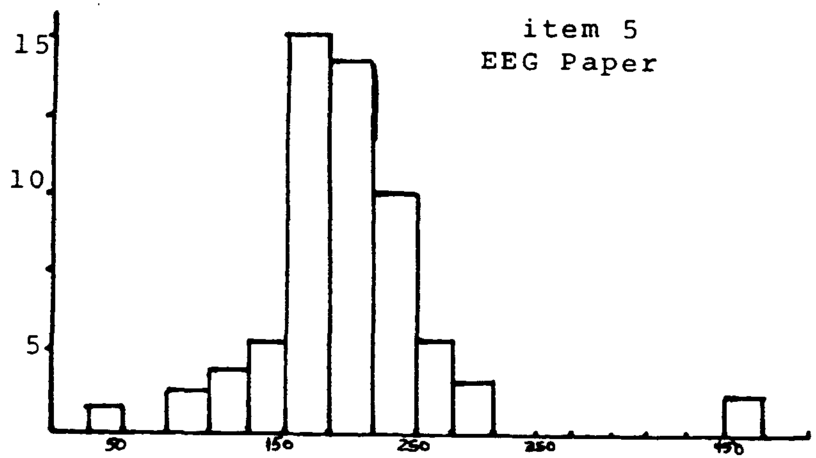
   This is associated with manufacturing situations, with demand for an item closely related to that for the end-product containing it. Hospital supplies are less frequently linked directly to a single end-use, save for a few highly specialized surgical or pharmaceutical products. Therefore if demand does closely approximate the distribution, value of this



item 5
EEG Paper



item 6
Face Tissue



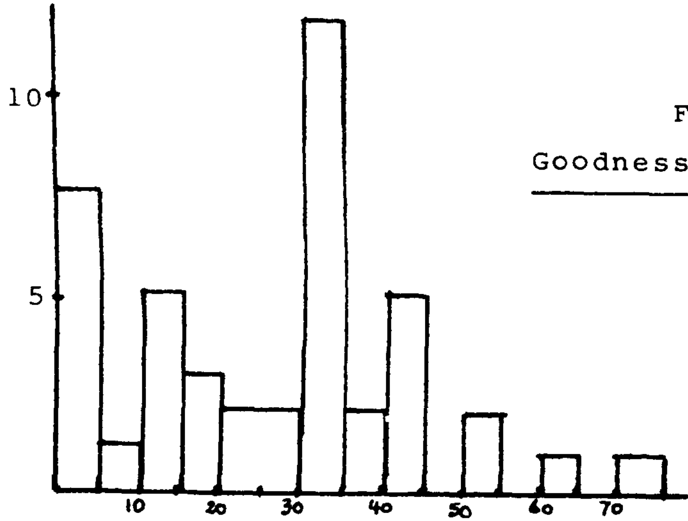
item 7 : Apple Juice

Figure XII

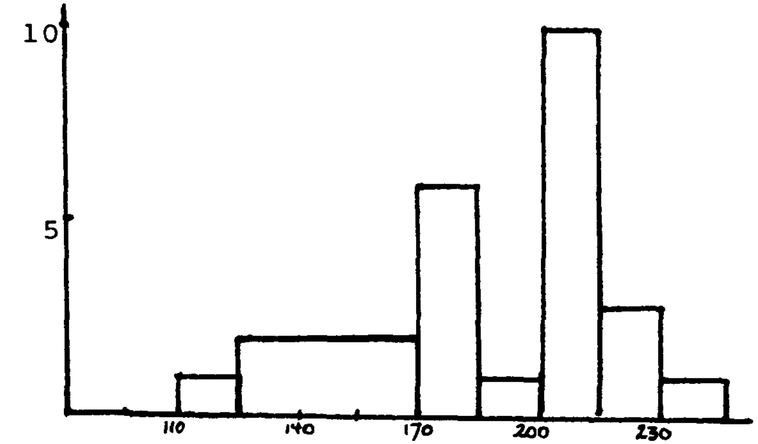
Goodness of Fit histograms

Figure XIII

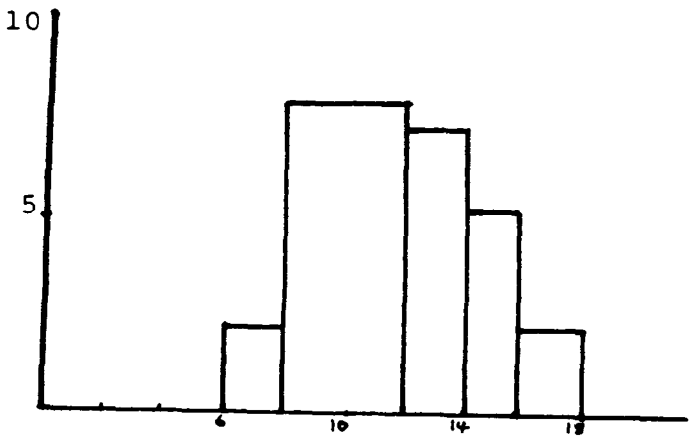
Goodness of Fit histograms



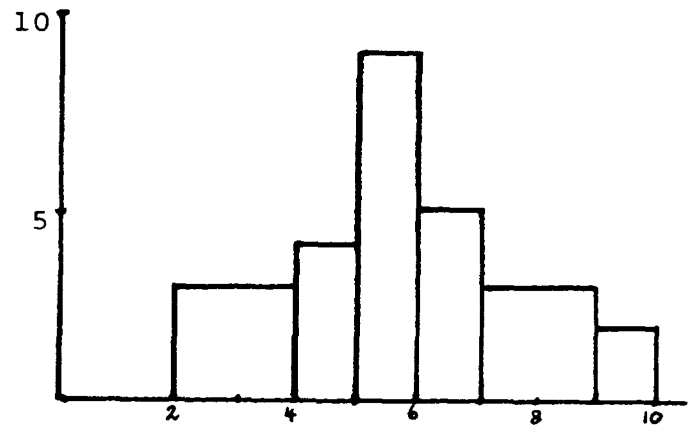
item 11
Ether Anaesthetic



item 15
Elastic Bandages



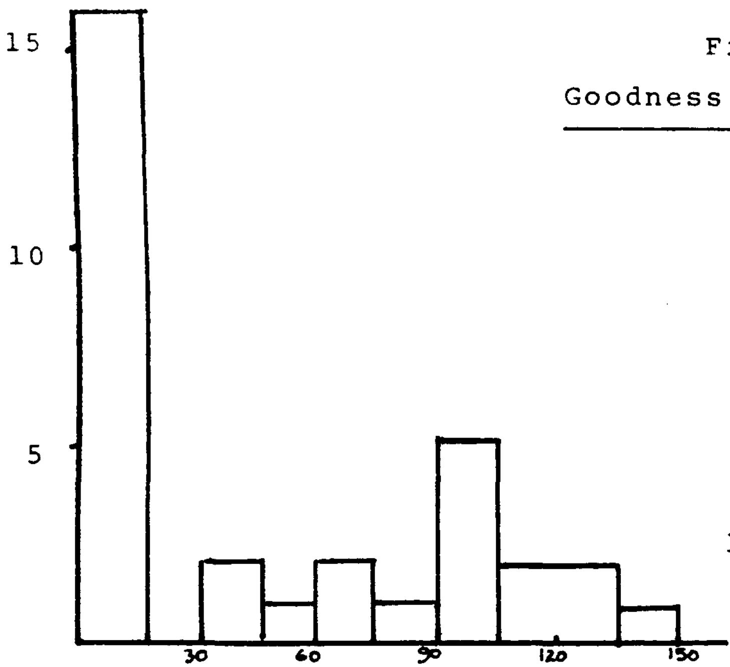
item 16
Baking Powder



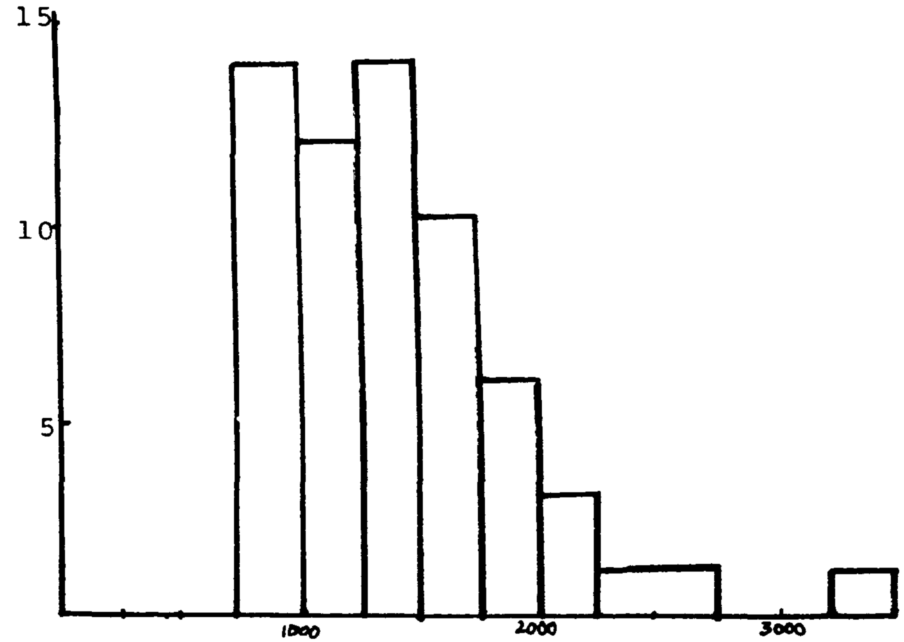
item 17
Jelly Powder

Figure XIV

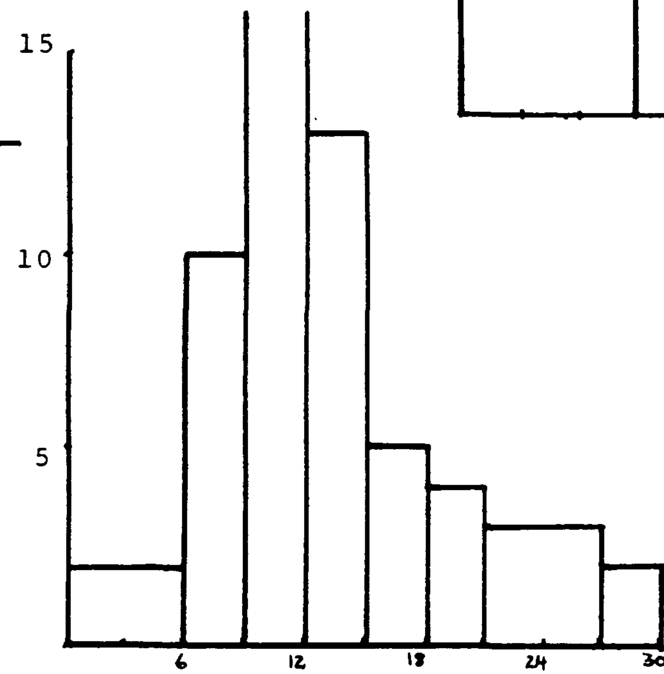
Goodness of Fit Histograms



item 23
Culture Bottle



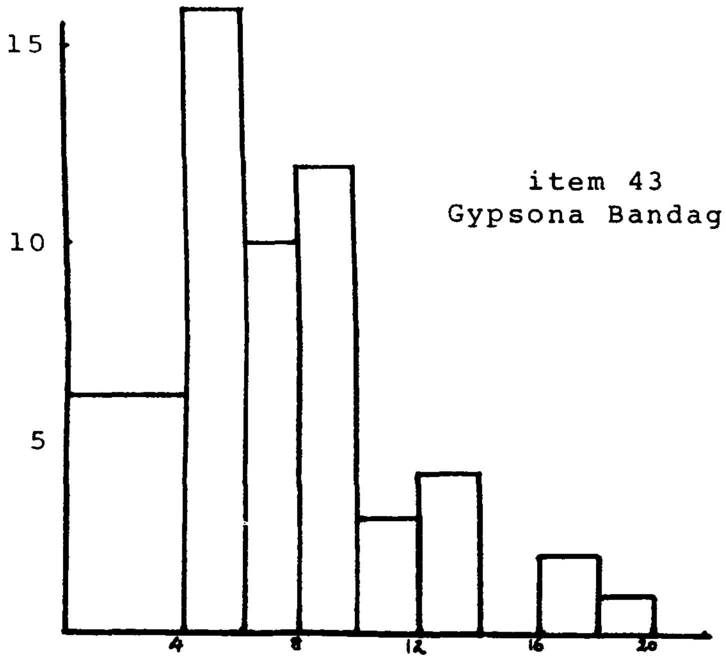
item 44
Ball Pen

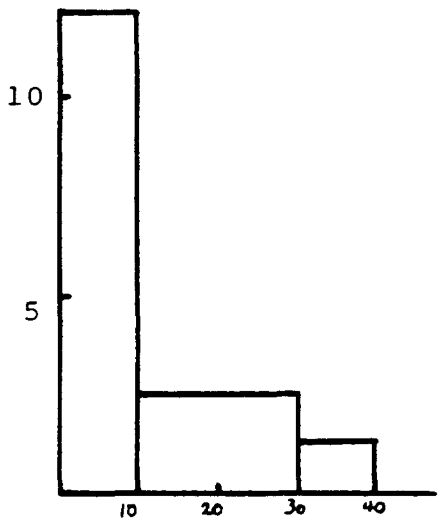


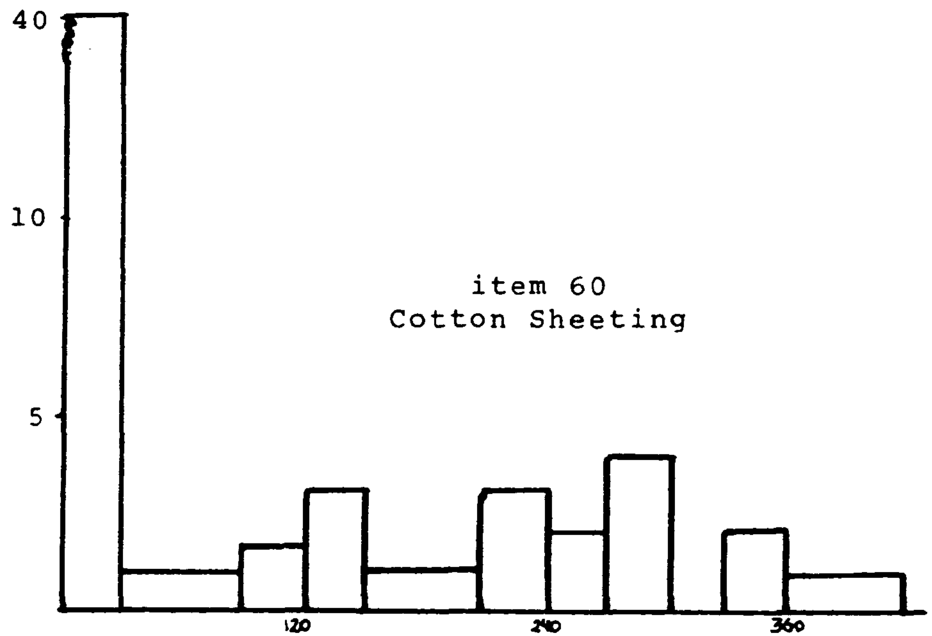
item 45
Copier Paper

Figure XV

Goodness of Fit histograms







information may not be great.

2. Poisson

A major application of this discrete probability distribution to inventory management relates to the situation where demand is infrequent and random. The quantity to be anticipated may be of less importance than the time at which the next demand is expected to arise - this time being defined in terms of an inventory planning period. The distribution is appropriate both when events take place at a constant rate through time and when demand at any time is small in proportion to the length of time (the opportunity) within which it can occur.

Demand may arise in non-random fashion and Poisson may still apply. A medical example might be demand for treatments for summer allergies, these being non-continuous but anticipated. Complex hospital needs are unlikely to be assessed through use of this distribution, though test results are small. Should Poisson be identified for any group of stores items, advantage could be taken of the property that variance is equal to the expected value; buffer stocks can be adjusted to mean demand very easily.

3. Negative Exponential

Mainly referred to in queuing and reliability literature, but relevant in some cases to inventory patterns in retailing. Results of testing data for similarity to the exponential distribution are given below.

Buchan and Koenigsberg (1963:117) successfully related sales for a few selected items which approximated this distribution to a whole class of items, when forecasting demand for paper stocks. Few items of hospital data in the sample resembled the Negative Exponential distribution.

4. <u>Normal</u>

Given a sample of "reasonable" size (say n = 30), the central limit theorem gives confidence that the normal distribution statistics may be used to study the behaviour of the sample, provided that the population is not severely skewed.

I.C.I. (1965) suggest that the forecast error distribution should be regarded as Normal if its average absolute value is less than 24 percent of average demand. Using normal probability paper, and plotting cumulated ranked data, normally distributed errors would be indicated by an approximately straight line. Table 29 shows results obtained by ranking and cumulating forecasting errors from an exponentially smoothed forecast made during 52 months, using a smoothing constant of 0.10. It would appear from figure XVI that errors are most likely normally distributed: the mean is roughly zero.

Shapiro, Wilk and Chen (1968) conducted an empirical sampling study of the sensitivities of nine statistical procedures, to evaluate normality of a complete sample. Forty-five alternative distributions in twelve families and five sample sizes from ten to fifty, were examined. The strongest performance was realised by the W test of Shapiro and Wilk (1965:1371) whose authors contend that distance tests such as the

Figure XVI
Testing Likelihood of
Normal Distribution

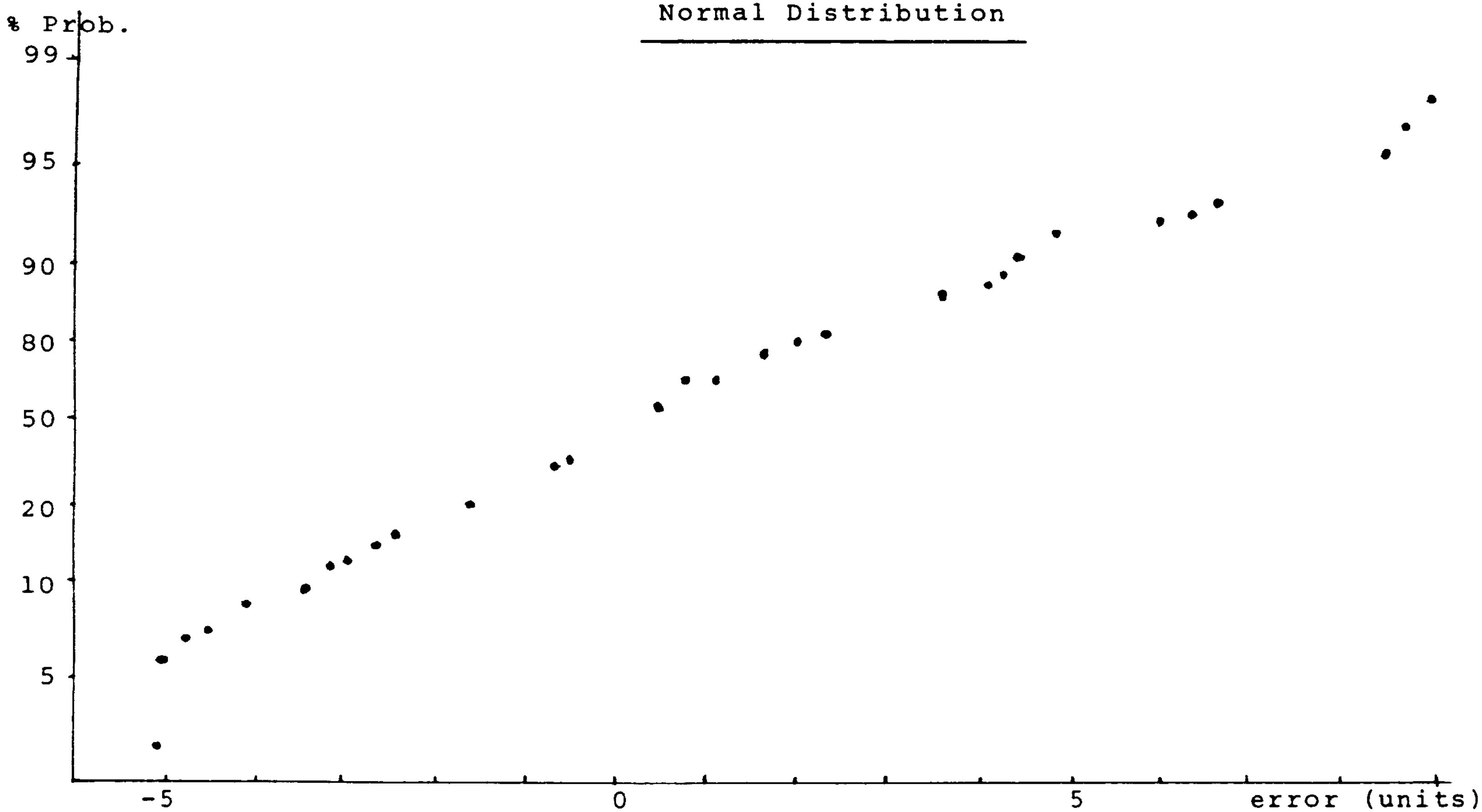


Table 29

RANKED, CUMULATED FORECAST ERRORS,

BANDAGE GYPSONA 4"

ST. JOSEPH'S HOSPITAL

Error	Frequency	Cum. Freq.	Prob.%	Error	Frequency	Cum. Freq.	Prob.%
-5.1	1	1	1.89	+0.7	2	30	56.56
-5.0	2	3	5.65	0.8	1	31	58.45
-4.8	1	4	7.54	1.3	1	32	60.34
-4.5	1	5	9.43	1.6	3	35	65.99
-4.1	1	6	11.32	2.0	2	37	69.75
-3.4	2	8	15.08	2.3	1	38	71.64
-3.3	1	9	16.97	2.8	1	39	73.53
-3.0	1	10	18.86	2.9	1	40	75.42
-2.6	1	11	20.75	3.6	1	41	77.31
-2.5	1	12	22.64	3.7	1	42	79.30
-2.2	1	13	24.63	4.1	1	43	81.19
-1.8	1	14	26.42	4.2	1	44	83.08
-1.7	1	15	28.31	4.4	1	45	84.97
-1.6	1	16	30.20	4.6	1	46	86.86
-1.3	2	18	33.96	5.9	1	47	88.75
-1.2	2	20	37.72	6.3	1	48	90.64
-0.6	1	21	39.61	6.9	1	49	92.53
-0.5	1	22	41.50	8.4	1	50	94.42
-0.4	3	25	47.15	8.5	1	51	96.31
-0.2	1	26	49.04	8.9	1	52	98.20
+0.4	2	28	52.80	15.6	1	53	100.00

Kolmogorov-Smirnov and Cramér-Von Mises are: "typically inferior in sensitivity against continuous distribution alternatives, with few exceptions." They favour a judgment based on both $\sqrt{b_1}$ and b_2 standard third and fourth moments as being sensitive, though the W test is as good as either, typically. The W test is not performed by the GOF programme, but the moments tests are available.

One criticism of Chi-square is recorded: "the results . . . were quite erratic, due in part to the difficulty imposed by the requirement of arbitrary choice of class intervals" (Ibid.). GOF allows choice if desired, or has a default of five intervals.

5. Lognormal

This may be appropriate if the logarithms of the attributes appear close to a normal distribution. Holt et al. (1960:283) explain: "a priori, it is not implausible to suppose that sales to any one customer might be determined by the product rather than the sum of a great many random factors." Hospital supplies indeed are called upon as the result of medical, social and other reasons. Logarithms of demand would then be the sum of independent random factors. As the number of these increase, the distribution will approach normal according to the central limit theorem.

Figure XVII shows plots of three items to test this. Two (items 45 and 6) were suggested as being close to lognormal and one (item 7) to normal by the GOF programme. The X scale is based on natural logarithms of demand, and the Y scale on normal probabilities. It is not possible to reject any of the three from the visual evidence.

Experiments upon the sample set of data, and examinations of histograms, lead to no firm conclusions as to closeness of association with theoretical distributions. Tables 30 to 32 give test results. Of the sample, four approximated most closely to

Figure XVII

Lognormal Scale Test

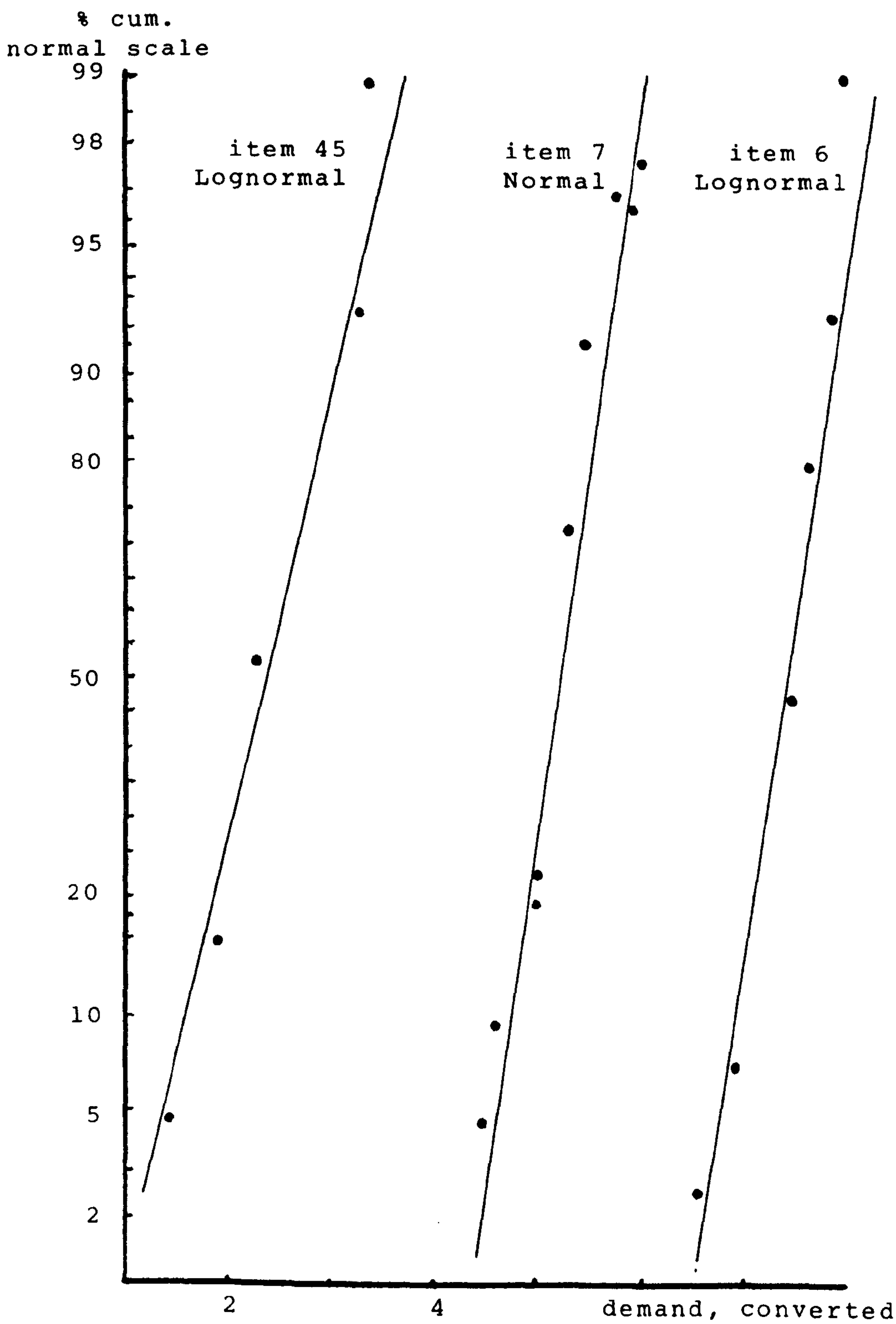


Table 30

GOODNESS OF FIT TEST: CHI-SQUARE

Item Number	N	D.F.	Exponential	Normal	Poisson	Uniform	Lognormal	Critical Value .05	Accept
5	62	4			Large	61	53	9.5	
		6	51	59				12.6	
6	62	4				28.4		9.5	
		5	85				10.4	11.1	Lognormal
		6		14.6	19.3			12.6	
7	62	4				94	13	9.5	
		5	108	13.5	15			11.1	
11	45	2			74			6.0	
		5	21.5			19.3		11.0	
		6		26				12.6	
15	29	4			11.6			9.5	
17	32	3			1.6			7.8	Poisson
23	34	2			38			6.0	
43	60	3			16			7.8	
		4				28	162	9.5	
		6	37	24	18			12.6	
44	62	4	76			58		9.5	Lognormal
		5		8.9			4.8	11.1	
45	62	4				38		9.5	
		6	52	12.7			5.1	12.6	Lognormal
		7			24.8			14.1	
60	62	4	57			150		9.5	
		5		60			78	11.1	

Table 31

GOODNESS OF FIT TEST: KOLMOGOROV-SMIRNOV

Item Number	N	D.F.	Exponential	Normal	Poisson	Uniform	Lognormal	Critical Value .05	Accept
5	62	15	.197	.176		.275	.364	.338	?
		62	.219	.192		.298	.395	.173	Normal
6	62	15	.389	.099		.186	.082	.338	Lognormal
		62	.385	.113		.181		.173	or Normal
7	62	15	.367	.114		.437	.105	.338	Lognormal
		62	.395	.144		.441		.173	
11	45	15	.200	.103		.289	.299	.338	Normal
		45	.201	.110		.324	.208	.203	
15		8	.0813					.457	Normal
	29	15	.4610	.1100		.225	.1097	.338	or
		29	.4312	.1342		.205	.1368	.240	Lognormal
16	32	12			.0995			.375	Normal,
		15	.422	.091		.1146	.1127	.338	Poisson or
		32	.414	.144		.1450	.1046	.240	Lognormal
17	32	8			.056		.055	.457	Normal,
		15	.3716	.097		.150	.1324	.338	Poisson,
		32	.3485	.151		.179	.1620	.240	Uniform or
									Lognormal

Table 31 (continued)

GOODNESS OF FIT TEST: KOLMOGOROV-SMIRNOV

Item Number	N	D.F.	Exponential	Normal	Poisson	Uniform	Lognormal	Critical Value .05	Accept
23	34	15	.280	.324		.433	.159	.338	Lognormal
		34	.296	.292		.457	.207	.233	
43	60	15	.249	.1198		.317	.369	.338	Normal
		60	.245	.1623		.389	.156	.176	
44	62	15	.315	.079		.455	.038	.338	Lognormal
		62	.413	.098		.467	.083	.173	or Normal
45	62	15	.3264	.132		.259	.093	.338	Normal,
		29			.142			.253	Poisson or
		62	.3290	.153		.2615	.1191	.173	Lognormal
60	62	15	.353	.388		.579	.326	.338	
		62	.585	.375		.632		.173	
65	17	15	.1789	.2224		.455	.318	.338	
		17	.4706	.2357		.506	.318	.318	Normal
		36			.647			.227	

Table 32

GOODNESS OF FIT TEST: CRAMÉR-VON MISES

Critical Values: 0.10 0.05 0.01
.347 .461 .743

Item Number	N	D.F.	Exponential	Normal	Poisson	Uniform	Lognormal	Accept
6	62	62	24			24		
11	45	45	2.26	4.72		7.3		
15	29	15	10	9		9.4	8.7	Normal or Lognormal
		29	2	0.103		0.455	0.15	
16	32	15	1.9	5.2	0.21	0.61	1.49	Normal?
		32		0.35		4.1		
17	32	8			0.371			Poisson
		15	1.7	2.4		2.4	4.5	
		32	1.9	6.4		6.0	6.3	
23	34	15	.280	.324		.433	.159	Lognormal, Exponential or Normal
		34	.296	.292		.457	.207	
43	60	60	7.7	12		17		
65	17	15	.204	.2133		1.89	1.37	? Exponential
		17	5.7	2.5	2.745	5.7	3.46	

lognormal, two to Poisson, one to normal, and six had no close fit. Failing any agreement, safety stock levels will be based upon the assumption of normal distribution; if a testing facility were available in the hospital, checks could be made.

A further experiment was undertaken, using forecasting errors arising from use of several simple forecasting methods described earlier, and exponential smoothing methods. Two items were studied: 6 and 2129, using both signed errors and mean absolute deviation. An abbreviated analysis is shown in Table 33 with conclusions as to normality; histograms are shown in figure XVIII.

This very small sample can only suggest that an assumption that signed error distribution is normal, cannot be dismissed. Investigation into the distribution of Mean Absolute Deviation shows that the likelihood is smaller.

Both SIMPAVE and LASTAVE errors were examined for exponential distribution and the differences were highly significant when Kolmogorov-Smirnov was used.

SUMMARY

Any forecasting system that depends on statistical analysis of past events, should incorporate controls to ensure rapid recognition of changes in demand patterns. An understanding of the underlying probability distribution relating to an item or group of items (if one can be discovered) would be valuable.

The goodness of fit programme GOF has been used with the limited sample of hospital data. Results have

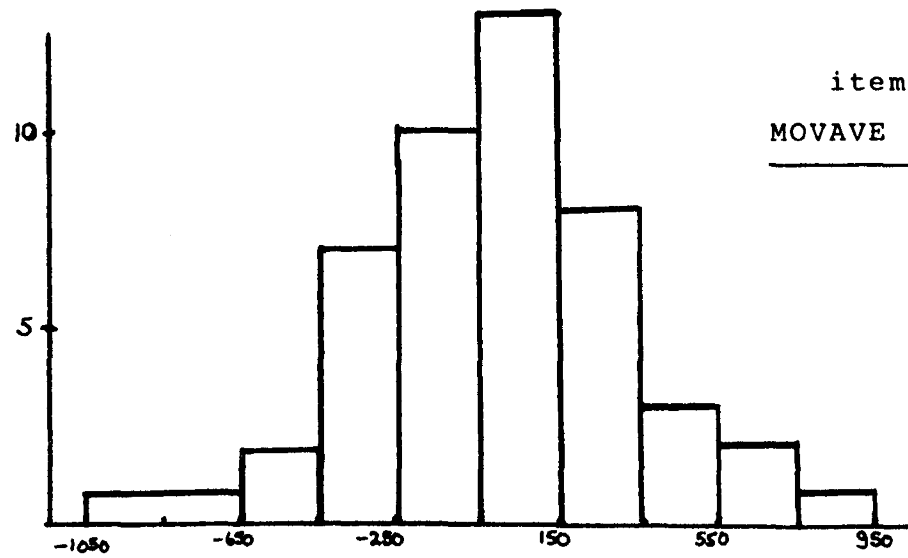
Table 33

TWO ITEM ERROR ANALYSIS

TESTING FOR NORMAL DISTRIBUTION

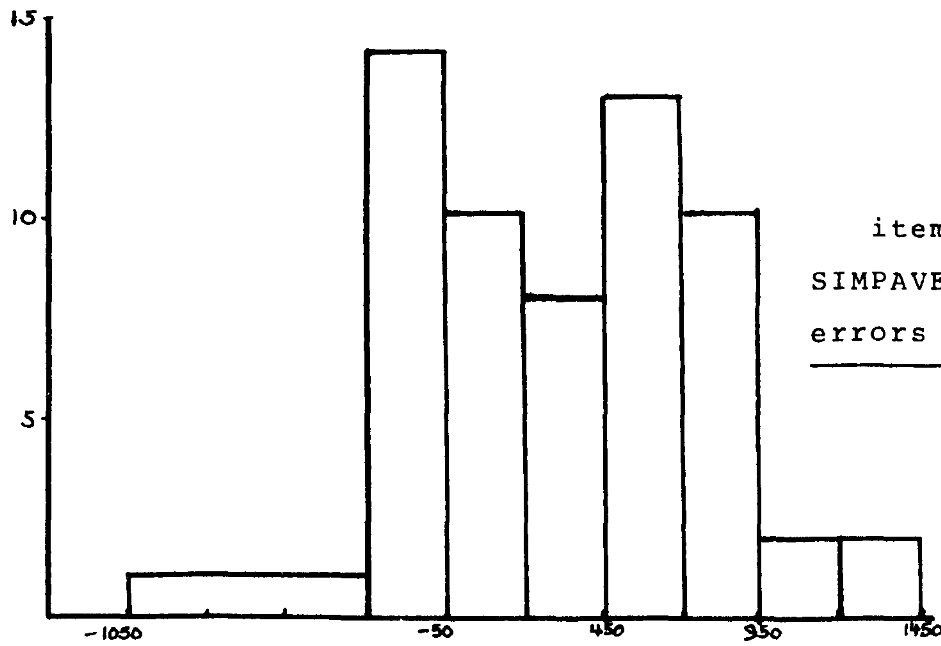
Forecast Method	Error	Error Mean	Biased Skewness	Biased Kurtosis	Kolmogorov-Smirnov	Chi-Square	Acceptable Decision
Item 6							
Simpave	Signed	292	.08	2.83	.0484	4.52	All Yes
	M.A.D.	271	.63	1.90	.2025	42.82	No
Lastave	Signed	437	-.47	3.26	.0632	5.98	All Yes
	M.A.D.	46			.0846	6.13	Possibly
Movave	Signed	-7	-.07	3.06	.0391		Yes
Movetrend	Signed	20	.23	3.34	.0784	4.65	Yes
Linfor	Signed	15	-.64	3.90	.0508	4.31	Unlikely
Simple Exp. Sm.*	Signed	117	.35	3.93	.0522	5.11	All Yes
Trend Exp. Sm.	Signed	12	1.00	6.87	.1018		No
Double Smoothing	Signed	54	.30	3.44	.0683		Yes
Seasonal	Signed	64	.30	2.58	.0686		Yes
Item 2129							
Simpave	Signed	16	2.10	28.7	.2626		Possibly
	M.A.D.	22	-.17	3.1	.1172		Possibly
Lastave	Signed	0	.33	3.0	.079	4.97	Yes
	M.A.D.	26			.150	18.27	Possibly
Movave	Signed	1			.0871	5.37	Unlikely
Linfor	Signed	-3			.1364	22.9	Possibly

* see chapter 8 for details.



item 6

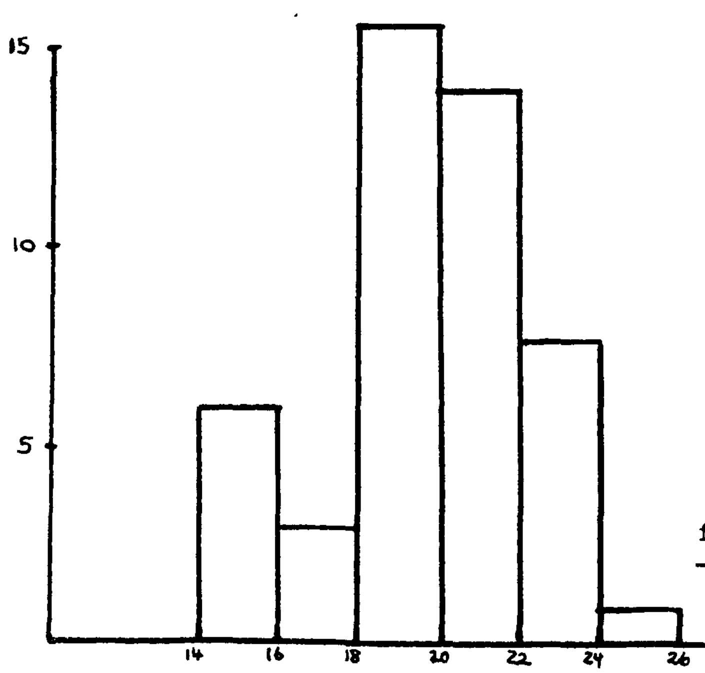
MOVAVE errors



item 6

SIMPAVE signed

errors : Expon.



item 2129

SIMPAVE M.A.D.

Normal dist.

Figure XVIII

Histograms of

forecasting errors

not been encouraging, and it may be that hospital demand data does not fit any well-known probability distributions. More extensive studies would be required to confirm this.

CHAPTER SIX

SIMPLE FORECASTING METHODS

Roth et alia (n.d.) are among those who have experimented to show that simple scientific forecasting methods can improve performance. Integrated forecasting directly benefits purchasing management; the requisite upgrading of the data base provides information that can be used widely by hospital executives; tighter control of forecast errors will improve stock-out experience, and economise on the quantity of safety stocks that must be maintained. Forecasting differentiates between impressions gained subjectively, and true phenomena such as trends and seasonal variability. Trenn (1971:28) confirms the findings of this writer that, for example: "seasonal fluctuation does not affect hospital general stores or total inventory." This fact permits simpler methods to be adopted than would be used typically by industry.

THE DATA BASE

Data has been obtained by the writer from the inventory records of several hospitals. Present record keeping, using cards or simple computer programmes, is inaccurate. There has been no realization of the importance of a data base, and requisitions from hospital departments are not classified, nor analysed in any way. Stores information is restricted to one or two years at most, which is insufficient to allow statistical analysis. 'Demand' used in the research consists of the summation of all recorded calls upon the stores for an individual item during a month, for as many months as possible.

Computer services are available to most Canadian hospitals. Availability of data storage has improved in the past decade, and it would be feasible to capture, maintain and analyse individual requisition data so that true monthly demand analyses could be prepared.

For each statistical forecasting method the full sample of 73 items has been run on the computer. Results and details of the computer programmes are found in the appendix.

SIMPAVE

This method is simply:

$$\bar{X}_t = \frac{\sum_{i=1}^{N} X_i}{N}$$

For each set of data, N represents the length of history at present available. The size of N must be restricted since out-of-date information can distort the accuracy of the forecast.

LASTAVE

Demand in the latest recorded month is used as this month's forecast:

$$\bar{X}_t = X_{t-1}$$

which may be efficient if the data is stable or highly autocorrelated.

LINFOR

Programme LINFOR has been written and tested with the sample of 73 items; the first (N-12) data points are used to develop the regression equation.

A seasonal index is created, using a base index developed from similar months in previous years, and the results applied to each of the most recent twelve months to form a seasonal forecast. In addition, these twelve periods are 'deseasonalised' by dividing demand by the base series index, to obtain an indication of possible seasonal influence. However, without knowledge of the characteristics of demand for each item, it is not possible to confirm that seasonal influences are present.

MOVAVE AND MOVETREND

To improve upon the method of linear regression, programmes to perform moving average forecasting have been prepared. MOVAVE is unit weighted and unadjusted, although a message is printed whenever the forecasting error exceeds 75 percent of actual data in any month. The average is based upon a span of twelve months, whereas MOVETREND experiments with a shorter time of six months, together with a procedure to track any trend that may be present. The methods use:

$$\bar{X}_t = \bar{X}_{t-1} + 1/N\ (X_t - X_{t-N})$$

N being twelve or six according to the programme being run. Trend adjustment is based upon the simple difference between demands in current and previous months, and the result applied to the value obtained from the simple moving average process.

A disadvantage of the moving average method is the necessity to store all N periods' data for each item, and recompute the averages each month. Managers must determine whether costs of storing and updating the data are significant.

MOVETREND has the facility to forecast through any lead time greater than one planning period. It is appropriate for linear trends but will not give accurate results when there is curvature in the data. Because triple exponential smoothing is most commonly used in this situation, discussion of this type of data pattern is deferred.

EVALUATION OF FORECASTING ERRORS

The main basis for comparison of forecasting methods lies in the measurement of errors. A variety of error evaluations is included in the thesis:

1. Sum of signed errors

   SSE will tend to zero if forecasting errors fluctuate evenly or randomly, uninfluenced by trends or sudden swings in demand. Conversely a large value will indicate a concentration of errors in one direction.

$$SSE = \sum_{t=1}^{N} e_t$$

2. Average cumulative signed error

For purposes of comparison with other methods or series, the average value of signed errors is to be preferred to the foregoing method.

$$ACSE = \sum_{t=1}^{N} e_t/N$$

where $e_t = f_t - x_t$

f_t = the forecast for time t.

3. Mean absolute deviation

This measure is related to the standard deviation, and was preferred by systems analysts when the square root funtion was expensive to perform by computer.

$$MAD = \frac{\sum_{t=1}^{N} |e_t|}{N}$$

4. Root mean square error

Whereas MAD gives equal weight to every unit of error, RMSE weighs errors so that those which are larger affect the results more substantially.

$$RMSE = \sqrt{\frac{\sum_{t=1}^{N} (e_t)^2}{N}}$$

5. Percentage balanced error

This measure has been devised by the writer to trace the degree of 'swing' around zero error.

$$PBE = \frac{SSE \times 100}{MAD \times 0.5} \text{ percent.}$$

This relates total errors accumulated during several forecasting periods, to average errors and - when used in comparison with several forecasting methods - should indicate which forecasting method allows the greatest or least oscillation.

SIMPAVE contains one further indicator, which will warn management that there are substantial numbers of outliers in a series. The trend test was proposed by Whybark (1973), and described recently by Dancer and Gray (1977). It involves measurement of the deviation from the regression line of the data, using a significance test based on student-t. The measure has been arbitrarily set at $\pm$ 3 S.D. from the arithmetic mean.

Of 68 items examined through runs of between 30 and 66 months, nineteen contained demands in excess of this limit, though in most cases this occurred only once in any run of data.

MEASURES OF PERFORMANCE

Economists have devised indicators which purport to show whether their chosen forecasting method is performing effectively. Many of the forecasts in this and later chapters include selected indicators, tested to discover whether they are able to assist the researcher in selection of a suitable forecasting system.

1. <u>The D'Amico Forecastability Index</u>

D'Amico (1971) based his experiments upon work by Parry (1969) who recommended an indicator which is the reciprocal of the coefficient of variation of a series from its average demand, in units of demand.

$$DFI = \frac{\bar{X}}{\sigma_e} \text{ or } \frac{\bar{X}}{1.25 \cdot (MAD)}$$

The authors give no indication as to the scale to measure results, and this writer has used:

good forecasting potential: 2.5 and above

poor forecasting potential: 1.5 and below.

2. The Theil Indicator: U

For economic time series, Theil (1961) devised a measure to analyze errors into systematic overestimation and underestimation, the rate of change and the ability to predict turning points in a series:

$$U = \frac{RMSE}{\sqrt{\sum (X^2)/N}}$$

Theil wrote: "it is immediately seen that U = 0 if and only if the forecasts are all perfect; also that U = 1 when the prediction procedure leads to the same RMSE as does naïve no change extrapolation." There are no published scales between zero and one to guide the user.

3. Accuracy Percentage

The writer devised ACCUR, which is simply the coefficient of variation of a series, using average demand and mean absolute deviation. It thus resembles DFI, but is inverted, in MAD and percentage terms.

RATING THE SIMPLE METHODS

Having computed forecasts for the entire sample of demand series, using the above simple methods of forecasting and evaluating by means of four error estimates and one performance indicator, table 34 was prepared as a summary. Of the simple methods used, it seems clear that the method of unit-weighted moving averages is best in overall performance. LASTAVE rates high mainly for reasons inherent in the method - the swing of errors is limited owing to the relationship between demand value and that same value becoming the forecast next period. SIMPAVE and LINFOR do not seem suited to short-term demand forecasting.

Table 34

RATED PERFORMANCE OF SIMPLE FORECASTING METHODS

Forecasting Method	Best Value Overall	PBE: First & Second Places	Theil 'U'
MOVAVE	52.6%	26.6%	76.7%
MOVETREND	8.0	17.3	*
LASTAVE	25.1	46.8	1.4
SIMPAVE	4.6	5.0	11.0
LINFOR	9.7	4.3	10.9
	100.0	100.0	100.0

Notes

* Theil was not computed for MOVETREND
: "Performance" means lowest forecasting errors.

Two items from the sample are presented in more detail.

(a) Item 88100010 (sequence number 6): Face Tissues

Demand is plotted in figure XIX together with results of forecasting method MOVETREND. Demand during periods 1 to 27 is erratic but has an underlying stability; periods 27 to 37 show increasing fluctuations leading to a step in periods 38 and 39, which is maintained to period

62. There is no real trend, nor evidence of seasonal periodicity. Despite its erratic nature, there are no values beyond three standard deviations of the mean.

Table 35

PERFORMANCE INDICATORS: ITEM 6

Fore-casting Method	Root Mean Square Error	Mean Absolute Deviation	Percentage Bal. Errors	Theil Coefficient	D'Amico Index
MOVAVE	303	265	18	0.10	n.a.
MOVETREND	284	230	18	n.a.	n.a.
LASTAVE	436	353	8	0.12	4.0
SIMPAVE	705	665	138	0.20	2.4
LINFOR	414	325	13	0.09	15.0

LINFOR shows high forecast potential, yet errors are substantial.

Figure XIX includes an error chart which may be compared with figure XX.

(b) Item 2129, Seasonal Demand

This series shows strict seasonal periodicity; only programme LINFOR has seasonal adjustments included in the procedure. Results of major error evaluations are given in table 36.

Table 36

PERFORMANCE INDICATORS: ITEM 2129

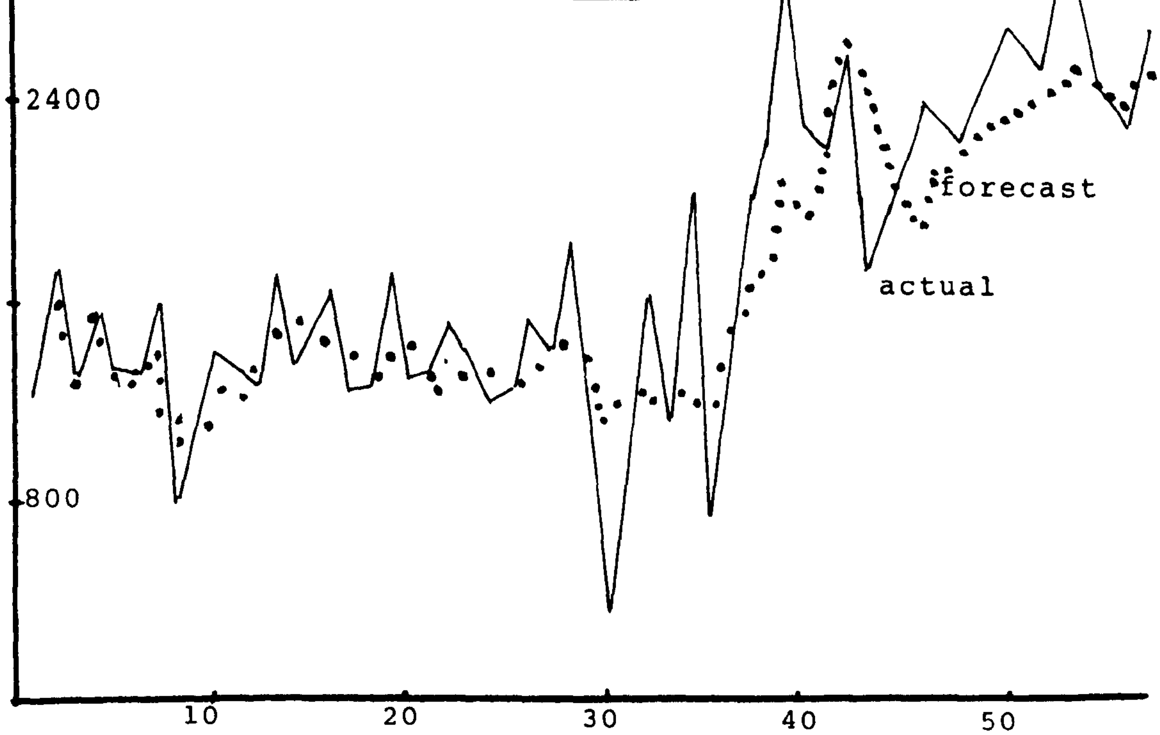
Fore-casting Method	Root Mean Square Error	Mean Absolute Deviation	Percentage Bal. Errors	Theil Coefficient	D'Amico Index
MOVAVE	31.1	28.1	13.4	0.24	n.a.
MOVETREND	29.5	23.1	4.9	n.a.	n.a.
LASTAVE	44.4	35.3	0.5	0.30	1.5
SIMPAVE	38.7	34.2	74.0	0.27	1.8
LINFOR	29.5	22.6	4.0	0.19	7.6

Figure XIX

MOVETREND

Demand, Forecasts and Errors

Face Tissues



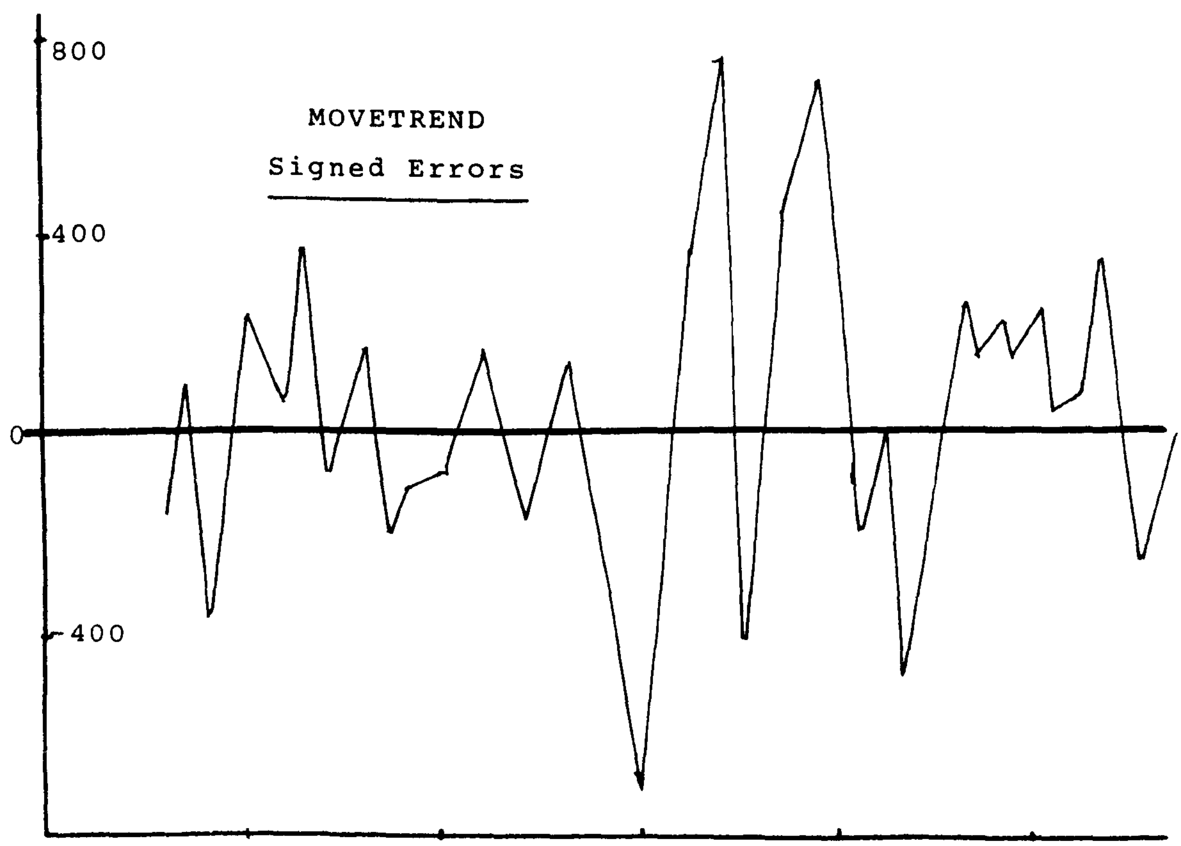
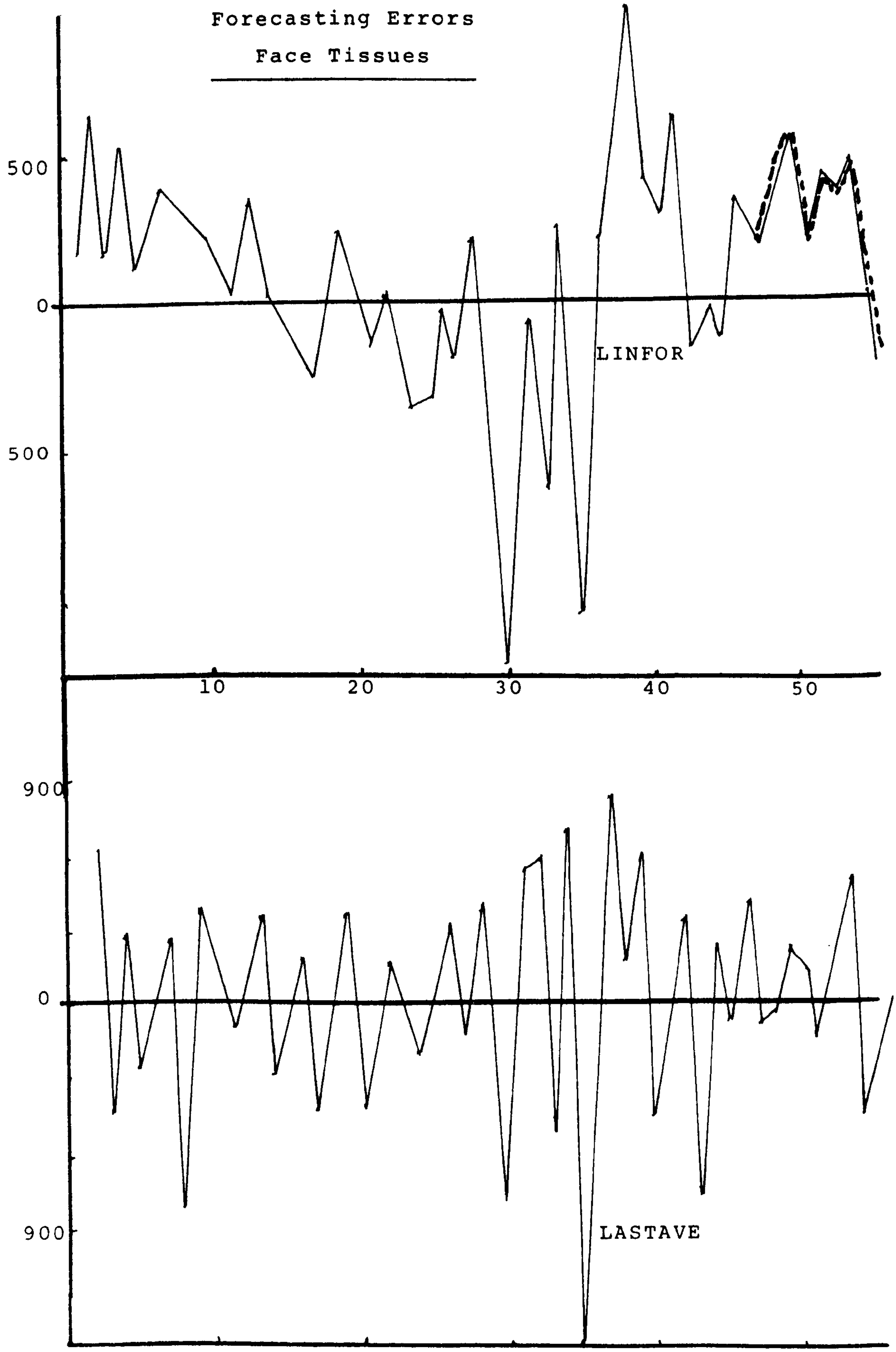


Figure XX
LINFOR and LASTAVE
Forecasting Errors
Face Tissues



The regularity of the seasonal demand is reflected by the strong performance of LASTAVE. Demand peaks regularly at months 1 and 7, with lows at months 3 and 11. Figure XXI shows selected errors graphically; there are swings of considerable magnitude, particularly with LASTAVE.

An evaluation incorporating an analysis of percentage balanced errors is made in table 37. Limits have been arbitrarily set at these values:

Above 100 percent: very unstable forecast.

Below 10 percent: very stable.

Table 37

BALANCED ERROR EVALUATION

COMPLETE SAMPLE

Method	Above 100%	Below 10%	
MOVAVE	1	27	
MOVETREND	1	31	
LASTAVE	1	55	Method itself restrains swings
SIMPAVE	23	6	
LINFOR	22	5	Final 12 months are seasonally adjusted.

These results give credibility to moving average methods. Examination of low values of overall mean absolute deviation showed these occurrences

MOVAVE: 46; LINFOR: 17; MOVETREND: 4;

SIMPAVE, LINFOR both 1, and LASTAVE: 0.

SUMMARY: SIMPLE FORECASTING METHODS

As computer programmes in the appendix show, there

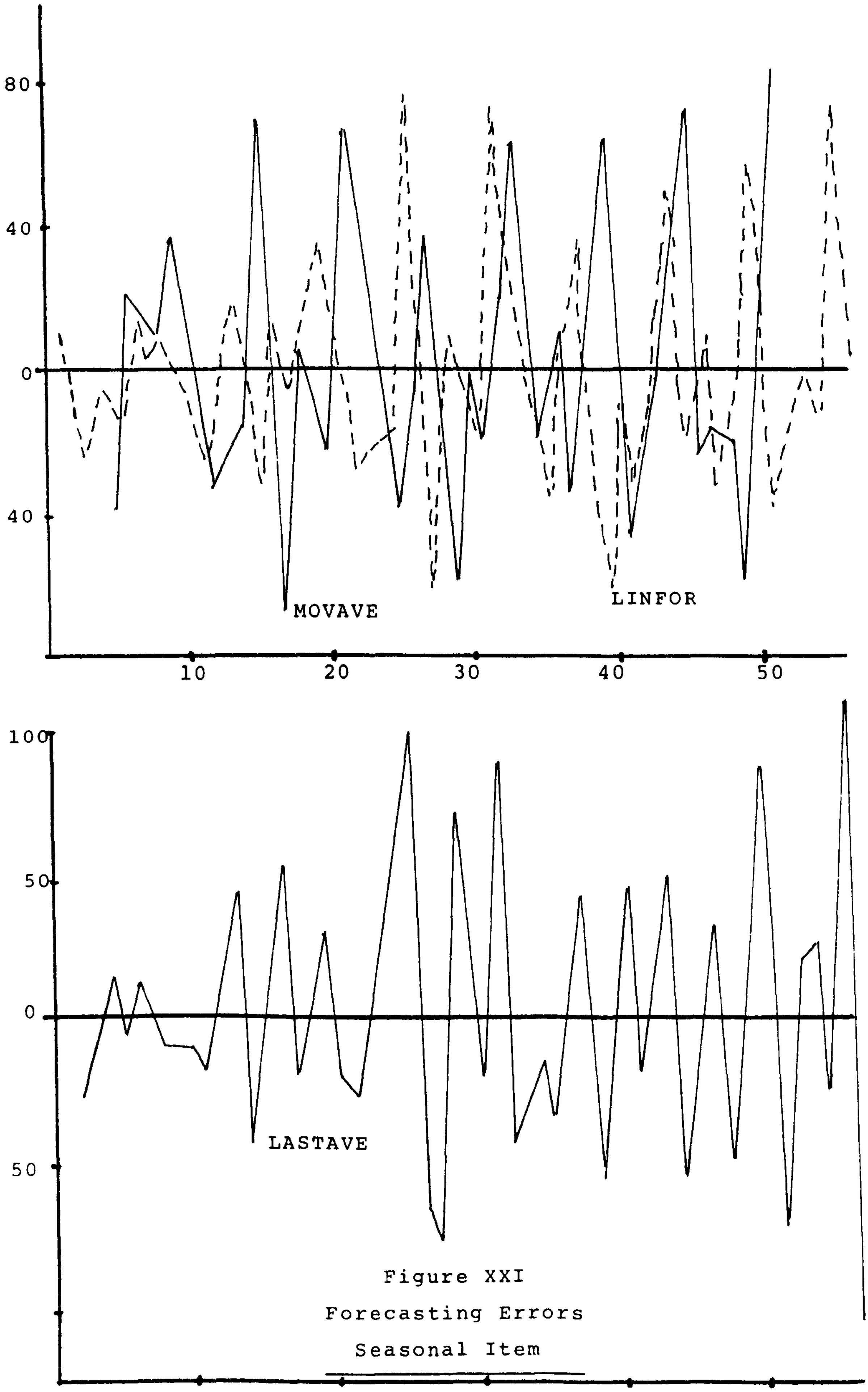


Figure XXI

Forecasting Errors

Seasonal Item

are no high levels of complexity inherent in any of the methods described in this section of the thesis. Most rely on stable demand patterns, and could be used to forecast demand for many non-perishable foods, bandages, catheters etc. To be useful to management, however, an adaptive feature would need to be programmed, whereby the system responds to changes either by relaying a message to the manager, or altering the format of the calculations. This could be done with moving averages by providing weights to each previous month, and amending the weighting system in the light of circumstances. Thus, as demand became more dynamic, heavier weighting would be placed upon the most recent past.

Any method described above would work, and could be incorporated within a hospital inventory management system. If however we consider that LASTAVE is not satisfactory for data with other than stable and well understood patterns (such as in the case of a call-forward contract), it is suggested that the method of moving averages with trend adjustment be considered the most efficient. It is to be shown that better methods do exist (though they may be more complex), and these are presented in subsequent sections of this thesis.

CHAPTER SEVEN

BOX-JENKINS UNIVARIATE FORECASTING

INTRODUCTION

Box and Jenkins described their forecasting ideas and methods in several publications: (1962, 1964, 1968, 1970). Others who have interpreted and illustrated their methods include Chatfield and Prothero (1973); Newbold and Granger (1974); Newbold (1975); Naylor et alia (1972) and Thompson and Tiao (1971). Application requires a sufficient run of data (at least 36 periods, especially if seasonal fluctuations are likely); a computer with adequate storage capacity, and substantial experience in interpretation on the part of stock controllers.

The approach is three-fold:

1. Identification of the model, using for this purpose basic theoretical autocorrelation functions;
2. Estimation of the model's parameters, in terms of the data sampled, and
3. Diagnosis, by means of an analysis of the autocorrelation pattern of the residuals.

The computer programmes used were developed at Queen's University, Ontario (1972) modified by this writer for utilization with an IBM 360/50 computer. There are two distinct stages of computation. APCORR furnishes autoand partial correlations of the data, together with first and second differences. Two periods for seasonal differencing may be specified; for each of these, first and second differences are provided. TYMPAC provides an estimation of the parameters in the model suggested by APCORR, with facilities for improvements in the light of successive interactions. In addition there is provision for forecasting to a limited extent.

Wheelwright and Makridakis (1973) observe that forecasting methods can be complex and expensive where the data pattern incorporates trend and seasonal factors with random and cyclical elements. Box-Jenkins is suggested as an effective method which does not necessitate undue management involvement. However, skill is required, and as yet no method has been discovered of identifying that the 'best' pattern has been attained.

IDENTIFICATION

Coefficients of autocorrelation are calculated and examined, to obtain a stationary series; suitable differencing is undertaken until the series appears to be stationary in mean and variance. The task that follows is to estimate the constants in the chosen model. Should the data prove random, autocorrelation among successive values would be zero, but in the case of hospital data this is unlikely. The influence of repeat orders for items in constant use, trends, and for some items, seasonal variation, will cause measurable autocorrelation values.

Fox (1968) wrote: "differences between successive periods may be smaller than from the assumed averages. A rough rule is that the standard deviation of first differences should be less than half as large as the standard deviation of the original values; the variance should be about one quarter of the variance in the original observation."

Box and Jenkins postulate three classes of models that can describe any pattern of data: Autoregressive (AR); Moving Average (MA), and Mixed Autoregressive - moving average (ARMA).

Thompson and Tiao (1971) in their studies of demand patterns for a Wisconsin telephone utility identify three autoregressive patterns which can be expected to occur: figure XX11.

The operator will decide the degree of differencing and the number of terms to use from a study of the shape of r_k, with reference to theoretical functions. For the moving average model figure XXIII shows those patterns which can be expected to occur.

Identification involves the choice of non-negative integers p, d and q representing autoregressive parameters (p), the order of difference (d) and moving average parameters (q). The moving average model of order one is indicated (p = o, d = o, q = 1), the AR model of order one is (p = 1, d = 1, q = o) and the ARMA model is (p = 1, d = o, q = 1). This latter model supposes that future values of demand depend upon both past demand levels, and upon the errors between actual and forecast demands.

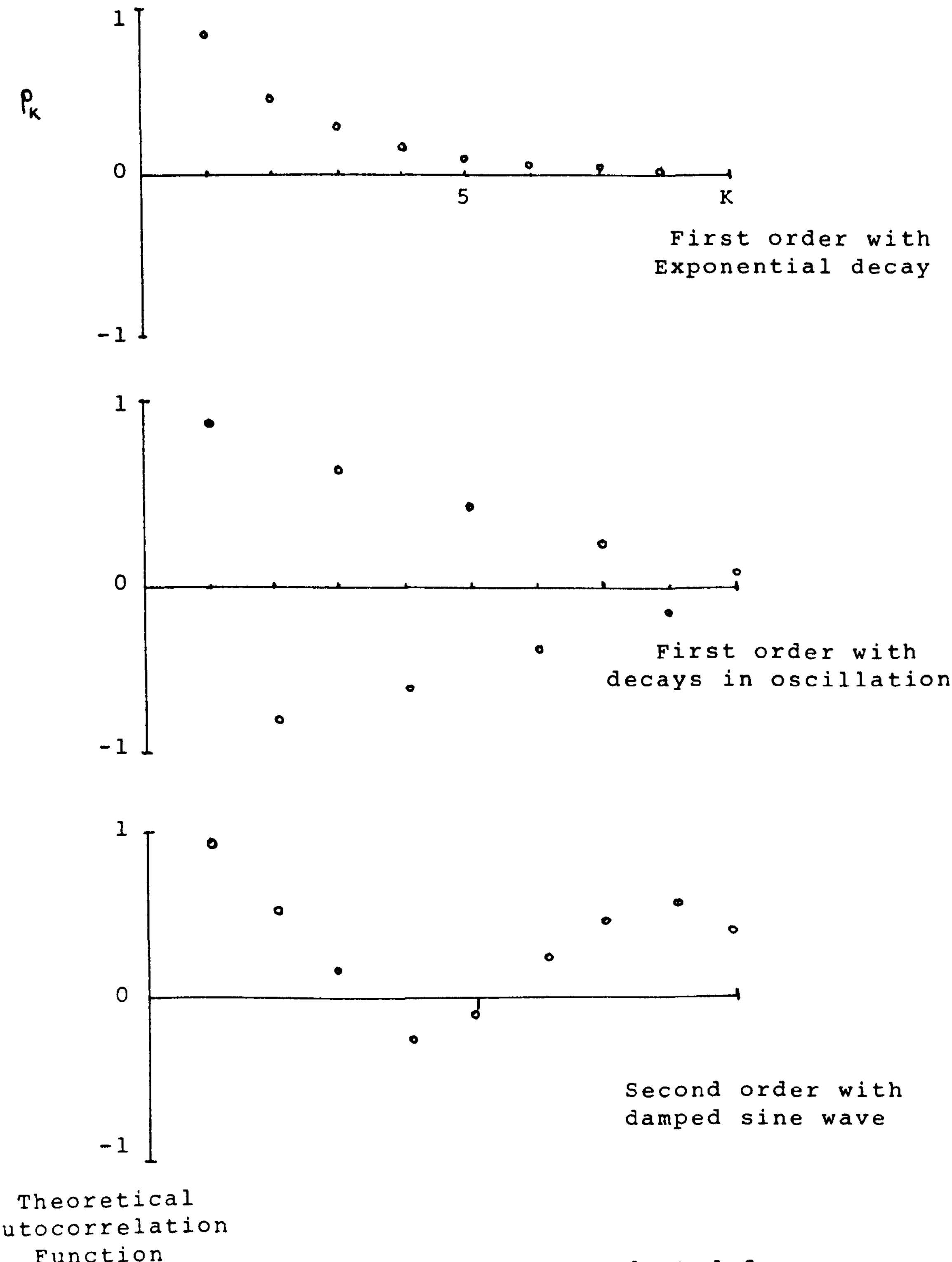
ESTIMATION

Parameters appropriate to the chosen model must be estimated, with the object of noise minimization. This is one task of TYMPAC, whose designers refer to Box and

Figure XXII

BOX-JENKINS

Autoregression Patterns

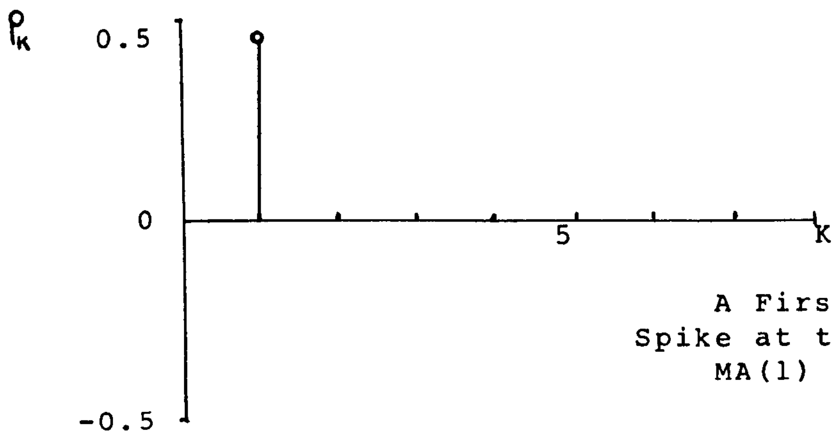


adapted from :
Thompson & Tiao (1971)

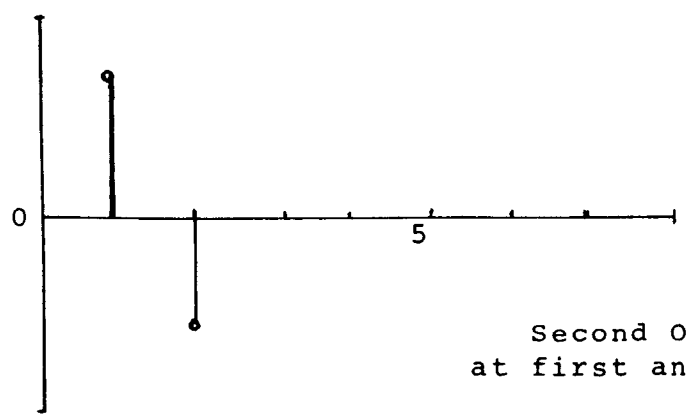
Figure XXIII

BOX-JENKINS

Moving Average Patterns



A First Order
Spike at the first lag
MA(1) Process



Second Order Spikes
at first and second lags

Jenkins (1970) and to Draper and Smith (1966) as sources for details of the method of non-linear least squares, used to estimate the parameters of the model applying the principle of parsimony.

DIAGNOSIS

Subsequent to model-fitting, residuals a_t will be checked for possible improvements. The average and the sample autocorrelation coefficient of residuals are useful checks. If they indicate that a_t are independently distributed, the fitted model is considered appropriate. If not, the pattern of the autocorrelations will give useful information for improvement, and the iterative process of identification, estimation and checking would be repeated.

Use of TYMPAC necessitates identification of the model with specific values for s, p, d, q, P, D, Q where

s: the length of the season

p: number of regular autoregressive terms

d: number of regular differences

q: number of regular moving average terms

P: number of seasonal autoregressive terms

D: number of seasonal differences

Q: number of seasonal moving average terms

and starting values for

$\phi_1, \phi_2, \ldots, \phi_p, \Phi_1, \Phi_2, \ldots, \Phi_P, \theta_1, \theta_2, \ldots \theta_q, \Theta_1, \Theta_2, \ldots, \Theta_Q$.

Output of the TYMPAC procedure includes estimates of parameters; 95 percent confidence limits for the individual parameters; a plot of the time series and best fitted values; correlations of the residuals, and twelve forecast values with confidence limits. It is required that parameters for any run be guessed sensibly following examination of current APCORR output: the initial values allow the iterative Gauss-Newton procedure to carry on, progressing toward maximum likelihood estimates. Iterations cease when any further reduction in linear approximation is less than the programmed required value.

A copy of the programmes and output is found in the Appendix.

FORECASTING

The forecasting programme produces tables and charts of the actual values and amounts which would have been obtained given that the chosen function were correct. A table of residual autocorrelations is produced, with 95 percent limits for correlations. This enables the analyst to decide whether further iterations would improve the fit of the model through parameter modification.

TYMPAC has been modified by the writer to produce tables of forecasts, with low and high confidence boundaries, and an error evaluation table showing mean, low and high possible errors, using actual known demands. These would enable the operator to shift the level of the model if it were too low or high.

Wheelwright and Makridakis (1973:135) claim that: "the technique is one of the most powerful and accurate . . . but it is also costly and complex in comparison with other techniques such as multiple regression, decomposition or adaptive filtering. In the final analysis it is up to the user to decide whether the benefit of higher accuracy will compensate for the higher cost . . . the specific situation will be a key factor in the final choice."

TWO ITEM EXPERIMENT

Two sets of data are analysed, and examples given from published literature. The first set is item 88100010 Face Tissues:

Table 38

ITEM 88100010: FACE TISSUES

RECORDED DEMAND (BOXES)

	Years					
	1	2	3	4	5	6
Jan.	1222	1629	1236	2064	2453	2482
Feb.	1707	1326	1536	2272	2670	2092
Mar.	1229	1421	1406	2830	2536	
Apr.	1524	1631	1834	2311	2523	
May	1253	1166	1183	2206	3026	
June	1334	1257	430	2562	2552	
July	1560	1673	1000	1748	2289	
Aug.	740	1283	1590	1966	2278	
Sept.	1125	1316	1110	1896	2476	
Oct.	1434	1501	2002	2366	3032	
Nov.	1355	1399	689	2279	2756	
Dec.	1259	1177	1237	2244	2176	

Figure XXIV shows actual demand data. There is no regularity to suggest a seasonal pattern, nor any distinct trends. In an endeavour to determine the closest underlying model, programme APCORR has been utilized. It is possible to run the programme as often as desired, until

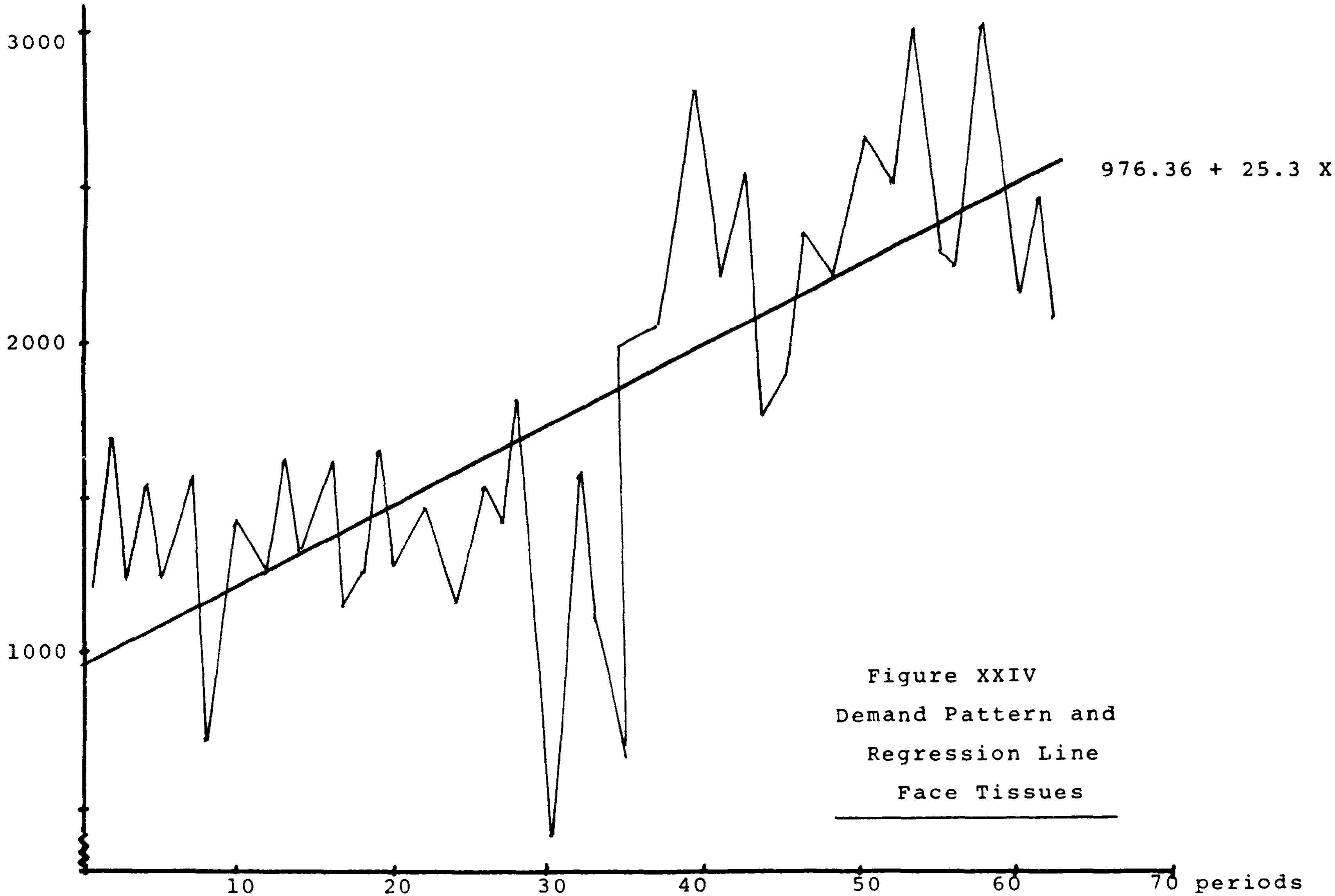


Figure XXIV
Demand Pattern and
Regression Line
Face Tissues

visual examination of the correlations suggest that a feasible model has been reached.

Using an IBM 360/50 takes 7 minutes Processor time per run for one single set of data and involves 2000 printed lines including the programme. A major cost would be the necessary examination of outputs and decisions to alter and rerun.

The number of lags for the computation of autocorrelations and partial autocorrelations, is specified as input. The degree of differencing and number of terms in $\phi_p(B)$ and $\theta_q(B)$ to be included are decided with reference to the shape of the curves produced as output, and knowledge of theoretical functions as displayed in figures XXII and XXIII above.

Two periods for seasonal differencing can be requested. Special attention in analysis of early printouts is given to any sample autocorrelations which are multiples of twelve. The second set of data to be analysed is strictly seasonal and this will be examined at that stage.

Output includes the mean and variance of the original data, auto- and partial correlation for the originally differenced and (if requested), seasonally differenced data.

Table 39 gives results of the first run, with no seasonal differencing applied; figure XXV shows correlations and first and second differences. The symbol 0 represents the autocorrelation function of the undifferenced series; the steep but steady decline indicates the non-stationary nature of the data (falling from +0.737 to

Table 39

ITEM 88100010 FACE TISSUE

APCORR: NO SEASONAL DIFFERENCING

Correlations, 24 lags, 62 data points

Lag/	Original Data		First Differences		Second Differences	
Order	Correlation	Partial Corr.	Correlation	Partial Corr.	Correlation	Partial Corr.
1	.737	.737	-.364	-.364	-.581	-.581
2	.665	.268	-.100	-.269	-.003	-.531
3	.637	.191	.111	-.041	.230	-.145
4	.552	-.023	-.265	-.319	-.312	-.374
5	.591	.231	.213	-.013	.226	-.253
6	.532	-.035	.064	.072	.047	-.002
7	.448	-.101	-.174	-.074	-.209	-.033
8	.432	.003	.092	-.044	.155	-.042
9	.376	-.018	-.064	-.042	-.066	-.061
10	.353	-.003	.007	-.010	.035	.087
11	.331	-.011	-.035	-.173	-.074	-.178
12	.325	.104	.101	.069	.090	-.095
13	.275	-.080	.034	.106	.003	.049
14	.203	-.126	-.058	.035	-.069	.063
15	.166	-.049	.023	.021	.040	-.031
16	.122	-.038	.021	.136	.040	.159
17	.054	-.153	-.094	-.039	-.075	.191
18	.044	.013	-.038	-.215	-.034	-.191
19	.061	.180	.154	.108	.157	-.007
20	-.010	-.110	-.130	-.050	-.190	-.100
21	-.018	-.019	.130	.067	.140	-.065
22	-.087	-.102	.007	.085	.025	.020
23	-.163	-.132	-.192	.015		
24	-.155	-.080				

Sample Mean: 1772 Variance: 374,038 Std. Dev.: 612

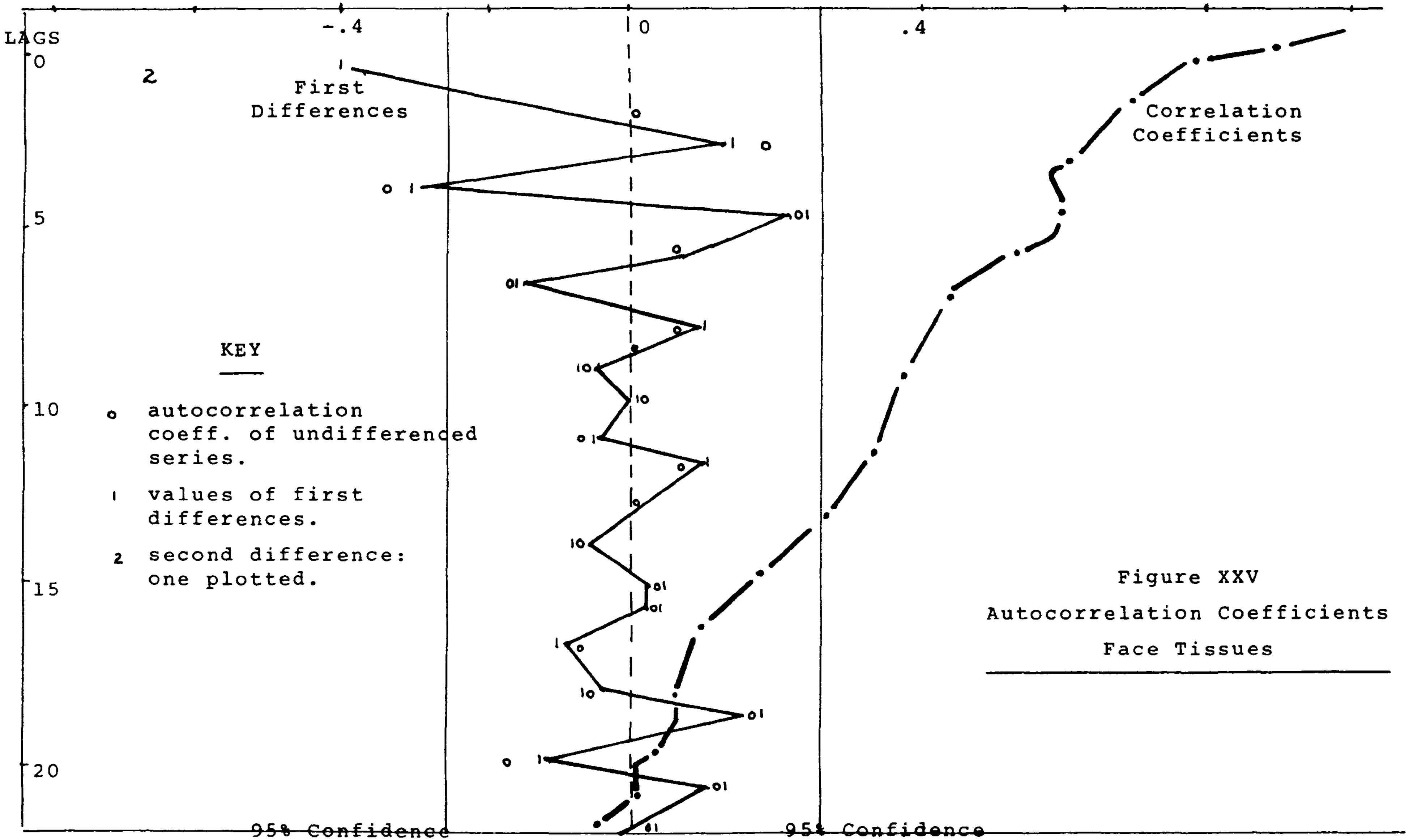


Figure XXV

Autocorrelation Coefficients

Face Tissues

-0.155) and the need to apply differencing to achieve stationarity.

The symbol 1 represents first differences; the large 'spike' at lag 1 (-0.364) is measured in relation to the dotted boundary, approximately one standard error from the mean. An experienced interpreter, (Mrs. C. Otte of Lakehead University) suggested a first-order moving average pattern was present: IMA (1,1). Examination of first differences on the chart indicates that their distribution is reasonably around the mean, showing that no constant term is needed to raise the model to the one or other side of it.

It is important to obtain a stationary situation if one can be found, since a probability distribution invariant with respect to the point in time t can then be applied.

The translation along the time axis makes no difference to the probabilities if it <u>is</u> a stationary process. An example would be a quality control chart, where the variate concerned is satisfactorily "in control". Most business series will be dynamic and non-stationary, but successive differencing should develop a reasonably stationary series.

A further comment favouring the IMA model is that of Newbold (1975), that partial autocorrelations will damp out approximately as a mixture of damped exponentials and/or damped sine waves. Partial correlations of face tissue data are recorded in table 39: there is a suggestion of a sinusoidal feature at the first difference which may reinforce the idea of a moving average model.

Figure XXVI shows correlations and differences, and

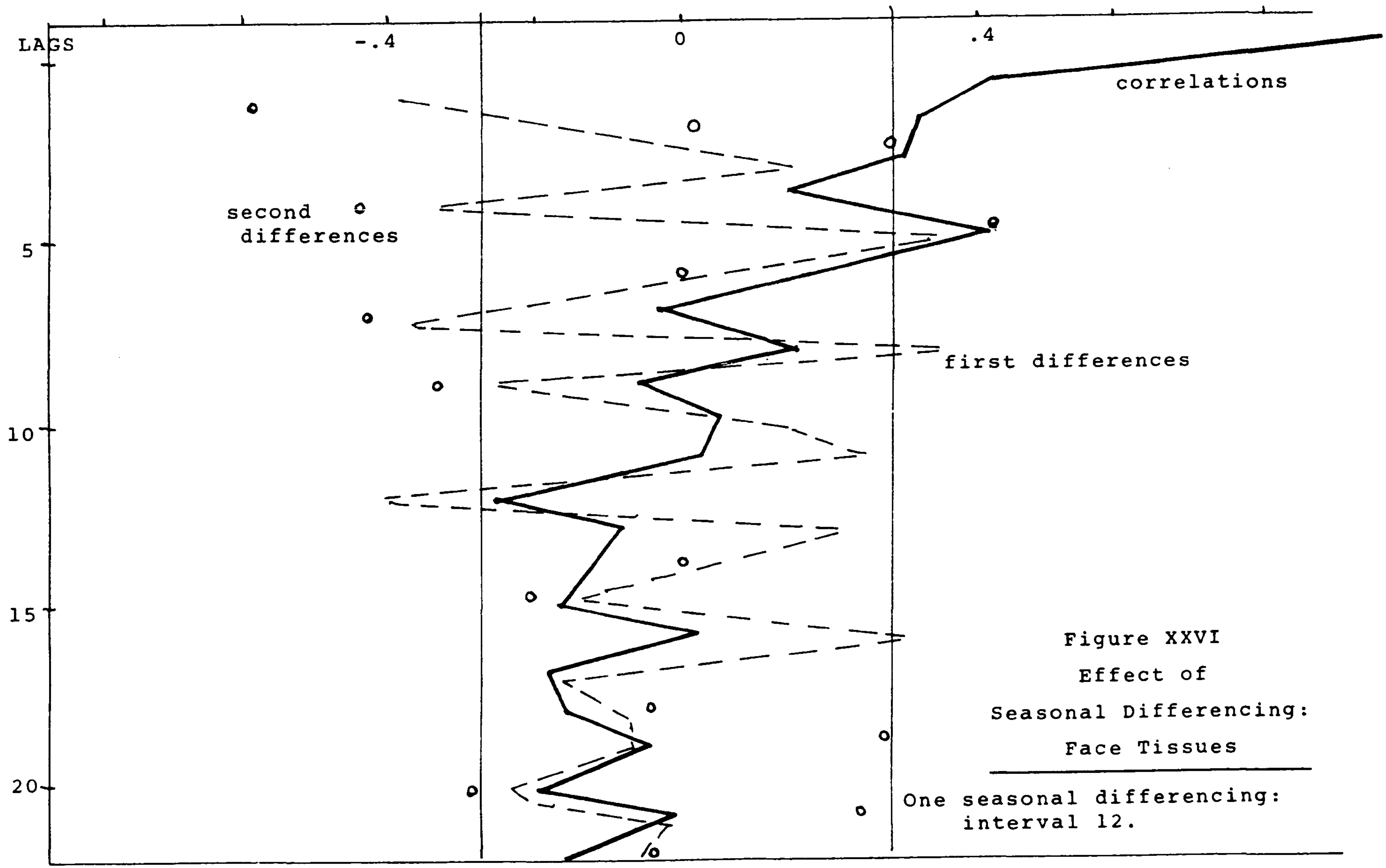


Figure XXVI
Effect of
Seasonal Differencing:
Face Tissues

One seasonal differencing:
interval 12.

it can be seen that one seasonal differencing aggravates rather than stabilizes the series.

Given that a model can be identified through runs of programme APCORR, the second stage -- TYMPAC is now utilized.

The first run was made assuming a first order moving-average model (q = 1) with first differencing (d = 1), no seasonal differences, and all available data being utilized. Figure XXVII shows both data and calculated function values appropriate to the chosen model, taken at the mean of the 95 percent confidence limits. Actual demand is followed quite satisfactorily though a lag is caused by the major step at period 35.

One diagnostic check is extensively described by Box and Jenkins (1970:287-293): the coefficient of residual autocorrelation. This is calculated by comparing each forecast with the actual value and computing the error. Recognisable patterns in the estimated autocorrelation functions of the $\hat{a}_t$'s could lead to appropriate modifications in the model. Results are compared with a standard error, and if substantially different an improvement should be sought. TYMPAC residual autocorrelation output from the first run is shown in figure XXVIII. Residuals do not exceed 95 percent confidence limits, but there is a swing noticeably on the low side; the two major residuals are negative and approach the limit of 0.26 (ρ_4 = -0.22 and ρ_{23} = -0.23).

The second run of TYMPAC was done with more parameters;

1 regular difference term d

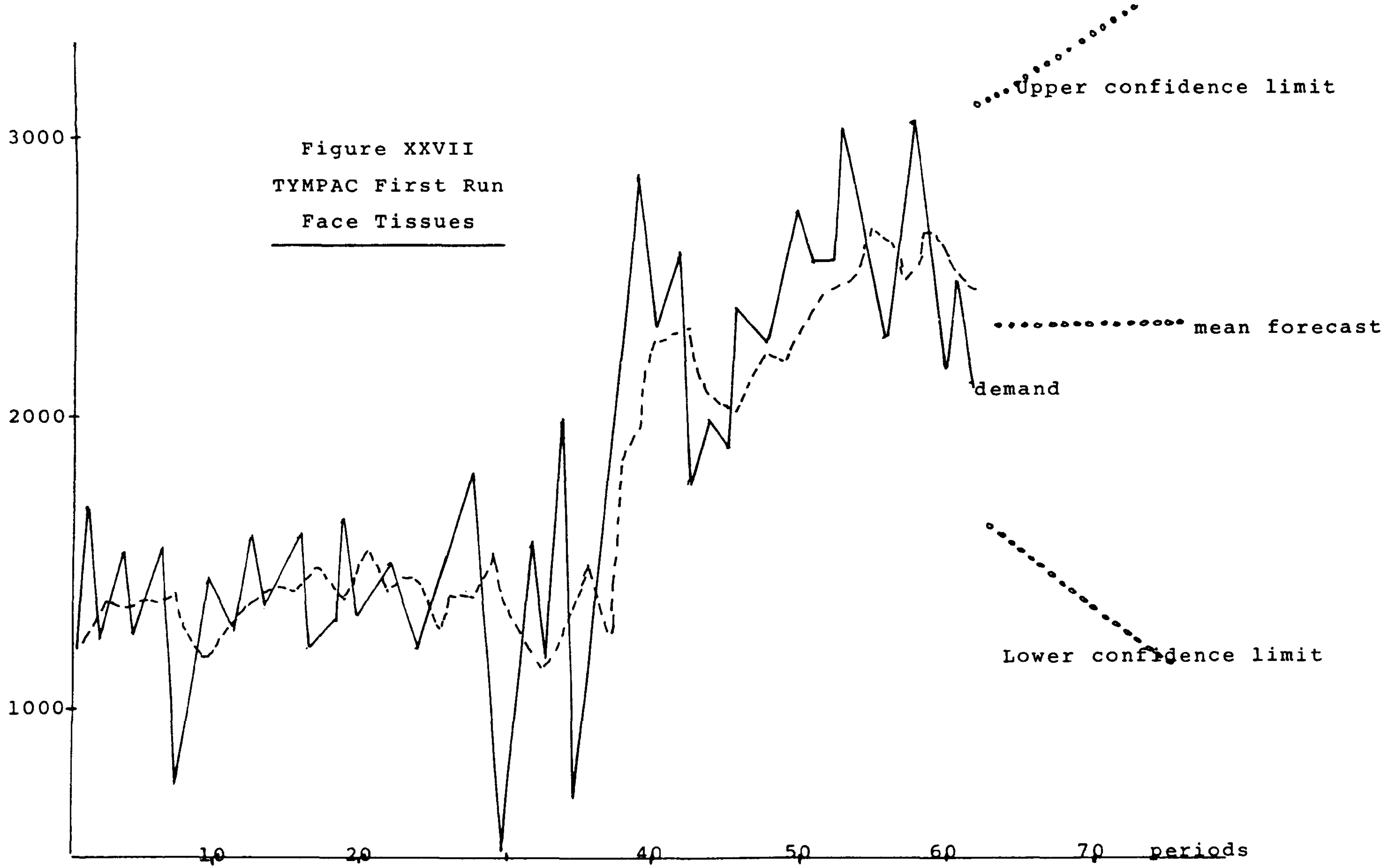


Figure XXVII
TYMPAC First Run
Face Tissues

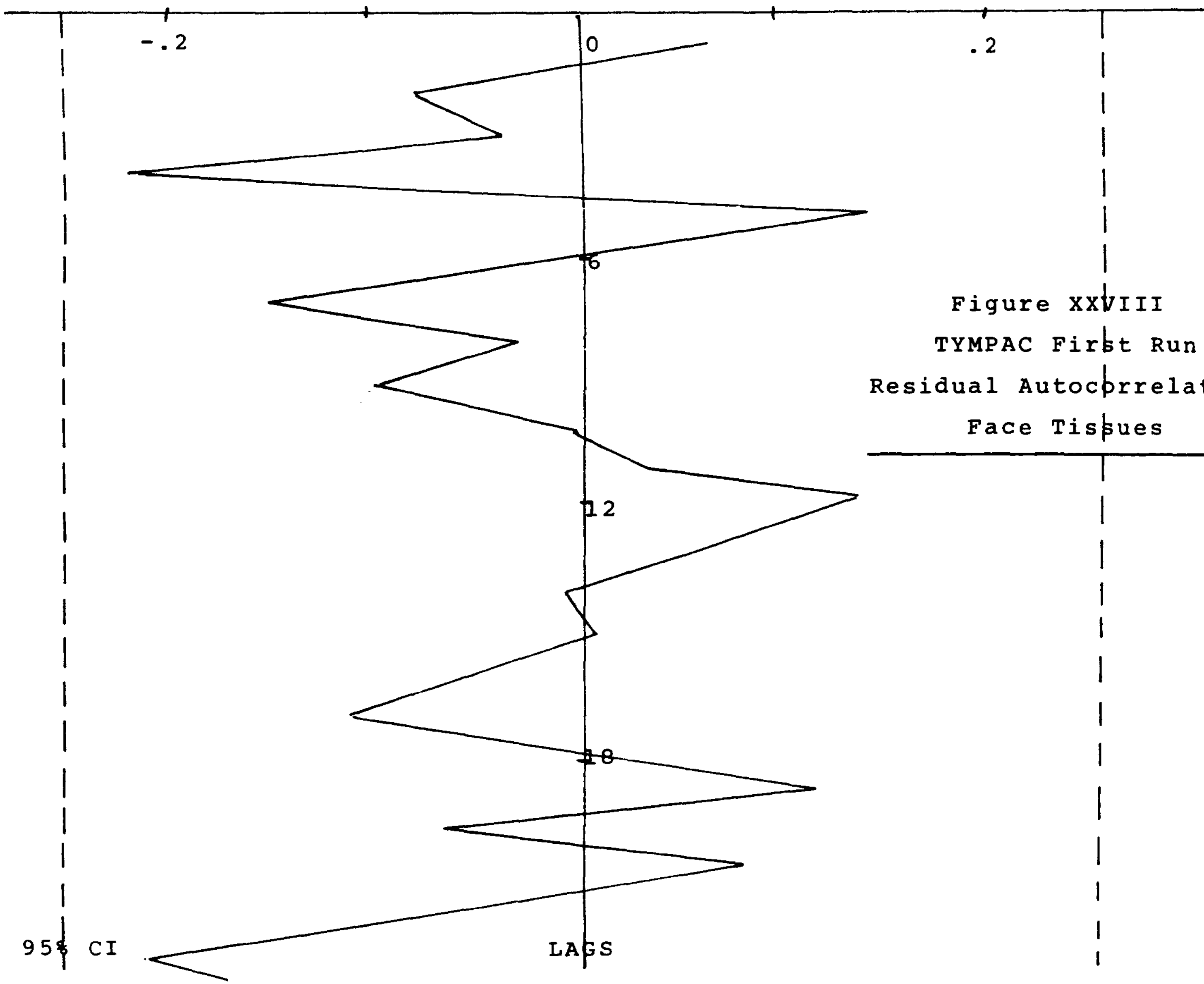


Figure XXVIII

TYMPAC First Run

Residual Autocorrelations

Face Tissues

0	seasonal autoregressive term	P
1	moving average team	q

Only 50 periods were used so that the remaining twelve would be available to check accuracy of the forecast against actual outcomes. The new residual autocorrelations are displayed by figure XXIX: a more stable pattern but still biased in a negative direction.

An attempt was then made to align observed and computed function values through changes in parameters:

$$d = 1, p = o, \text{ and } q = 2$$

an additional moving average term being added.

A card "Parameters", enables the experienced operator to choose the speed of convergence between the chosen model values and the true unknown values. One method of measuring efficiency is the number of iterations required to reach convergence. The first run needed four iterations to reach the programmed level -- in this case when the relative change in each parameter (i.e. 0.5 in run one) is less than 0.04. Run two (AR = 0.5 MA = 0.614) required nine iterations; run three, seven, and run four, five iterations. Two later runs required six.

Figure XXX shows residual autocorrelations resulting from the fourth run.

FORECASTING WITH BOX-JENKINS

Forecasting will depend upon the efficiency of identification and estimation which determine the model being used, and it is likely that errors will be present. Nelson (1973:145-146) observed that: "there is a starting-

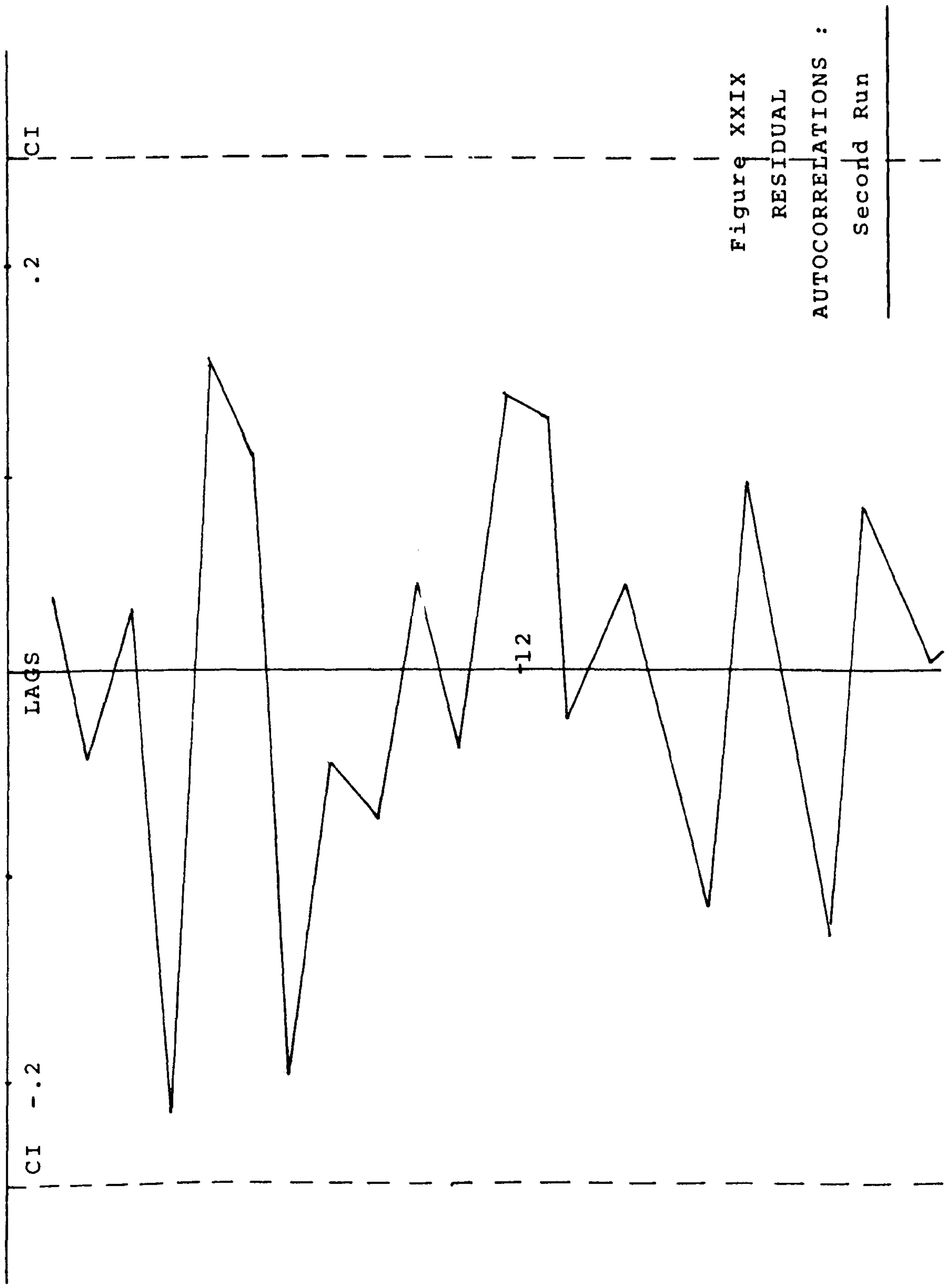


Figure XXIX
RESIDUAL
AUTOCORRELATIONS :
Second Run

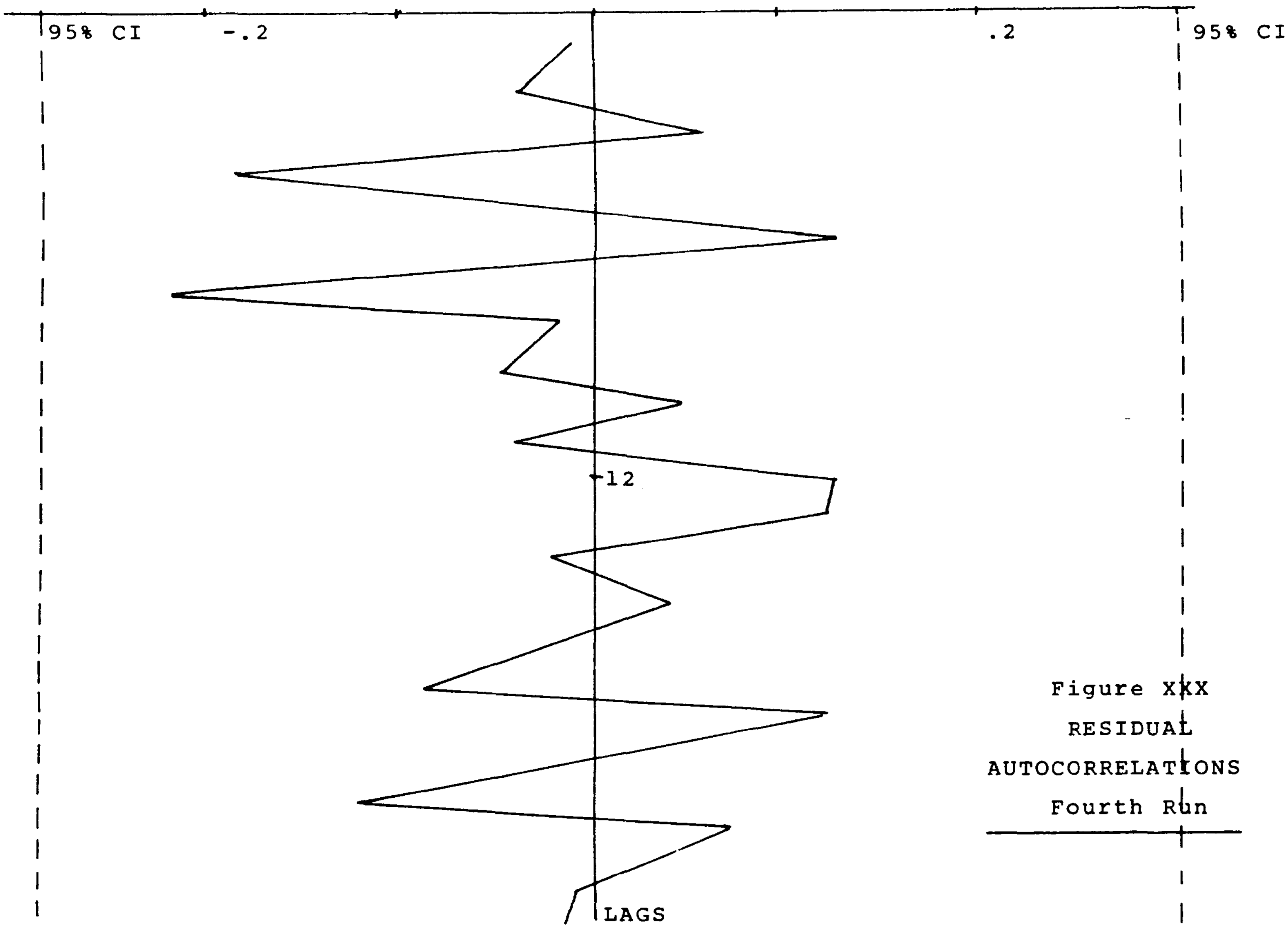


Figure XXX
RESIDUAL
AUTOCORRELATIONS
Fourth Run

value problem . . . since there must have been a first forecast at which time there were no past errors available . . . The most intuitively appealing procedure is to set (values of prior disturbances) at their marginal expected values of zero . . . In practice we should begin forecast computation at the beginning of our data series to have available the longest possible sequence of past errors for computation of the forecasts of real interest."

In forecasting for inventory management, a series of values of sufficient length is not usually available, and some measure of autocorrelation is important. Brown (1959) observed that a time series with high autocorrelation will require an entirely different method of forecasting than a series not so influenced. In the one case the last observed values provide a good indication for the immediate future, whereas the other will be more reliable if a longer term average is used. Due consideration will need to be given to autocorrelation in the calculation of buffer stocks. Positive autocorrelation in demand data may happen when a seasonal pattern is present. If this seasonal feature is not taken into account there is the risk of systematic error, and of autocorrelation in the errors which occur in the forecast. This latter may also happen if a forecast is invariably made for a number of future periods simultaneously; it often happens that if an error is made in the forecast, the deviation of the real from the forecast demand is in the same direction in all those periods for which a common forecast was made.

Negative autocorrelation of demand may occur if the overall usage of a component is very regular, but an intermediate store transmits intermittently; this may well have relevance to local and regional hospital stores organization.

Figure XXXI illustrates the actual values for final months of item 88100010 Face Tissues, plus TYMPAC-generated twelve month ahead forecasts. A single parameter was used, with convergence values of 0.6 and 0.5. It can be seen that the 'trend' which obtained during months 43 to 53 was predicted to continue. In fact the series 'settled' at an erratic but level pattern, not discernable by the system. This final run is by no means ideal and emphasizes that regular runs with adaptive forecasting would be essential. However, the improvement in comparison with an earlier run highlights the benefits that a reasonable model with efficient parameter choice, can bring: table 40.

Table 40

ITEM 88100010: FACE TISSUES

COMPARISON OF ACTUAL, FORECAST AND ERROR

		Run with Three Regular Differences		Final Run 1 Regular Difference	
Periods Ahead	Actual Demand	Forecast	Error	Forecast	Error
1	2536	2963	-427	2741	-.205
2	2523	3306	-783	2812	-289
3	3026	3699	-673	2882	144
4	2552	4142	-1590	2953	-401
5	2289	4636	-2348	3024	-735
6	2278	5181	-2903	3095	-816
7	2476	5776	-3300	3166	-690
8	3032	6421	-3389	3236	-204
9	2756	7116	-4360	3307	-551
10	2176	7863	-5687	3378	-1201
11	2482	8659	-6177	3449	-967
12	2092	9506	-7414	3520	-1427
		Mean Error	-3254	Mean Error	-569.

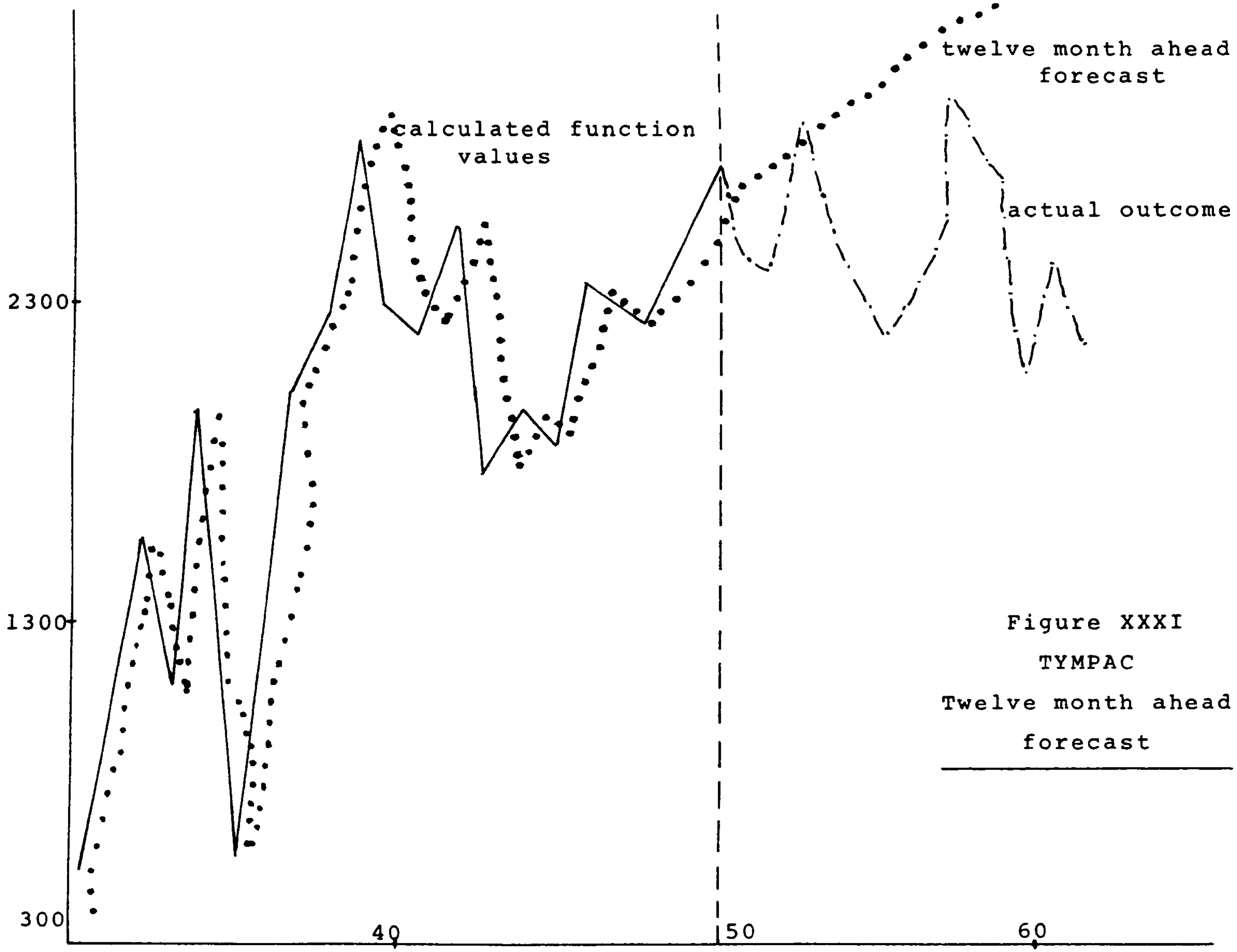


Figure XXXI

TYMPAC

Twelve month ahead

forecast

A single run of TYMPAC for one set of data, including compiling and printing, required 5 minutes 41 seconds C.P.U. time. In addition, wage costs of skilled interpreters would be substantial, although a rapid learning curve effect might be anticipated. Wheelright and Makridakis (1973:135) record 68 seconds C.P.U. time on an IBM 370/145 to fit 100 data points in four models during a single computer run "which makes its use expensive".

SEASONAL DATA

The second data set tested was item 2129. Figure XXXII illustrates the seasonal, trendy and non-stationary pattern.

The first run of APCORR showed that with no seasonal differencing, there was a tendency for correlations to move downwards as the lags increased: figure XXXIII. The repetition noticed in first differencing suggested that seasonal differencing would be advisable.

A run of 24 lags proved insufficient to determine the pattern, so a further run of 30 was made to obtain more output.

Five repetitions took place with modifications to parameters before reasonable estimation was obtained. Figure XXXIV shows highly erratic correlations; there is no evidence of tapering found within the two confidence limits. Figure XXXV shows results of two seasonal differencing (12,6) where correlation coefficients behave steadily, with just one second difference value outside the limits. This suggests one regular differencing and the

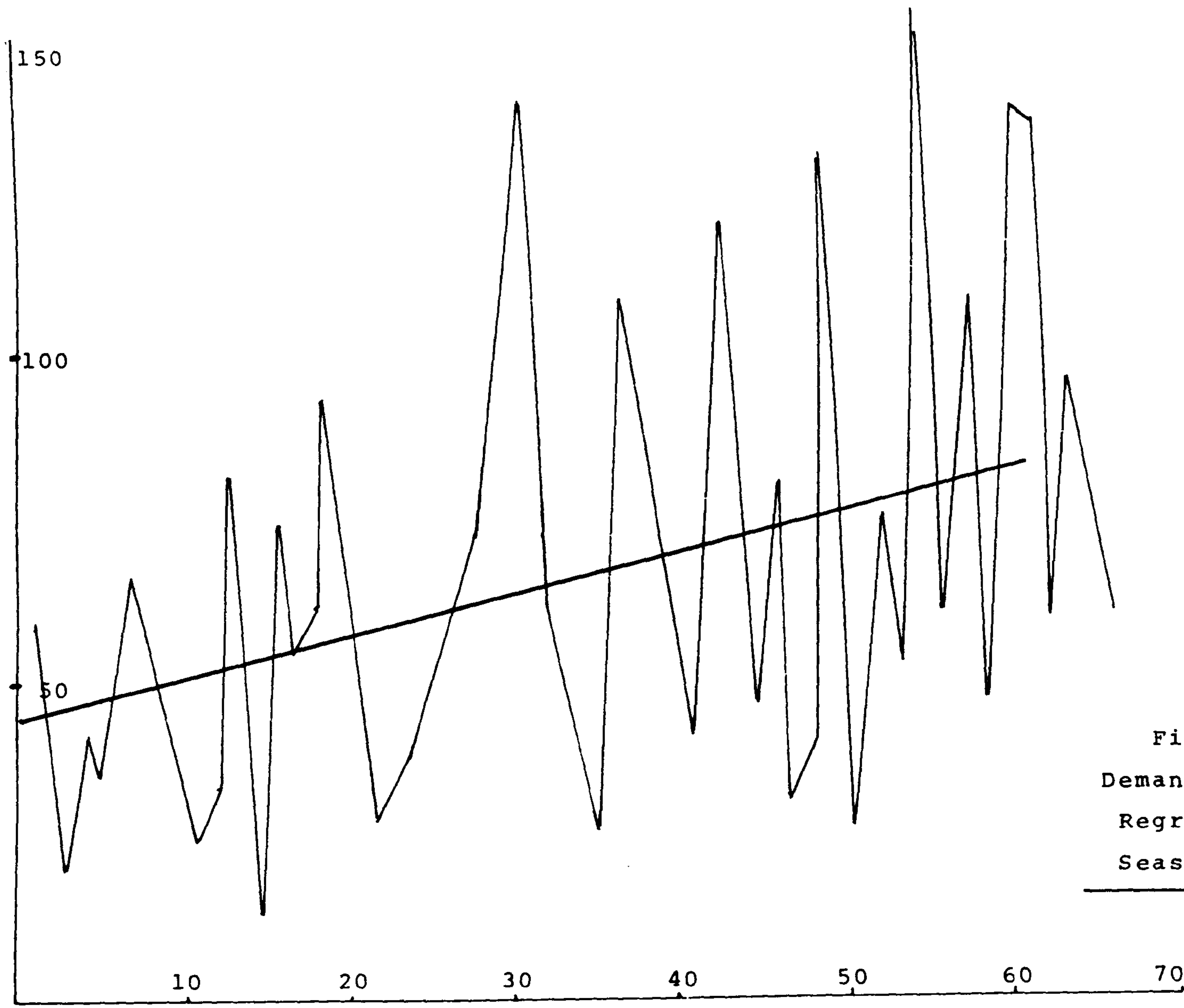


Figure XXXII
Demand pattern and
Regression Line
Seasonal Item.

Figure XXXIII

Autocorrelation Coefficients

Seasonal Item

No Seasonal Differencing : 24 Lags

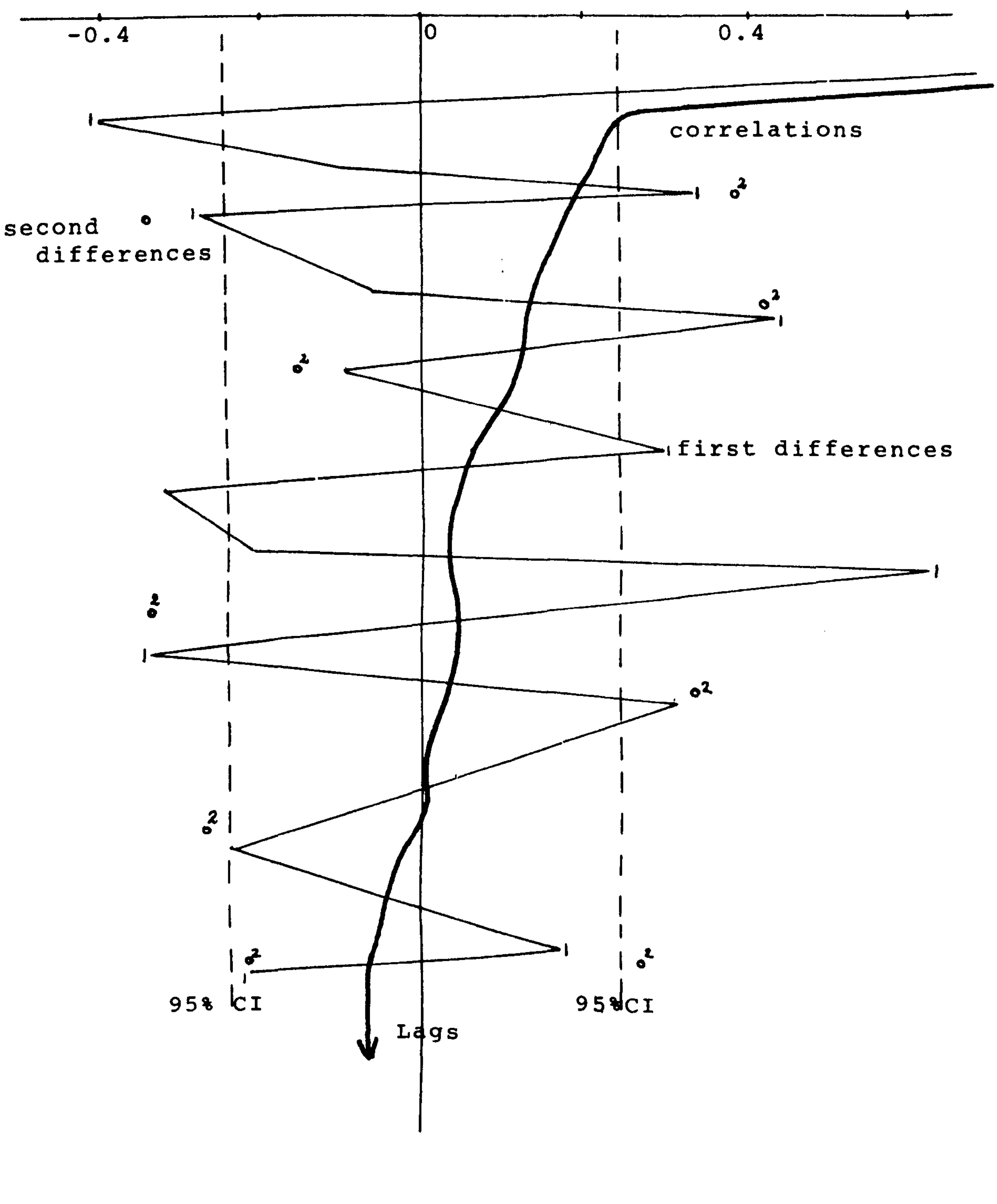


Figure XXXIV

Autocorrelation

No Seasonal Differencing

30 Lags

Seasonal Item

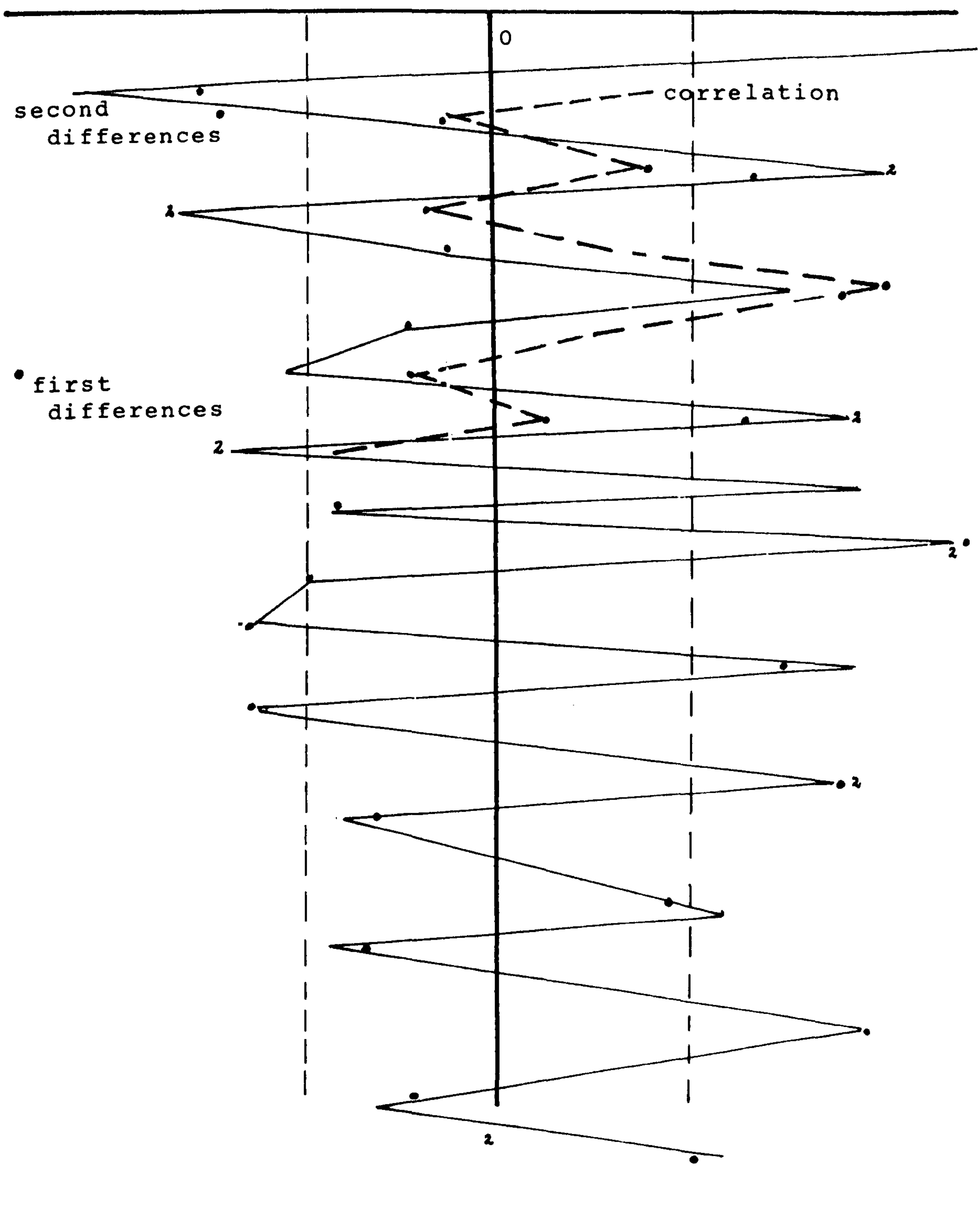
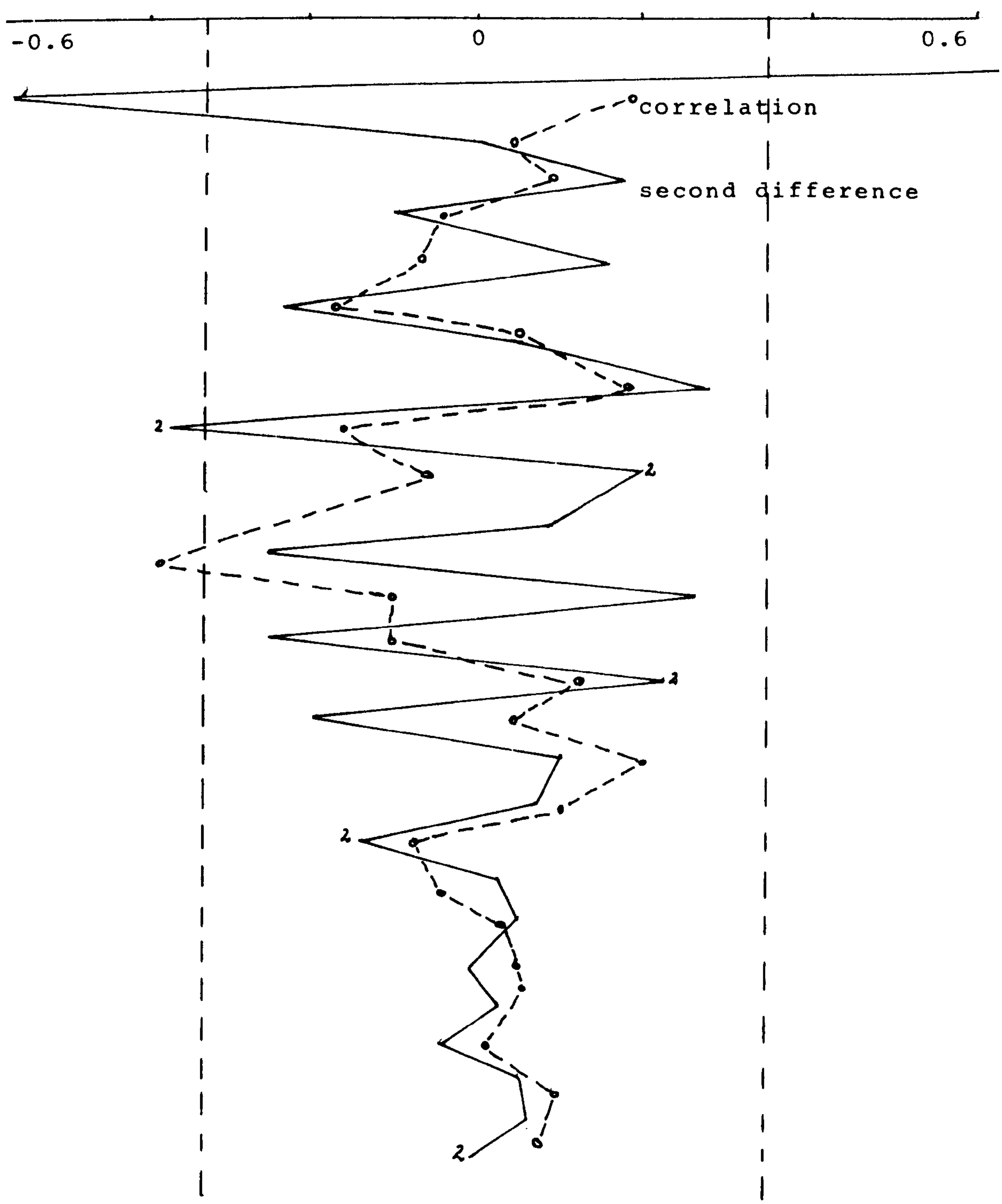


Figure XXXV
Two Seasonal Differencing
Lags of 12 and 6
Seasonal Item



first run of TYMPAC used one regular difference d; twelve months season S; one seasonal difference D; one regular autoregressive term p and one regular moving average term q. TYMPAC was run with selected parameters, and the chosen model is shown in figure XXXVI.

An experiment was carried out by this researcher, using seasonal data and various specifications with three runs: table 41.

Table 41

SEASONAL DATA

EXPERIMENT SPECIFICATIONS

		RUNS		
		1	2	3
Regular Differences:	d	1	1	1
Length of season:	S	12	0	12
Seasonal Differences:	D	1	0	2
Regular Autoregressive terms:	p	1	1	1
Seasonal Autoregressive terms:	P	0	0	0
Regular MA terms:	q	1	1	2

Two convergence parameters were tried, and for run three a third parameter added: tables 42 and figures XXXVII to XXXIX.

Table 42

INITIAL AND CLOSING

PARAMETER VALUES

	Initial Values			Number of Iterations	Closing Values		
	p	q	P		p	q	P
1	0.100	0.700		8	0.060	1.000	
2	-0.100	0.600		6	0.066	0.914	
3	-1.000	0.500	0.100	12	0.720	1.369	-0.380

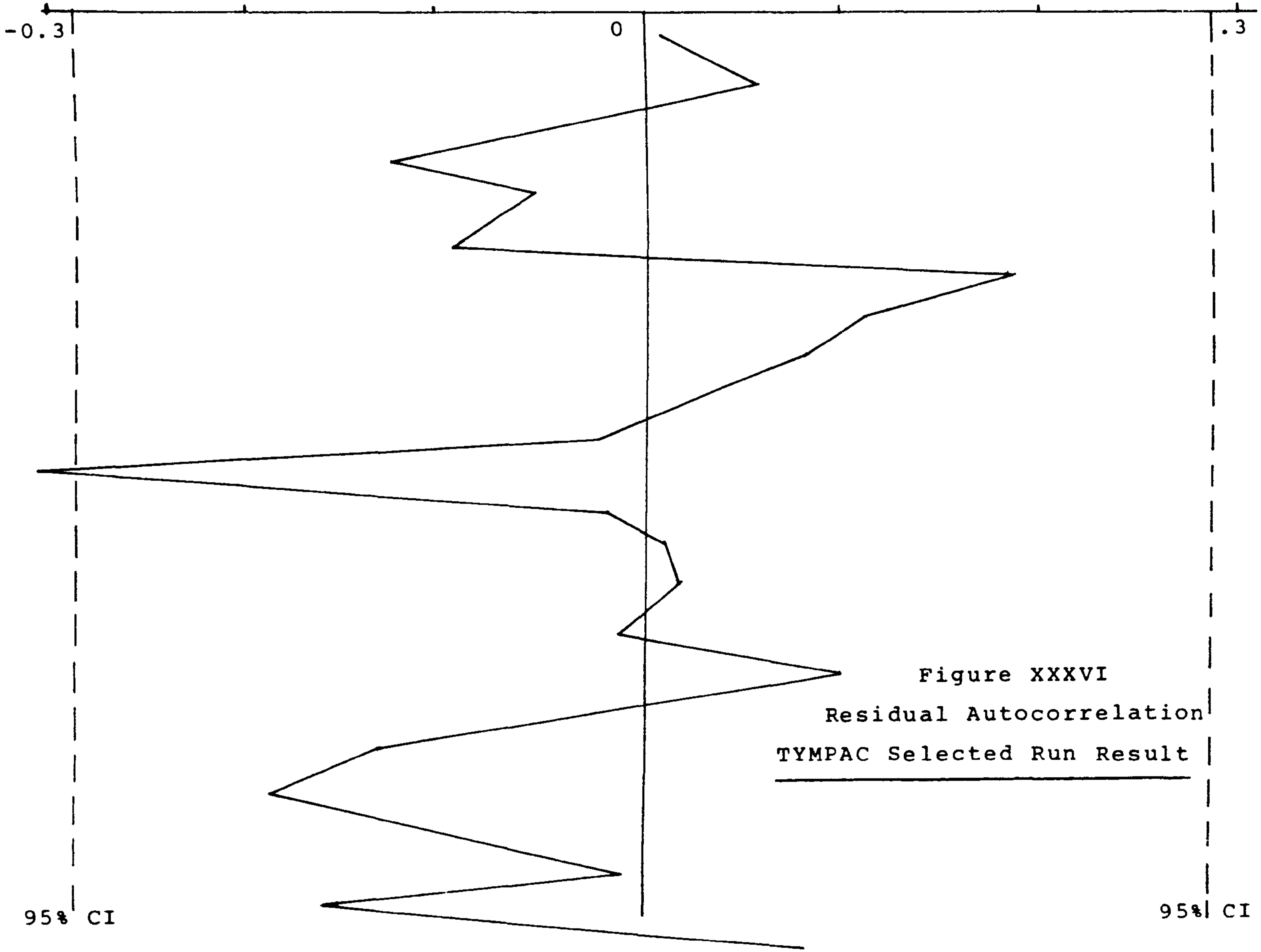


Figure XXXVI

Residual Autocorrelation

TYMPAC Selected Run Result

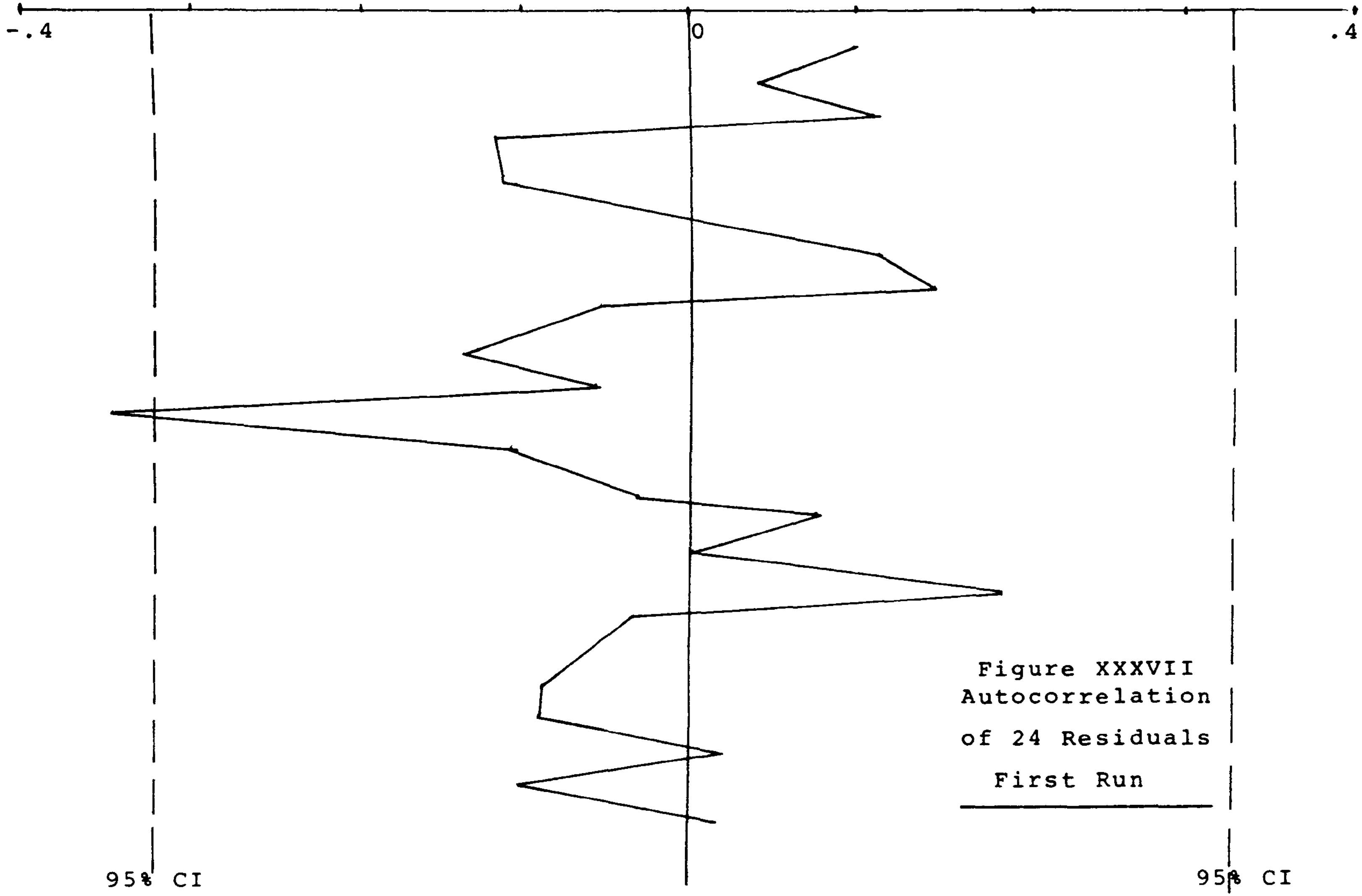


Figure XXXVII
Autocorrelation
of 24 Residuals
First Run

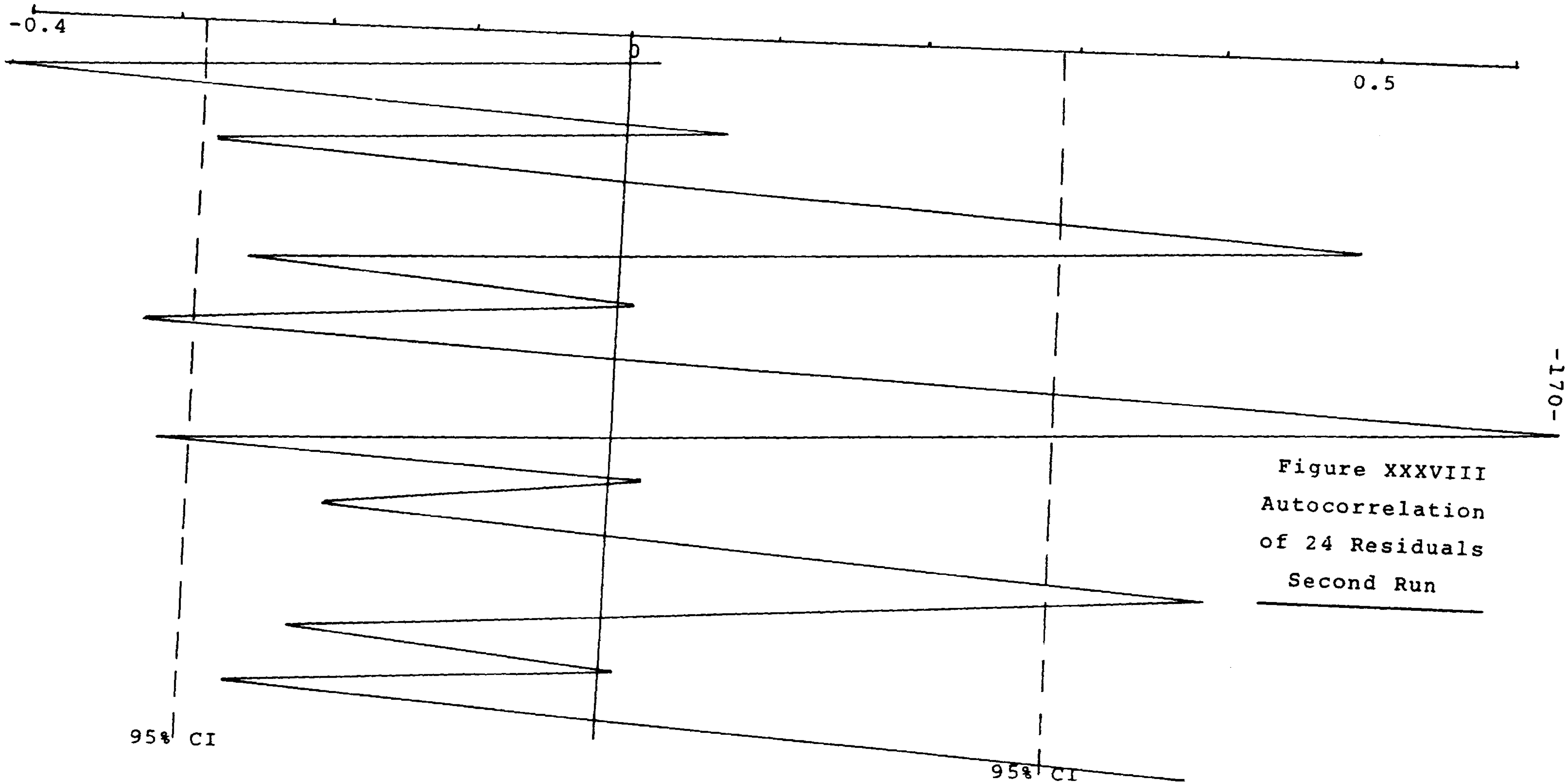


Figure XXXVIII
Autocorrelation
of 24 Residuals
Second Run

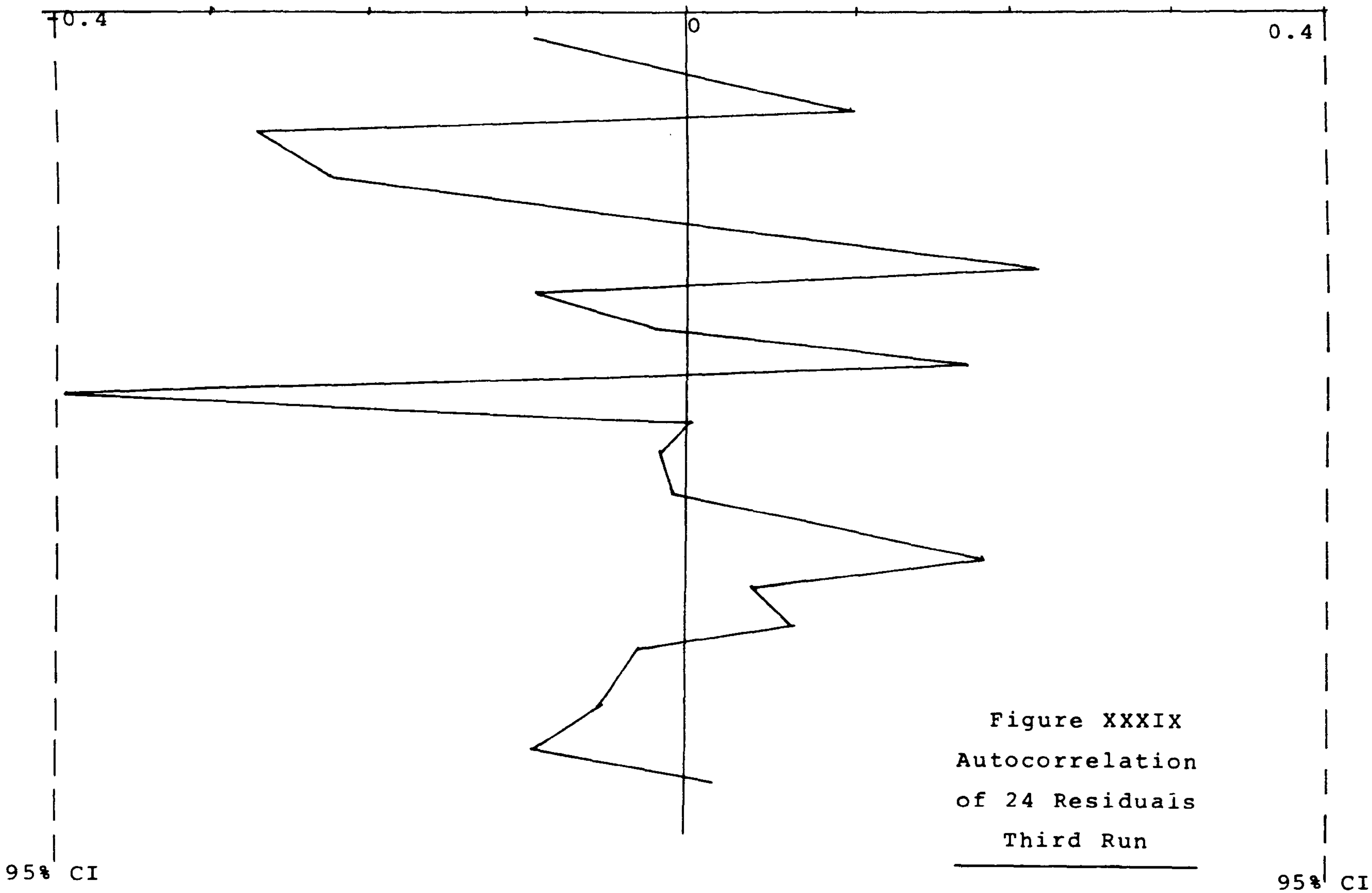


Figure XXXIX
Autocorrelation
of 24 Residuals
Third Run

The three figures are drawn to the same scale to emphasize differences in ranges of swings. The benefit of the additional parameter seems obvious: there is little drift and no value beyond the confidence limit. The parsimonious model two shows several extremes.

Table 43 summarizes three forecasting runs, with the values of signed errors. Because of the experimental nature of the choice of model parameters, actual values are not regarded as showing excellence; rather they emphasize differences in outcomes due to the varied input parameters.

Table 43

TWELVE MONTH AHEAD FORECASTS

SEASONAL DATA 3 PART EXPERIMENT

Periods	Actual Demand	(1) Fore-cast	(1) Error	(2) Fore-cast	(2) Error	(3) Fore-cast	(3) Error
1	167	122.8	44.2	63.5	103.5	100.2	66.8
2	63	70.7	-7.7	64.1	-1.1	39.7	23.3
3	85	49.8	35.2	64.2	20.8	22.8	62.2
4	111	81.8	29.2	64.2	46.8	99.5	11.5
5	48	36.8	11.2	64.2	-16.2	43.1	4.9
6	121	47.8	73.2	64.2	56.8	34.5	86.5
7	141	133.8	7.2	64.2	76.8	158.7	-17.7
8	138	99.8	38.2	64.2	73.8	139.0	-1.0
9	66	30.8	35.2	64.2	1.8	58.1	7.9
10	98	50.8	47.2	64.2	33.8	43.2	54.8
11	87	78.8	8.2	64.2	22.8	115.3	-28.3
12	66	56.8	9.2	64.2	1.8	46.3	19.7
Sums of Errors			+330.5		+421.4		+290.6

THE EFFECTIVENESS OF BOX-JENKINS

Reilly (1975:1) claimed that: "statistical forecasting has reached new heights with the development of powerful statistical methods, which can be used to create forecasts based on the probabilistic structure of the time series itself." McKenzie (1974:114) has written:

> . . . the system, unlike the other three (Brown Exponentially weighted Moving Average, Holt and Winters, and Harrison) may be extended to deal with several time series and possible interrelationships in a satisfactory manner. There can be little doubt . . . in the present context at least, the Box-Jenkins approach to forecasting is by far the best, if only because it has such a wide scope for application. In addition, the attempt to identify the underlying stochastic model analytically is without parallel in other approaches and the consequent diversity of possible processes for which an optimal system may be found also makes this attack much more powerful. It can provide a system which is optimal in a minimum mean square error sense for any process whose k^{th} difference is an ARMA process . . . These other systems however, are unable to deal optimally with either AR or mixed ARMA processes, and we need consider the usefulness of their application with respect to only purely moving average processes.
>
> In application of the standard systems, all the parameter values have to be chosen, and in this matter two attitudes prevail. The first . . . is to choose the values in a fairly arbitrary manner e.g. rapidly decreasing values for the weights in unstable, and slowly decreasing values for stable situations. It is difficult to imagine that this approach cannot be bettered. In the second method, the data is passed through the system in question and the parameters "estimated" by "fitting" the system to the data. It is usually the case that the parameter values chosen that yield a minimum sum of squared forecast errors, although other methods are used. Since this is essentially the criterion used in the Box-Jenkins system, there is little to be gained in using the standard systems, and certainly much to lose. Much of the efficiency of the standard systems might be wasted on trying to fit the wrong model, and even if the correct model is being considered, we may be using a system that does not allow every possible value of the parameters. This can easily happen since (the other systems) are very special cases of the Box-Jenkins model because

(a) they are confined to situations where an appropriate difference of the series is a MA process,

(b) they assume that the order of differencing is the same as the order of the moving average process.

It is clearly this lack of complete general applicability, combined with the unrealistic attitude to the underlying model, which has caused the past difficulties and failures in the use of these standard systems.

The need for skilled intervention is stressed by Newbold (1975:133): "Indeed, a good deal of skill and/or experience is essential if Box-Jenkins models are to be used to best effect - in particular, the identification stage of the model building cycle often demands a high degree of judgement. This being the case it is pertinent to ask whether much the same success could be obtained through a more ad hoc procedure." In the discussion on Newbold's paper, G. J. A. Stern, of ICL, London observed:

> the sort of manual intervention allowed by Box-Jenkins is not really what is needed in the forecasting contexts (of practical business) because it has to be applied by experts. This means that the decision maker . . . has to have his knowledge filtered through an expert and a computer programme. In practice this will often pose an insuperable barrier to the practical use of the technique for decision making forecasting even supposing that such experts as the authors are readily available, which is by no means the case . . .
>
> I suspect that Box-Jenkins is more suited to one-period-ahead forecasts in a technological context (e.g. control of Machines), or for studies of time series of compatible terms. For many other contexts of decision making forecasting, I suspect that simpler methods are all that can be justified. In conclusion, I would like to see more research directed to problems of dealing with short, dirty time series with tools that managerial users can understand.

Anderson (1977) has stated that: "in general, the choice of identification, and the estimation and verification of the model, should be the work of the specialist time series analyst, allowing the data to have its full say."

The Box-Jenkins method is powerful and sophisticated, but its operation involves substantial costs of skilled manpower and computer time. In the context of modern hospital management, there is no example at present of its use, so far as this writer is aware because:

1. Although most hospitals have access to computer, it is common that the main operations are routine batch processes such as payroll or, in less common instances, analytical such as patient scheduling;
2. The degree of understanding of the method is necessarily high. To the present, no simple explanation has been published which could be adopted by hospital inventory managers;
3. In any case, the level of awareness of the benefit of good control, including forecasting, is low.

Box-Jenkins methods will remain unused in hospital inventory management, with the most likely development taking place in the British N.H.S. This is because of the intention to standardize equipment using ICL machinery: this manufacturer has had ample experience with Box-Jenkins methods through its SCAN Inventory Control programmes, available to industry for the past decade. Careful study of Canadian hospital plans indicate that sophisticated forecasting methods have no degree of priority.

CHAPTER EIGHT

FORECASTING BY EXPONENTIAL SMOOTHING

INTRODUCTION

The first mention of exponential smoothing as a means of estimating the current central tendency of a time series seems to have been by Holt (1957), and since that time Brown (1959) and other writers and practitioners have developed the forecasting aspects considerably. Trux (1968) observed that the method satisfies five requirements of a good forecasting procedure, namely, rapid recognition of discontinuities; estimation of margins of error; economy of effort for computation, elimination of random deviations, and reasonable demands upon computer data storage.

Exponential smoothing involves weighting past data with quantities that decrease exponentially (geometrically with age). It can be very simple to operate. Geoffrion (1962:226) observed: "No one claims that exponential smoothing is the most sophisticated forecasting technique ever devised, but for mass producing forecasts on a routine basis it is well worth consideration, particularly when the most obvious alternative is some sort of moving average." Most published descriptions of exponential methods have come from large industrial users and academics. Little has been published concerning the benefits or disadvantages of forecasting by these means, from the viewpoint of hospital management.

The following list contains symbols used in descriptions of the methods.

α	:	Basic smoothing constant, alpha
β	:	$(1 - \alpha)$, beta
G	:	Seasonal smoothing constant, gamma
A	:	Average ratio for seasonal calculations
B	:	Base series value for month m
C	:	Current trend between time t and t-1
D	:	Demand, or sum of requisitions
E	:	Smoothed trend forecast - expected demand
F	:	Simple unadjusted forecast
e_t	:	forecasting error
L	:	lead time in months
N	:	Number of forecasting periods
P	:	Tracking signal (Trigg & Leach)
R	:	Demand ratio, for a given month
S	:	Double Smoothing process trend slope
T	:	Smoothed trend
ART	:	Average ratio, trend
SART	:	Smoothed average ratio
ERAT	:	Expected ratio
SF	:	Seasonally adjusted forecast

SINGLE EXPONENTIAL SMOOTHING

If the appropriate model is the expected value of demand as a constant, Brown's first order smoothing is:

$$F_{t+1} = (\alpha D_t) + (\beta F_t) \quad \ldots(1)$$

where smoothing constant Alpha, is used to adjust the forecast:

Alpha $\doteq \frac{2}{N+1}$, Beta = $(1 - \alpha)$, and N represents the number of time units included in the first forecast. If demand is erratic, management may choose weights which decay through only the previous six months, for example, since they would not rely on older history to determine likely future demand. The value of alpha would be $\frac{2}{7}$ or 0.286, and the exponential decay summed over six periods:

$$.286 + .286\,(.713) + .286\,(.713)^2 + \ldots + .286\,(.713)^6 = .905$$

implying that the accumulated influence of all earlier periods has a weight of ten percent only.

For some hospital consumable items, delivery may be delayed for a longer time than one forecasting period, and the simplest estimate of demand during the entire "lead time" L is then:

$$F_{t+L} = F_{t+1} \times L \qquad \ldots(2)$$

DOUBLE EXPONENTIAL SMOOTHING

An extension of this first-order smoothing system is necessary to track changes caused by an underlying trend.

Given a data series including trend, single smoothing will lag behind actual data by:

$$\frac{1-\alpha}{\alpha} \cdot S$$

where S is the slope of the process trend.

The method of double smoothing is intended to correct for the lag, yet requires only the one parameter -- alpha. It proceeds from the simple smoothing forecast and in Brown's terminology (1963:128):

$$S_t^{[2]}(X) = \alpha\, S_t(X) + (1 - \alpha)\, S_{t-1}^{[2]}\ (X) \qquad \ldots(3)$$

where S_t (X) is a linear combination of all past observations (i.e. the first forecast):

$$S_t^{[1]}(X) = \alpha\, X_t + (1 - \alpha)\, S_{t-1}^{[1]}\ (X)$$

and the symbol [2] indicates double smoothing.

A current estimate of the value of a point on a line through the data is obtained by:

$$\hat{X}_t = S_t^{[1]}\ (X) + (S_t^{[1]}\ (X) - S_t^{[2]}\ (X))$$

$$= 2S_t^{[1]}\ (X) - S_t^{[2]}\ (X) \qquad \ldots(4)$$

The slope of the line is given by:

$$\frac{\alpha}{1 - \alpha} \cdot \left\{ S_t^{[1]}\ (X) - S_t^{[2]}\ (X) \right\} \qquad \ldots(5)$$

whence the trend corrected forecast for the next subsequent period (T = 1) or any further period ahead is:

$$S_{t+T} = 2S_t^{[1]}\ (X) - S_t^{[2]}\ (X) + \frac{\alpha}{1 - \alpha} \cdot \left\{ S_t^{[1]}\ (X) - S_t^{[2]}\ (X) \right\} \cdot T \qquad \ldots(6)$$

SEASONAL VARIATION

Although investigation of hospital records by the writer suggests that seasonal periodicity is not often important to hospital supply management, provision is made for seasonal forecasting if desired, in the computer programme.

Some rules for the identification of seasonal variation are found in Lilly (1967):

1. Peak demand must occur during the same period each cycle (year, etc.)
2. Peak demand should be 50 percent greater than the average demand for the year and substantially greater than the noise.
3. There is some identifiable reason for seasonal influence.
4. At least two years data must be available.

One commonly used measure of camparison is the base series, one value per month. The seasonal forecasting method begins with the values of base series and actual demand for a given month:

$$R_m = D_m/B_m \qquad \ldots(7)$$

The average ratio may incorporate alpha, or a separate smoothing constant gamma, whose value can be determined by experiment.

$$A_m = G(R_m) + (1 - G)\,(A_{m-1}) \qquad \ldots(8)$$

Trend adjustment may be included using a simple smoothing technique based on the difference in demand between two adjacent months. Then the trend is smoothed, and the expected ratio calculated:

$$ART_m = A_m - A_{m-1}$$

$$SART_m = \alpha(ART_m) + [(1 - \alpha)\,(SART_{m-1})]$$

$$ERAT_m = A_m + [\frac{1 - \alpha}{\alpha} \times SART_m]$$

to which the seasonal factor is applied, giving the expected demand value applicable to the current month:

$$XPDM_m = ERAT_m \times B_m$$

The seasonal adjusted forecast for the subsequent period is now compiled:

$$S_{t+1} = (ERAT_t + SART_t) \times B_{t+1} \qquad \ldots(9)$$

Niland (1970:206) stressed that: "It is sometimes surprising how often a forecasting model without any seasonal adjustment will prove more efficient than one including a seasonal. If the seasonal is constantly changing from one year to the next, recognizing it in the model may do more harm than good, since any revision of a seasonal for a particular month will not become effective until a year later - by which time it may have changed again." However, managers will need the option of seasonal adjustment, and can decide to eschew it if they so desire.

Tersine (1974) gives an interesting variation of seasonal adjustment to exponentially smoothed forecasting.

Using:

R_t : trend

I_t : seasonal index

X_t : actual demand

C : appropriate seasonal smoothing constant

b : trend smoothing constant

m : number of periods in seasonal pattern

$$\bar{X}_t = \left((\alpha X_{t-1} + (1 - \alpha)\ (\bar{X}_{t-1} + R_{t-1}) \right) \cdot \frac{I_t}{I_{t-1}} \qquad \ldots(10)$$

within which the deseasonalised trend is:

$$R_t = \left(b \cdot \left\{ \frac{\bar{X}_t}{I_t} - \frac{\bar{X}_{t-1}}{I_{t-1}} \right\} \right) + \left((1 - b) \cdot R_{t-1}) \right) \qquad \ldots(11)$$

The seasonal index is updated using:

$$I_{t+m} = \left\{ C \cdot \frac{X_t}{\bar{X}_t} + (1 - C) \cdot I_t \right\} \qquad ...(12)$$

The Tersine method has been applied to item 2129, seasonal pattern. Of the 66 demands, the first three years data are used to construct the base index. Results from January to December are:

I_t = 1.64 0.90 0.25 1.12 0.93 0.96 1.77 1.34 0.99 0.77 0.54 and 0.80

Tersine used smoothing constants of $\alpha = 0.10$, $b = 0.10$ and $C = 0.30$.

Table 44 shows forecasting results for the fourth year, and table 45 gives results for later years with updated base series. Graphs of demand and Tersine forecasts are presented in figure XL.

Table 44

TERSINE SEASONAL FORECASTING

ITEM 2129, SEASONAL PATTERN

Year and Month	Demand X_t	Trend T_t	Base Index I_t	Forecast $\bar{X}_t$	Error e_t
4 Jan.	108	0	1.64	78.0	-30.0
Feb.	60	0.68	0.90	49.0	-11.0
Mar.	3	5.0	0.25	24.5	21.5
Apr.	58	-2.1	1.12	35.7	-22.3
May	42	-1.9	0.93	29.9	-12.1
June	67	-1.7	0.96	30.3	-36.7
July	121	-1.3	1.77	59.8	-61.2
Aug.	68	4.1	1.34	115.3	47.3
Sept.	47	3.6	0.99	84.4	37.4
Oct.	79	3.1	0.77	65.3	-13.7
Nov.	34	4.5	0.54	46.7	12.7
Dec.	45	4.6	0.80	73.3	28.3

Table 45

TERSINE SEASONAL FORECASTING

ITEM 2129 YEARS 5, 6

Year and Month	Demand X_t	Trend T_t	Base Index I_t	Forecast $\bar{X}_t$	Error e_t
5 Jan.	131	4.3	1.83	170.6	39.6
Feb.	97	4.0	0.96	89.4	-7.6
Mar.	28	4.1	0.18	17.6	-10.6
Apr.	48	6.3	1.33	165.0	117.0
May	76	5.2	1.04	124.3	48.3
June	54	4.8	1.31	156.4	102.4
July	167	3.7	2.31	265.4	98.4
Aug.	63	3.0	1.18	132.2	69.2
Sept.	85	2.3	0.86	93.3	8.3
Oct.	111	2.2	0.82	90.1	-20.9
Nov.	48	2.5	0.50	57.4	9.4
Dec.	121	2.5	0.71	83.4	-37.6
6 Jan.	141	3.1	1.70	214.1	73.1
Feb.	138	2.5	0.98	120.8	-17.2
Mar.	66	2.6	0.21	26.7	-39.3
Apr.	98	5.3	1.05	164.9	66.9
May	87	4.6	0.92	142.8	55.8
June	66	4.0	1.06	162.9	96.9
July			2.05	303.3	

Although the data is regularly seasonal, it appears that the base series values are aggravating the swing in the exponentially smoothed forecast, and there is need for some adaptive control. Signed errors are:

Year 4: -39.8

Years 5, 6: +652.7

and mean absolute deviation for the 30 months is 42.

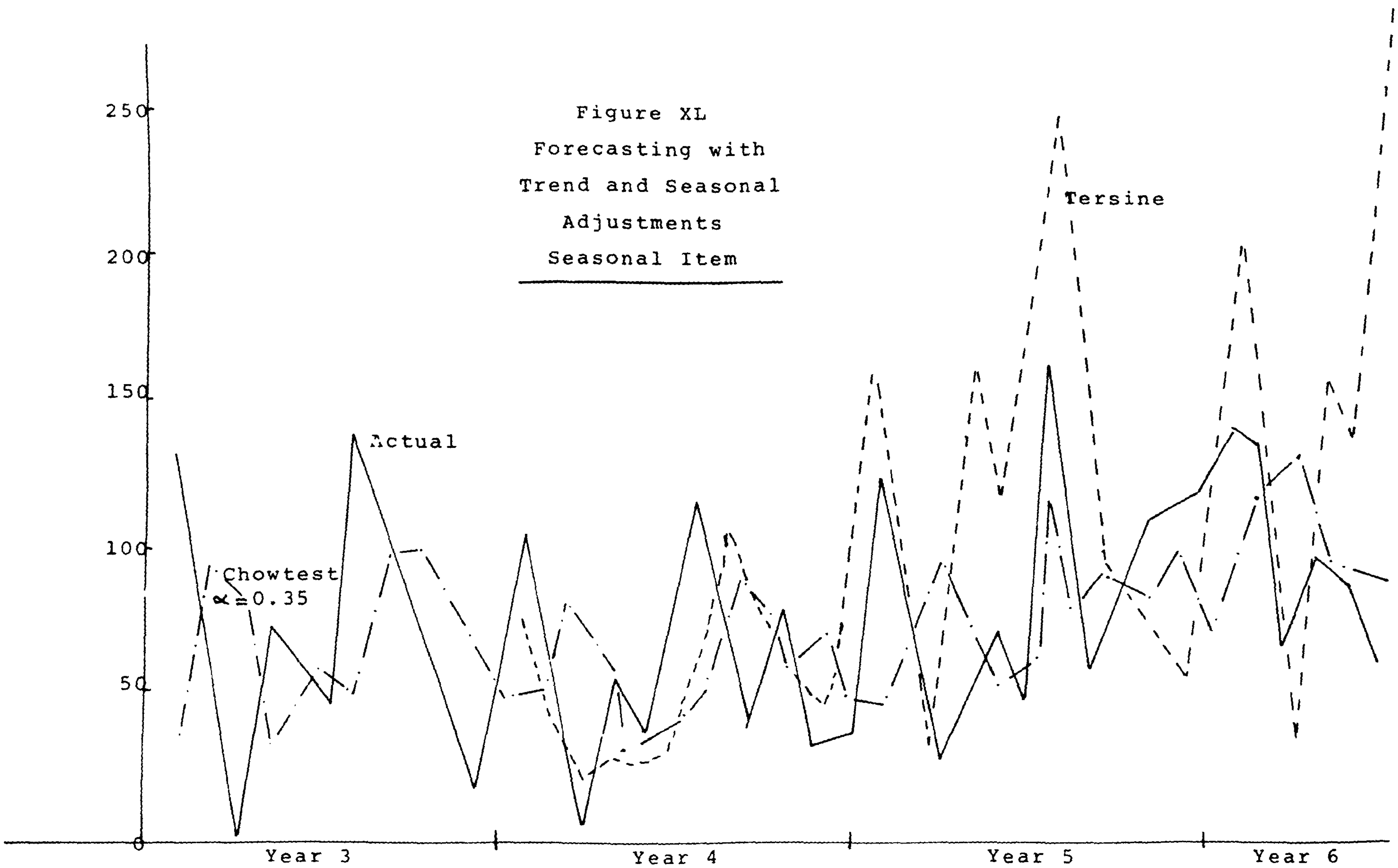


Figure XL
Forecasting with
Trend and Seasonal
Adjustments
Seasonal Item
250
200
150
100
50
0
Tersine
Actual
Chowtest
α = 0.35
Year 3
Year 4
Year 5
Year 6

Given tight control over the permitted deviation from actual demand, the Tersine method is one that could easily be programmed, for use with inventories whose demand is substantially seasonally influenced.

An alternative method for seasonally based data is that of Winters (1960), programmed for computer by Sullivan and Claycombe (1977), and adapted for this thesis in the programme COMPARE included in the appendix. The method enables forecasting equations to be updated as new information becomes available. Three parameters are estimated, for current intercept, slope of trend line and seasonal factor, though there seems little guidance (except experience and judgment) to assist with their selection, other than simulation.

The formulas incorporated within COMPARE are derived from Sullivan and Claycombe (1977:101-103):

$$a_t = \alpha\left(\frac{X_t}{F_{t-N}}\right) + (1 - \alpha)\ (a_{t-1} + b_{t-1}) \qquad \ldots(13)$$

the estimate of current intercept;

$$b_t = \beta\,(a_t - a_{t-1}) + (1 - \beta)\ b_{t-1} \qquad \ldots(14)$$

the estimate of slope of trend line;

$$F_t = \sigma\left(\frac{X_t}{a_t}\right) + (1 - \sigma)\ F_{t-N}, \qquad \ldots(15)$$

the updated seasonal factor, whence

$$Y_{t+T} = (a_t + b_t T)\ F^* \qquad \ldots(16)$$

the forecast developed at time t for a period T time units into the future. In the equations N represents seasonal periodicity; F_t the estimate of the multiplicative seasonal factor for period t; F_{t-N}, the estimate of the seasonal factor N periods in the past; F* is used to denote the best estimate of the seasonal factor in period t+T. Sullivan and Claycombe (ibid.) comment that: "Winter's method is a direct, simple, computationally tractable technique for forecasting seasonal data. It can be applied to data with periodicity of any number of data points and to data with an unusual pattern if a cycling trend can be observed."

TRIPLE EXPONENTIAL SMOOTHING

This method is used with data exhibiting changes in trend (curvature) and is generally sufficient, so that higher order smoothing is not required. Using the terminology of formulas (3) to (6):

$$S_t^{[3]}(X) = \alpha S_t^{[2]}(X) + (1 - \alpha) S_{t-1}^{[3]}(X) \quad \ldots(17)$$

The quadratic model is developed by Brown (1963:137):

$$Y_{t+T} = a_t + b_t T + c_t T^2$$

where $a_t = 3S_t^{[1]}(X) - 3S_t^{[2]}(X) + S_t^{[3]}(X)$

$$b_t = \frac{\alpha}{2(1-\alpha)^2} \left[(6 - 5\alpha) S_t^{[1]}(X) - \right.$$

$$\left. - 2(5 - 4\alpha) S_t^{[2]}(X) + (4 - 3\alpha) S_t^{[3]}(X)\right]$$

$$c_t = \frac{\alpha^2}{2(1-\alpha)^2} \left[S_t^{[1]}(X) - 2 S_t^{[2]}(X) + S_t^{[3]}(X)\right]$$

The problem of which values of a, b, c to use is solved only by experience and simulation. Illustrations of the programme and output are given in the appendix.

DEMAND DURING LEAD TIME

Computer systems which have been designed for industrial or retailing purposes frequently incorporate an analysis of lead time experience. The nature of the product and geographical location serve to determine whether fluctuating lead times are matters of concern to hospital procurement officers. Most Canadian hospitals can obtain delivery of supplies in days or, at most, weeks. For example, delivery time for most medical/surgical items in the Toronto area is one day. In Thunder Bay, 900 miles away, it may be one week. For imported items, such as some textiles and surgical instruments, several weeks may elapse.

Collier (1975), referring to industrial situations, wrote: "Lead times are critical variables in any order point system. Lead time estimates that are significantly inaccurate can sabotage the effectiveness of these powerful techniques. Lead time is a variable that must be continually monitored." He recommended that items be grouped into common lead time categories and common vendors, but recognized that the effort required might be excessive. Current inventory systems rely on demand data per item and grouping would require new systems. Therefore, small size and individual item analysis is characteristic of the real situation.

Since most hospital item lead times are less than the forecasting period, the computer system simply multiplies the current month's forecast by the lead time in months, for safety stock allowance calculation. In addition, this calculation is performed in the programme:

$$DDLT = \left(\begin{matrix} L.T. \times \text{Current} \\ \text{Expected Demand} \end{matrix} \right) + \left(\frac{(LT)+(LT+1)}{2} \times \text{Trend} \right)$$

A value for lead time is recorded for each item, based on recent actual experience. In the BRUFICH programmes, provision is made to forecast through lead times longer than the planning period. The effect of these has been considered by Brown (1967), whose conversion factor for safety stock purposes is

$$\sigma_L = \sigma_1 \cdot (0.659 + 0.341L)$$

Safety factors are tabulated for known probability distributions, and programmed for any level of service specified by management. Since BRUFICH is intended to be an operating system much of the programme deals with order quantity and order point computations, including safety stock determination. These matters are discussed briefly in chapter nine.

CHOICE OF SMOOTHING CONSTANTS

Smith (1974:421) observed that the 'best' value has been sought without success. "The difficulty seems to centre on the fact that various demand conditions require substantially different parameters . . . a large number of products with varied and transient demand conditions will require varied and transient rates of discounting past information. A proper solution would appear to be to adjust the parameter adaptively to prevailing demand conditions." Geoffrion (1962:224) wrote that:

> Before one may determine a 'good' combination of

> smoothing constants for a particular model, one must face three difficult issues: the description of the pertinent time series, the choice of a suitable criterion against which to evaluate alternative combinations of weights, and the choice of what method to use in searching for the optimum weights within the framework of the first two issues.
>
> As in all forecasting problems, the description of the time series will always be incomplete. Other than useful assumptions about the stochastic process in question, the best one can hope for is copious and reliable historical data.
>
> The second issue requires one to associate a loss function with forecasting errors. Frequently this loss function is assumed to be proportional to the variance or standard deviation of forecast errors - with little justification other than mathematical expediency. In fact . . . the proper loss function to use in a given situation will depend on the effects which forecast errors have on the objective function of the overall parent model.
>
> . . . If the character of the time series and the loss function are simple enough, it may be possible to mathematically derive the optimal weights. A reasonable way to behave would be to assume a plausible loss function, use the historical data to simulate the best combination of constants by trial and error, and hope that the resulting choice of weights will remain nearly optimal in future.

Thamara (1968:9-10) wrote: "Judging from tests run with different weights, it would appear that the best weights for the permanent component, trend and seasonal factors generally are .2 .2 and .5 respectively. A higher weight is indicated for the seasonal factor because it is updated less frequently. Giving a value of 0.5 to the seasonal factor merely implies that most importance is placed upon the most recent seasonal pattern. Weights of 0.2 for the trend and permanent components provide a steadying influence on these variables by ignoring random fluctuations for the most part." Thamara used his model in banking to plan staffing requirements based on forecast activity levels. These activities included measurable operations such as the number of cheques processes, and purchase orders written.

Trux (1968:54) considered that the constant to use with error smoothing should be maintained between 0.05 and 0.30 regardless of the noise level in the time series. The higher values should be used whenever there is a high likelihood of errors in the initial preparatory forecasting.

A contribution by Chow (1965) has attracted attention due to its simplicity. Given any exponential smoothing forecasting method, three constants are applied with arbitrarily chosen commencing values: high, normal and low. Having selected a criterion of forecasting efficiency -- perhaps the value of signed errors, or mean absolute deviation -- Chow instructs: "when on the basis of an error criterion, one of the 'outer' forecasts turns out better than the actual (normal) forecast, the next period's forecast is made based on this new 'best' series: at the same time new high and low series surrounding the normal one are introduced. In no case are the constants allowed to exceed certain upper and lower limits, namely 0.95 and 0.05. Chow claimed no optimal properties, suggesting that efficient application or simulation would ascertain best values.

The computer programme CHOWTEST has been written to illustrate these ideas using two items: face tissues and 2129, seasonal pattern; the programme and selected output is included in the appendix.

Table 46 gives a summary of one item, with its graph shown in figure XLI. Since the data is erratic, the low starting value of 0.05 allowed a lag to develop,

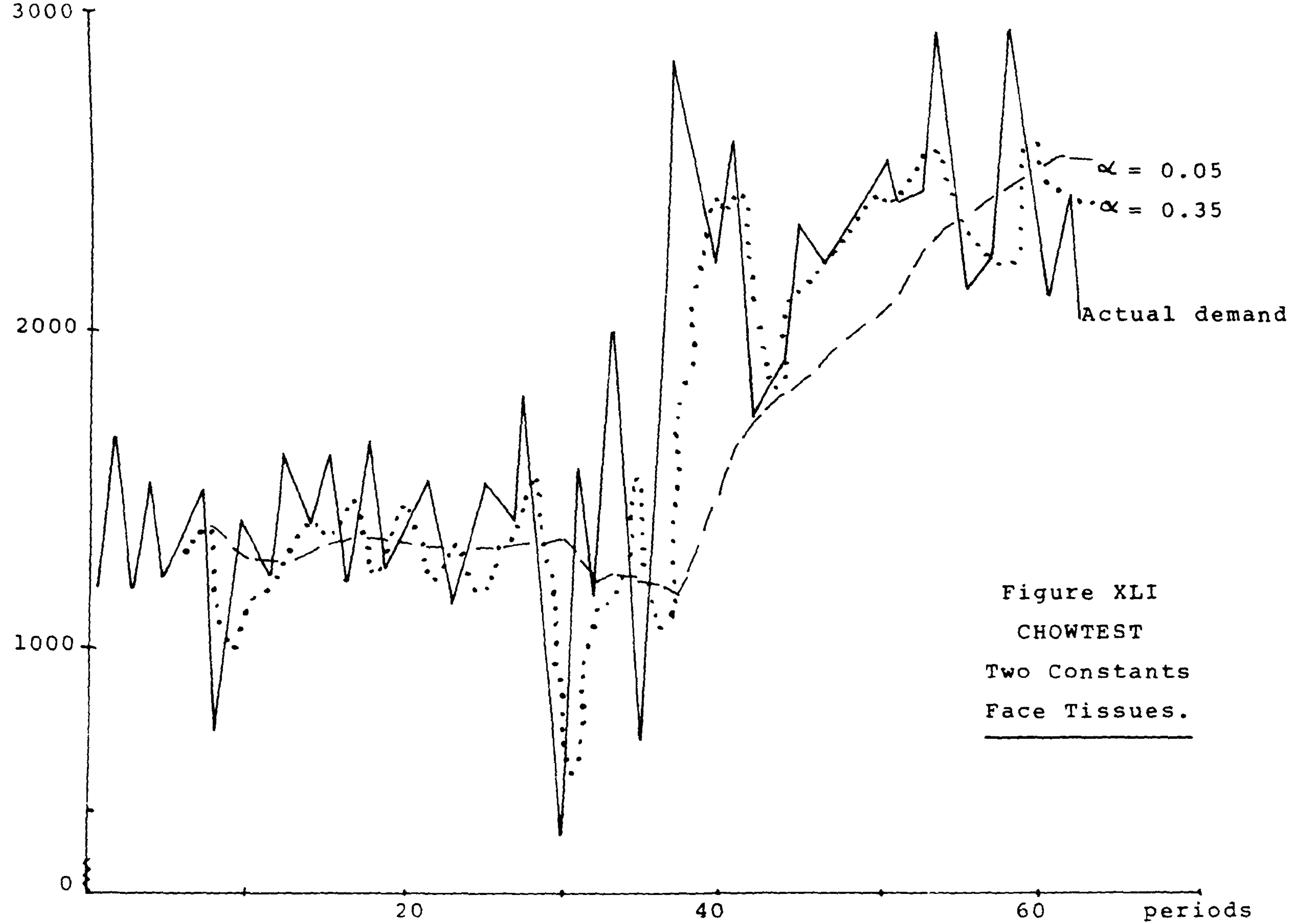


Figure XLI
CHOWTEST
Two Constants
Face Tissues.

exacerbated by the step at period 36. The selected alpha was 0.35, and figure XLI shows improved tracking obtained by use of this alpha, together with the simple trend adjustment included in the programme.

Table 46

CHOWTEST: SUMMARY

ITEM 6: FACE TISSUES

Iteration Number	Low Alpha	Sum of Errors	Medium Alpha	Sum of Errors	High Alpha	Sum of Errors	Selected Alpha
1	0.05	8462.	0.10	3067.	0.15	1399.	0.15
2	0.10	3067.	0.15	1388.	0.20	863.	0.20
3	0.15	1388.	0.20	863.	0.25	696.	0.25
4	0.20	863.	0.25	696.	0.30	645.	0.30
5	0.25	696.	0.30	645.	0.35	636.	0.35
6	0.30	645.	0.35	636.	0.40	642.	0.35
7	0.30	645.	0.35	636.	0.40	642.	0.35
8	0.30	645.	0.35	636.	0.40	642.	0.35
9	0.30	645.	0.35	636.	0.40	642.	0.35
10	0.30	645.	0.35	636.	0.40	642.	0.35

Figure XL includes a forecast made using this procedure; the optimum value was reached after only five iterations.

Chow's method is simple to apply, although extravagant with computer time, in that each set of data must -- at least periodically -- be run three times or more in order that the most suitable smoothing constant be chosen.

ERROR MEASUREMENT AND CONTROL

If the underlying process of a time series is being traced reasonably well, errors will tend to fluctuate around a zero mean, and these fluctuations should not exceed certain limits whose extent can be determined if the underlying probability distribution can be discovered.

It is desirable to incorporate some monitoring method into the forecasting system, which should recognize when a significant change is taking place. 'Tracking' is intended to ensure that neither the size of the error, nor the extent of fluctuation above or below zero errors exceed limits established by management. Procedures must be designed to ensure a balance between the effort required to deal with random 'trips' of the signal, and the desire to detect and correct conditions causing bad forecasting. Whichever method is used, it must permit automatic recognition of statistically significant deviations, and also notify management through an exceptions report.

A trip can indicate:

1. heavy demand caused by some substantial promotional activity: swine flu vaccine in Canada in 1976-77 for example;
2. poor initial values established for the forecast, or wrong model chosen. This might happen if an item with strong seasonal demand were not programmed correctly; or
3. a heavy build-up of 'random' errors in one direction.

An economic tracking signal was devised by Brown (1963):

$$\frac{\text{Sum of forecast errors}}{\text{M.A.D.}}$$

Most applications of tracking signal controls today derive from the work of Trigg (1964) and Trigg and Leach

(1967). Trigg discovered the paradox inherent in the Brown method that, if the system commences with a good forecast the tracking signal may soon exceed limits. If the forecast is perfect, the mean absolute deviation tends toward zero, while overall sum of errors remains stable. In consequence the tracking signal will tend to infinity! He suggested that smoothed error be used in place of sum of errors:

Smoothed error: $\bar{e}_t = (1 - \alpha)$ Previous Smoothed Error $+ (\alpha)$ Latest forecast error

Smoothed MAD: $MAD_t = (1 - \alpha)$ Previous MAD $+ \alpha$ (|Latest Error|)

and the tracking signal would be:

$$P_t = \bar{e}_t / MAD_t \qquad \ldots(18)$$

Having selected a control signal, management requires assistance with establishment of control limits. One commonly used value is $\pm$ 0.55 which represents two standard deviations around the mean, with alpha of 0.10. Subsequent action to be taken will depend on inventory management policy. A rule devised by Lilly (1967) is that alpha should be doubled when the signal exceeds $\pm$ 4 (MAD) for two successive periods, and remain doubled until the signal returns within the limit.

The Trigg signal contained a flaw, recognised by Trigg and Leach (1967). When a low alpha tracking signal is used on a series, and a sudden genuine change in the underlying process occurs, the forecast will lag for a considerable time. With an adaptive forecasting system, sufficient response will be lacking since the errors arising from it will be serially correlated. The authors did not consider modification of recommended confidence limits necessary, but Batty (1969) disagreed. He considered that substantial modifications are involved, of the order of 20 percent with an alpha of 0.1. Table 47 shows an excerpt from his paper.

Table 47

TRIGG TRACKING SIGNAL

BATTY MODIFICATION

Level of Confidence %	Tracking Signal (+ or -) Alpha 0.1	0.2	0.5
80	0.29	0.40	0.64
90	0.35	0.50	0.82
95	0.42	0.58	0.88
97	0.45	0.62	0.90
98	0.48	0.66	0.92
99	0.53	0.71	0.94
100	1.00	1.00	1.00

Source: adapted from Batty (1969): table 2

Batty maintained that we should continue to monitor the forecast produced by an adaptive response system. Simulations of the response of a constant model to step changes have shown that although the model homes in to the new average fairly quickly, there is a tendency for the tracking signal to remain large, for a longer period. This will have a detrimental effect on the system's ability to filter out random noise, particularly if the constant used for smoothing the error and M.A.D. is small (say 0.05). On the other hand, a large value of alpha increases the variance of the smoothing error, somewhat defeating the object of using an adaptive response rate system.

Batty warned that tracking signal limits given in his paper cannot be used to monitor an adaptive response system. This has encouraged the adoption of the method advocated by Trigg and Leach (1976) with modification by Stone (1967):

Alpha = Modulus | Tracking Signal |.

With the recommended one period lagging of P_t, the simple exponential smoothing formula is:

$$F_{t+1} = |P_{t-1}| D_t + (1 - |P_{t-1}|) F_t \qquad \ldots(19)$$

The programme BRUFICH includes Trigg and the Trigg and Leach tracking signal methods.

Reid (1969) emphasized that: "forecasting techniques should be assessed in terms of the cost involved due to inaccurate information available to decision makers. Only that part of the cost that is directly attributable to inaccurate forecasting should be allocated to the predictive technique, and the best predictor is the one that minimizes expected cost due to forecast errors." He explained that the expected cost of using a particular forecasting method will depend not only on the cost function, but also upon the distribution of forecast errors. Brown (1973) stressed that a good system together with properly used market intelligence, is preferable to intensive efforts improve the statistical forecast; users should concentrate on the bigger errors. Brown reminded the tracking signal designer that there is no validity in evaluation of forecasts by means of measures of accuracy, since a forecast is effective only as it leads to a decision.

EXPONENTIAL SMOOTHING AND HOSPITAL DEMAND FORECASTING

Few investigations have been undertaken into the use of demand forecasting by Canadian hospitals. In the U.S.A. Raitz (1964) sampled twenty stock items from a group of surgical dressings. He used simple exponential smoothing and introduced his system experimentally, with twenty percent operating cost reductions. Davis (1966) considered the relationship between demand for surgical gloves and three variables: the total hospital census, total number of births and of operations performed. Multiple regression analysis proved unsatisfactory for short term prediction and exponential smoothing used. Experiments were undertaken with a range of smoothing constants, and base series seasonal forecasting. Since then, individual thesis work has been prepared, but little reported of relevance to the present thesis until a U.S. study by Adam *et alia* (1974). They commented that: "little difference was found between exponential and adaptive smoothing techniques on the basis of mean absolute deviation. Similarly, computer time . . . is not consistently better for one method or the other . . . By employing management science techniques the hospital administrator can improve the utilization of resources tied up in inventory. This is a direct step toward improved efficiency and toward releasing hospital administrators valuable time for devotion to problems at the top of his list."

In Canada, improved inventory management will follow development of tighter group purchasing agreements.

Thus, Hospital Purchasing Incorporated, with members among most Toronto, Ontario hospitals, purchases $10 millions of food for those members, with savings of 7 to 10 percent. The cooperative bill for all products in 1975 was $24.1 million, a seven-fold growth in dollar value since 1972. This represented 82 contracts covering food, drugs, equipment of all kinds, and assists hospitals in obtaining not only keener prices, but the purchasing strength needed to obtain the level of service given to major industrial consumers. With greater purchasing effectiveness will come the demand for better systems, and interest in adaptive forecasting as a component of inventory management will rapidly grow, and simple, easily programmed exponentially smoothed techniques should find their place.

A relevant study was made for the Department of Health and Social Security, U.K., and described by Smith (1973). Expenditure in 1972 in England and Wales on provisions, uniforms and clothing, bedding, linen etc. was £40 million. The National Coal Board Operational Research group considered a variety of stores systems and the likely differential costs. Using data from hospital ledgers, a computer-based experiment was undertaken, for the purpose of estimating manpower, operating and transport costs incurred by any type of stores organization. Table 48 shows examples of six methods, using a standard value of supplies of £2.65 million in each case. The two central stores with distribution to hospitals by group or larger area would seem to be most cost efficient. Vehicle utilization would be high, manpower operating costs would fall, and the benefits of group purchasing discounts could be

Table 48

ESTIMATED STORES COSTS BY STOREKEEPING METHOD

Cost	Group Warehouse and Hospital Sub-Stores	Area Warehouses and Hospital Sub-Stores	Hospital Stores	Regional Warehouse and Hospital Sub-Stores	Group Central Stores	Area Central Stores
	£(000) per annum					
Manpower	431	387	351	341	250	173
Operating	122	108	108	86	112	99
Transport	31	33	22	38	16	18
Total Cost	584	528	481	465	378	290

Source: NCB Operational Research Group.

more substantial.

No common policy could be established in Canada, but with an increasing proportion of the population residing in urban centres opportunities for central stores in the larger areas should be great. Cities such as Montreal, Toronto, Vancouver, Ottawa, Halifax, Winnipeg, Edmonton, and Calgary would be such centres, although it is believed that no central stores are in operation or seriously planned at present.

THE BRUFICH SIMULATION SYSTEM

The BRUFICH system has been outlined in chapter five. This section describes its major components, with particular reference to the performance of a variety of methods of exponential smoothing.

The full system was developed from work done by this writer for the department of Industrial Engineering at the Toronto Hospital for Sick Children. In cooperation with members of the department, this writer investigated both the theoretical and practical aspects of supplies and inventory management for hospitals as they are organized in Canada, and designed a system which - as a more theoretical presentation - is now called BRUFICH.

By 1972 certain elements of the system were being introduced. Statistical studies were made into inventory costs and lengths of time items were held in stock; an employee redesigned the physical layout of the stores, and an improved stock status reporting system was introduced. This writer completed his reports in 1973 and was advised that the systems engineers would be implementing the system.

Farid (1974) described the system, giving details of its implementation to date and planned.

The first stage involved computerized stock status reporting systems. Farid (*ibid.*) commented:

> Systems engineers had estimated that the stock value could be reduced by approximately 10 percent by simply reorganizing and streamlining stores operations. The actual result, however, was a gratifying 32 percent reduction . . . Stage 1 has already proved its worth.

He described plans for stage 2, involving sub-programs to calculate monthly demand forecasts, demand during lead time, economic order quantity and reorder point, and commented: "Needless to say, demand forecasting is the most important single element in the system . . . so a history of 'true' demand is essential." All requisitioned quantities (issued and back ordered) of an item constitute its demand. Since a user might reorder an item already on back order just to reconfirm the initial order, departments are instructed not to overstock and not to reorder except due to real need.

Farid hinted at a problem that this writer stressed early in his studies at the hospital: non-stores items. The greatest amount of items received into the hospital, by value, were classified as "non-stores" and the only control was departmental, through their individual budgets. Farid stated that: "the total system will be flexible enough to add other non-stores items at a later date."

In reply to a letter, the present Director of

Systems Engineering, E. Gillespie stated that: " . . . the system is fully implemented and has run successfully since the summer of 1973." He goes on to say that the hospital is now, however, converting to the business systems developed by the Hospitals' Computer Centre from South-Western Ontario. This will probably take over the inventory management procedures in 1977, but no details are available at present.

Care was taken during the preparatory stages of this investigation that data should be obtained from reliable hospital sources. The investigator visited hospitals in Toronto, Winnipeg, and Harrow (London), and recorded demand data directly from stores records. His own statistical experience was valuable for selection of sample items from the wide range of stocked goods, but in every case facilities were inadequate to permit the use of scientifically unbiased sampling techniques.

Demand forecasting and inventory control procedures in hospitals do not usually allow for the combination of similar items into groups. Many examples can be found of closely linked medical, surgical, dietary, pharmaceutical and housekeeping items. It would be possible for example, to group the sulfonamides in the pharmacy, and derive demand forecasts for the entire group. The rather specialized uses for many hospital items, each with their own storage requirements, dosage levels and different users, could make this combination system difficult to introduce. It would be a useful research undertaking for a student with permission to experiment with inventory management in the hospital.

In manufacturing and distribution there is a wide range of computer packages for inventory management. No such packages seem to be available to hospitals, other than as an adaptation of an industrial or retailing system. Hughes and Morgan (1967) investigated software, and discovered that in 1967 there was only one generalized short term package with a standard simple trend forecast. Even in 1977 true purpose-designed hospital forecasting sub-systems are rare, and BRUFICH is intended to provide the background and simulation facilities to enable such a task to be undertaken without undue difficulty.

The Forecasting Sub-system

For thesis purposes several methods of exponentially smoothed forecasting have been programmed.

In practical situations, the number of data points in a series will be limited. Computation of the first forecast values is important, but the lack of extensive past data reduces efficiency. For linear data patterns, starting values may be obtained by simple average of past demand, or by the least squares regression line method of Brown (1971); the first forecast BRUSTART, is the value obtained by extrapolation (BRUFICH reference numbers 4605-5040).[1] Since the number of data points varies from item to item, the programme adjusts the number of points to use [4625-4632].

Single smoothing procedure - using simple exponential smoothing (equation (1)). Provision is made to iterate the

---

[1]BRUFICH programme (see Appendix) line references are given in this chapter due to the length of the programme.

smoothing constants over any range of values desired (5323-5330), but alpha is made independent on the current value of Trigg's tracking signal as forecasting proceeds. If TRSIG, the unsmoothed tracking signal exceeds 4 x M.A.D. for three consecutive periods, alpha is raised by a specified amount, to be lowered three periods later - this modifies the effect of the alpha used at the beginning of the forecast (6260-6580). A second tracking signal is included: TRIGG, and described in (5740-5855). It is based upon modifications of the work of Trigg and Leach (1967) made by Batty (1969) and Shone (1967). Error measurements include mean absolute deviation, average cumulative signed error, percentage balanced error, and root mean square error. Attempts to assess the efficiency of the forecast are performed through the Theil coefficient [6610-6756]; D'Amico index of forecastability [6760-6818], Percentage balanced error [6711-6718] and Accuracy percentage [6774-6788].

Double exponential smoothing - based upon equations (3) and (6). New drugs are created and accepted by hospitals; scarcity of glass or textiles affects purchasing contracts; changes in morbidity, age structure or population concentration cause demands upon medical care to change substantially. Management in small hospitals may be aware of these changes and their influence upon demand for individual products. The larger hospital, however, will hold thousands of items in the general stores, pharmacy and catering departments; it is impossible to examine changes in trends to each of these without computer assistance. Unless influences are obviously extrinsic (such as new legislation affecting drug dispensing), a testing device should be found in the system. Two tests are those of Crowe, whose simple and robust method is programmed in [7060-7600], and of Siegel (1956) in [7660-8581]. These tests are matched [8630-8990] to assist the user in judging the true likelihood of trend.

The double smoothing routine is based upon Brown (1963), programmed in lines [10374-10385 and 51990-52225], and includes a procedure to extend the forecast through mean lead time (two and three months are actually programmed). The procedure is not adaptive and no tracking errors are calculated. The error summary consists of average cumulative signed errors, mean absolute deviation sum of signed errors and balanced errors for the current forecast and two and three months ahead.

Seasonally adjusted forecasting - Brown (1963) recommended that data with seasonal regularity should be incorporated within a model that attempts to evaluate seasonal patterns in terms of sine values. Sines can be used by assembling as many curves as seem appropriate, and adding any necessary trend. Benton (1972) observed that his approach tends to be more accurate for appropriate data than single smoothing, but not more accurate than the base index system, and is more complicated.

The method used is: "same-month last two years" base indexes, provided that 36 or more data points are available [10890-11490]. A test of seasonality has been designed based upon repetition of peaks and lows at the same months in earlier years. The smoothing constant gamma is used to smooth mean absolute deviation, and is raised adaptively if errors exceed established limits for three consecutive periods: TSSIG [13283-13347]. In this programme gamma is not iterated and seasonal forecasting is affected only by changes in alpha and beta at the beginning of each iteration.

Error evaluations included are average cumulative signed error, percentage balanced error, mean absolute deviation and root mean square error.

BRUSIM simulation - the programme includes an adaptation of a routine designed by Carter and Huzan (1973). It enables the effect of different values of alpha to be ascertained, since two tables are not adaptive. A third procedure incorporates Trigg and Leach tracking signal with Shone's amendment (1967): alpha is set to the penultimate value of the tracking signal.

Triple Exponential Smoothing - evaluations are made of this method, using a programme COMPARE, adapted from work done by Sullivan and Claycombe (1977). The routine uses formula (17) above, and measures forecasting errors by means of the root mean square errors, and average cumulative signed error.

Winters Method - included in programme COMPARE, which allows choice of the three parameters according to the operator's experience. The overall root mean square error is computed.

PERFORMANCE EVALUATION

For experimental purposes, item 88100010 Face Tissues (sequence number six) and 2129 Seasonal Pattern demand series were once again selected, and programmes BRUFICH and COMPARE were run. Forecasting errors are tabulated in chapter nine following, and compared with errors obtained in runs of other forecasting methods.

SUMMARY AND COMMENT

Programmes CHOWTEST, BRUFICH and COMPARE are included in the appendix, together with relevant output from the computer. These programmes have been designed to allow experiments to be conducted upon each method of exponential smoothing, with changes to parameters, alterations of tracking signal limits, and summaries of a variety of error and efficiency evaluations. The system as it would be applied by a hospital, could include selected methods to be used upon data series of different patterns. If one were chosen, it would be double or triple smoothing, unless the demand pattern were very stable.

Since comprehensive inventory management systems are rare or non-existent in North American hospitals, and since contributors to hospital management journals usually record successes, not failures, there is nothing available to the researcher upon which to base an evaluation of the effectiveness of exponential smoothing techniques. Indeed, such applications are uncommon in industry; Lee (1976) did comment at length on the outcome of an Air Canada forecasting system application designed to predict traffic growth.

The system incorporated a computerized, multiplicative exponentially smoothed model with provision for trend and seasonal factors. From monthly traffic returns, forecasts were made for each month through the coming two years for several hundreds of city pairs. Each month exceptions reports were provided if the system discovered substantial changes in pattern, so that smoothing parameters could be adjusted.

Although no fault was found with the simple model, it was discovered that the human component created substantial difficulties. The more able the analyst, the more likely Air Canada would promote him from the system. Two improvements were identified by Lee, the first to develop better training for new users, and the second, to provide a more sophisticated model. In 1966 only the former was feasible, and this solution did improve the situation.

Hospital inventory management will benefit from the (limited) experience of industry, but to the present, there seems little interest in modern inventory methods and consequently, simple yet seemingly sophisticated components such as exponentially smoothed demand forecasting, must remain in experimental models.

CHAPTER NINE

COMPARISON OF FORECAST PERFORMANCE AND RATIONALE FOR CHOICE

INTRODUCTION

In order to select a forecasting method for use within inventory management systems, certain performance attributes must be studied and compared. Briscoe and Hirst (1972) observed that: "many criteria in addition to basic data availability, are likely to be involved . . . the exact approach must depend on the length, frequency and reliability of alternative data sources, the amount of time and computing facilities available for generating output forecasts, the level of accuracy required and the flexibility which each convey for revising the forecasts as new or more information is obtained . . . the technique which is chosen may well be influenced by the level of knowledge and appreciation of those who produce the forecasts." The authors then advise that: "when sales forecasts are required for short periods ahead and no significant bank of historical data exists to permit a rigorous time series analysis, the application of models employing exponentially weighted moving averages is a particularly useful means of generating a forecast . . . ." A recent survey by Dalrymple (1975) of American corporations, disclosed that forecasts are used by 80 percent of finance departments, and 53 and 55 percent of purchasing and inventory management departments, respectively. Prevalent forecasting methods include use of executive opinion (52); sales forecast composite (48); trend analysis (28); moving averages (24) and survey of industrial prospects, 22 percent of corporations. Less often used are regression analysis (17); exponential smoothing (13) and simulation, 8 percent; least used is the Box-Jenkins method (1.7 percent).

In a review of Kendall (1976), O.D. Anderson (1976) commented that use of the Box-Jenkins method has developed substantially since publication of those writers' text in 1970. Anderson claimed that its use was widespread, but in correspondence with this researcher he suggested that: "if large numbers of series need to be quickly and cheaply forecast, say for stock control . . . purposes, a fully automatic adaptive forecasting method, based on exponential smoothing . . . will be preferred. But in areas where there are relatively high costs associated with forecasting errors, and there is the time and expertise to carry out a Box-Jenkins procedure, such analyses will frequently be found."

EVALUATION BY FORECAST ERROR

Several factors influence the choice of an appropriate method, as discussed by Briscoe and Hirst (supra). Kendall (1976) believes that: "the safest way to gauge the reliability of a forecasting method is to consider its performance over a period. From a suite of observed errors we can form a good empirical estimate of the error likely to be encountered in the future." Other influences which are not statistical include, ease of comprehension by hospital employees; economy of manual effort with the concomitant reduction of clerical error, and compatibility within the overall objectives of the inventory manager.

Each forecast presented in chapters six to eight is accompanied with error measurements. One indication of efficiency might be that based upon the smallest overall error, given that the method itself is feasible and acceptable to management. Four error measures have been programmed:

ACSE - average cumulative signed error.

MAD - mean absolute deviation.

PBE - percentage balanced error.

RMSE - root mean square error.

Tables are given of results from simulations upon the two items, face tissues and seasonal pattern. Wheelwright and Makridakis (1973) encourage the use of simulated data: "although many practitioners seem to feel that they can examine alternative forecasting techniques using only real data, this is not the case . . . it can be argued that synthetic data is more useful than real . . . In studying a forecasting technique, two things should be known: how well it can represent different underlying patterns and how well it can distinguish between the true pattern and randomness. Synthetic data is obviously much better in answering the first question, since a series can be generated containing no randomness at all. Even in answering the second question, synthetic data is often better because the amount of randomness can be controlled and changed experimentally."

Demand for face tissues is illustrated in figure XXIV above. It is erratic to period 36 when a substantial step occurs. This is followed by steady random demand from periods 39 to 62. Trend tests have been made, but results are confused due to the step. The Siegel runs test records a Z value of -5.0, suggesting a high probability of trend; the Crowe test is less definite - 'there is some evidence of a trend', and the Whybark test (in programme SIMPAVE) records a t value of 8.6512 at .01 (60 degrees of freedom) indicating a pattern not likely to be random. This latter test calculates deviation from a regression line and uses the t test as a measure of significance of these deviations in terms of randomness.

Table 49 displays selected results from several forecasting methods.

Satisfactory results, in low error terms, are recorded by LINFOR, moving averages, Exponential double smoothing, and Triple smoothing. The effect of high smoothing constants upon single smoothing results, is noticeable. Trend adjusted forecasting performed well but seasonal forecasting gave rise to substantial errors.

Measures of forecasting effectiveness which have been incorporated into certain programmes are the Theil measure designed by H. Theil (1961) for longer term economic forecasting; the Accuracy Percentage, and D'Amico Index of P. D'Amico (1971). Low values of the two former, and high values of the latter, suggest

Table 49

SUMMARY ERROR ANALYSIS

FACE TISSUES

Method		ACSE	PBE	MAD	RMSE
SIMPAVE		321	138%	475	705
LASTAVE		14	8	353	436
LINFOR		22	14	325	414
MOVAVE		24	18	265	304
MOVETREND		20	18	230	284
EXPONENTIAL SMOOTHING:					
Single smoothing	α = 0.1	160	88	363	472
	0.3	89	55	322	422
	0.5	48	30	315	380
Double smoothing	0.1	56	33	339	444
	0.3	11	6	351	451
	0.4	10	6	373	456
Seasonal	0.1	53	30	442	569
	0.3	38	22	434	572
	0.4	36	21	437	606
BRUSIM:					
No trend	0.1	183	--	355	456
	0.3	69	--	289	--
	0.5	43	--	279	397
Trend	0.1	162	--	340	427
	0.5	34	--	280	373
Adaptive		49	--	300	414
COMPARE:					
Regression		--	--	--	406
Single smoothing	α = 0.1	191	--	--	454
	0.3	74	--	--	392
Double smoothing	0.1	63	--	--	388
Triple smoothing	0.1	14	--	--	392
Winter's seasonal		55	--	--	543

effective forecasting capability. Table 50 shows results for the face tissues run.

Table 50

FORECASTING EFFECTIVENESS

FACE TISSUES

Method		Theil Coefficient	Forecastability Index	Accuracy Percentage %
SIMPAVE		0.20	2.4	26.5
LASTAVE		0.12	4.0	19.9
LINFOR		0.09	15.6	20.4
MOVAVE		0.10	--	15.0
MOVETREND		--	--	13.0
EXPONENTIAL:				
Single	α = 0.1	0.12	4.5	27.0
	0.3	0.11	2.4	51.1
Double	0.1	--	--	25.3
	0.5	--	--	29.9
Seasonal	0.1	0.10	--	--

Moving averages and high alpha single smoothing methods are recognized as effective by these tests.

Similar records have been kept for item 2129 and are displayed in tables 51 and 52.

The trend tests were run. Whybark resulted in a t value of 3.6633 (.01) with 64 degrees of freedom, suggesting the data is not random (tabular value 2.660), but the two runs tests agree that there is little evidence of a trend (Z = -1.37). The seasonal test used in BRUFICH naturally recognizes a high likelihood of a seasonal pattern.

Since seasonal data is not common in hospital demand for supplies, the methods to be selected would seem to be moving averages, double or triple exponential smoothing.

Table 51

SUMMARY ERROR ANALYSIS

ITEM 2129: SEASONAL PATTERN

Forecasting Method		ACSE	PBE	MAD	RMSE
SIMPAVE		9.2	74.0%	22	39
LASTAVE		0.1	0.5	35	44
LINFOR		0.4	4.0	23	29
MOVAVE		1.9	13.4	28	31
MOVETREND		0.5	4.9	23	29
EXPONENTIAL SMOOTHING:					
Single smoothing	α=.1	7.1	49.0	30	38
	.3	2.6	17.0	31	38
Double smoothing	.1	1.7	11.0	31	39
Seasonal	.1	3.3	49.0	19	57
BRUSIM:					
No trend	.1	9.6	--	29	35
Trend	.1	8.9	--	29	35
Adaptive		8.1	--	30	35
COMPARE:					
Single Moving Average		2.6	--	--	36
Single smoothing	α=.1	4.2	--	--	34
	.3	1.4	--	--	36
Double smoothing	.1	1.4	--	--	34
Triple smoothing	.1	0.1	--	--	36
Winter's seasonal		1.5	--	--	28

Compared with table 50, almost all the values in table 52 suggest lower forecasting ability, though the Theil Coefficient indicates that seasonal forecasting should perform satisfactorily.

Figures XLII and XLIII illustrate forecasts produced by several methods described earlier.

The CHOWTEST procedure indicated that a smoothing constant of 0.35 would be best both for face tissues

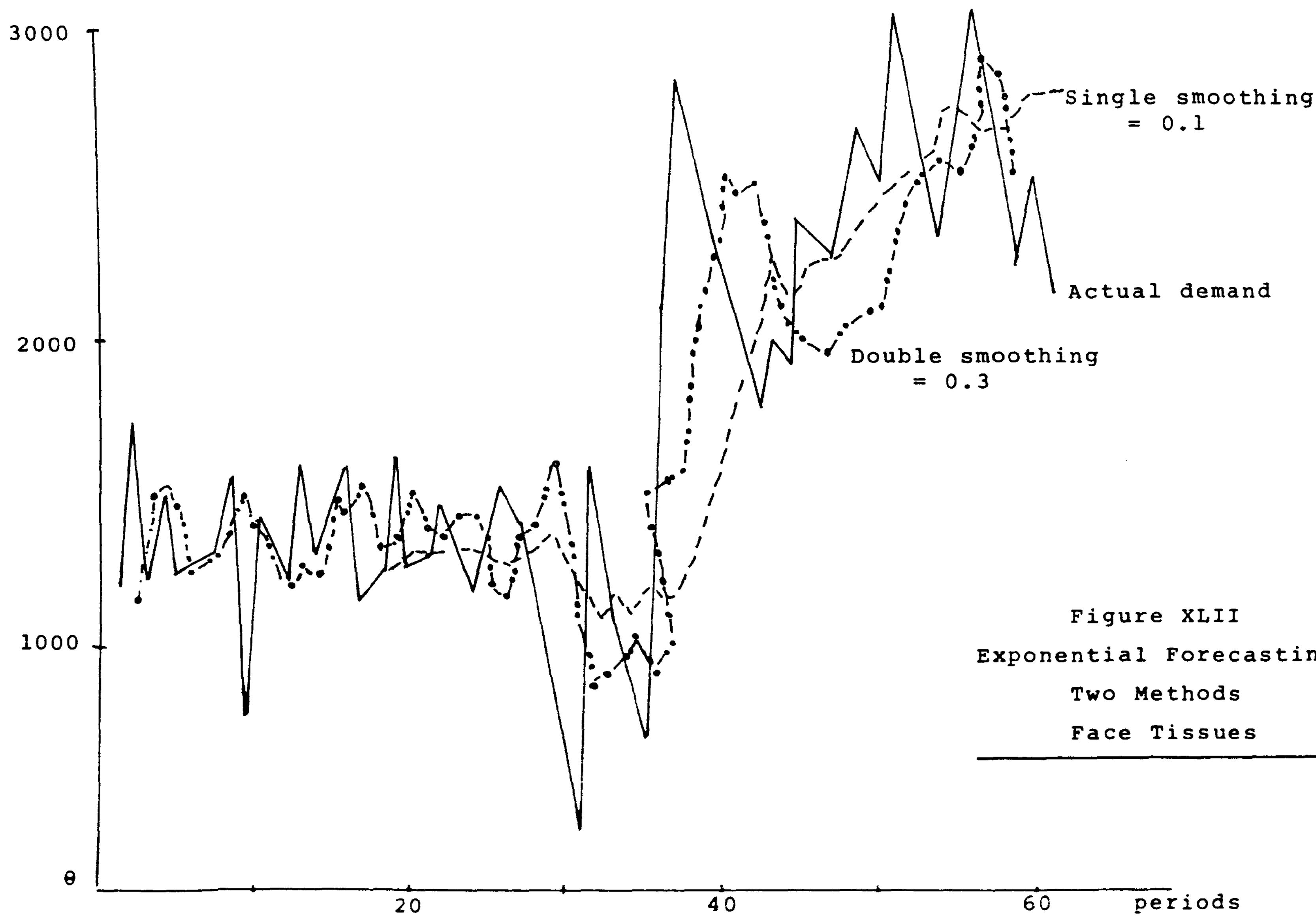


Figure XLII
Exponential Forecasting
Two Methods
Face Tissues

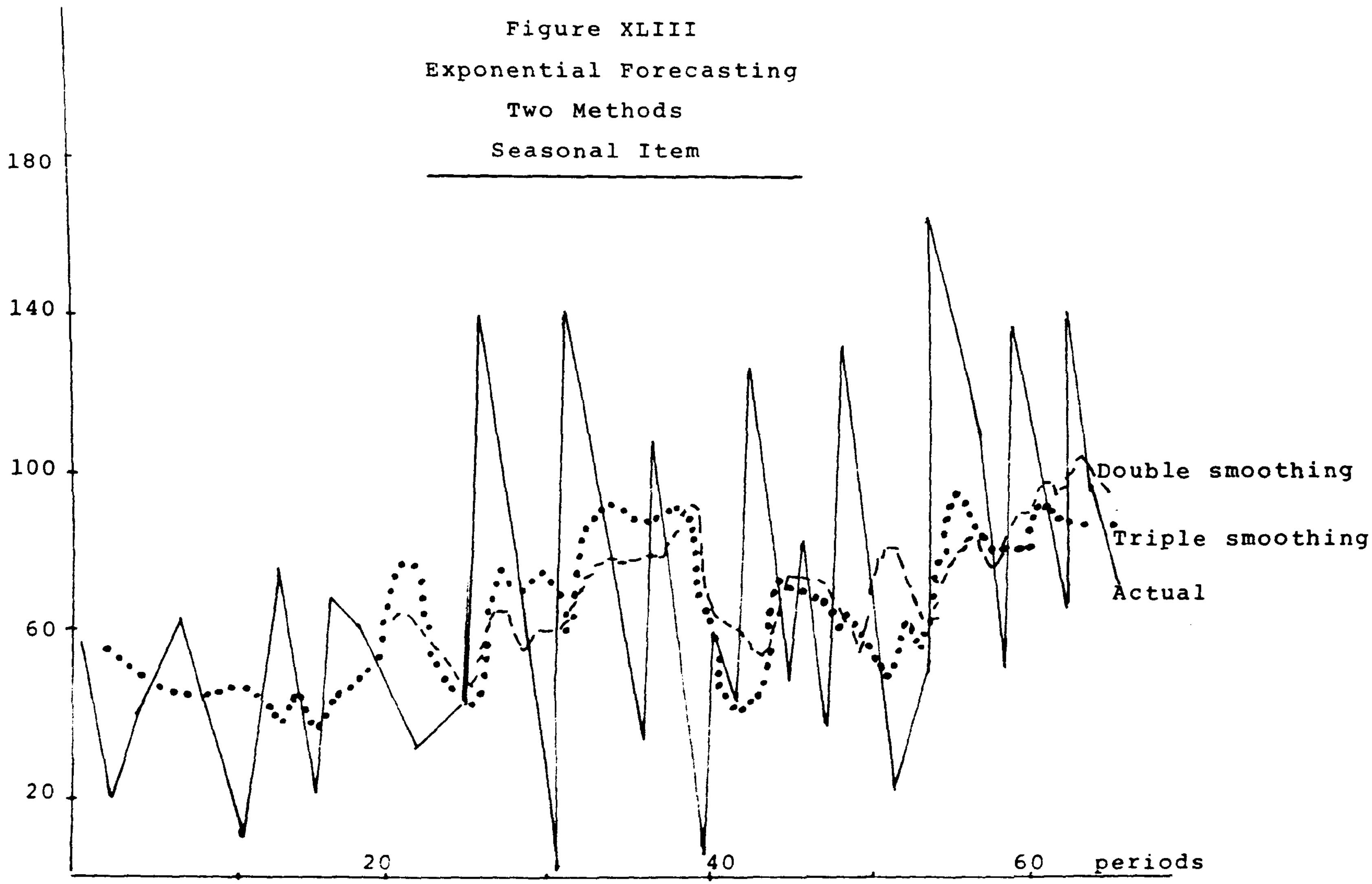


Figure XLIII
Exponential Forecasting
Two Methods
Seasonal Item
180
140
100
60
20
20
40
60
periods
Double smoothing
Triple smoothing
Actual

Table 52

FORECASTING EFFECTIVENESS

ITEM 2129: SEASONAL PATTERN

Method	Theil Coefficient	Forecastability Index	Accuracy Percentage
			%
SIMPAVE	0.27	1.8	51.1
LASTAVE	0.29	1.5	52.8
LINFOR	0.19	7.6	37.9
MOVAVE	0.24	--	41.9
MOVETREND	--	--	34.6
EXPONENTIAL:			
Single $\alpha = .1$	0.25	2.1	59.7
Double .1	--	--	63.2
Seasonal .1	0.10	--	--

and the seasonal item. This would seem to be confirmed in tables 49 and 51 above.

To demonstrate the spread of errors, a programme: RESTRAIN has been written, comprising statistical control methods used by industry. The programme is included in the appendix; it is based upon use of standard error limits around the mean of zero forecasting error. Since normal industrial tolerances are not applicable to this data, the standard error of the mean of the first 19 months is chosen as basis, to be multiplied by K factors 2 or 3 as desired by management. To allow for probable changes of demand pattern, an arbitrary reevaluation is undertaken at month 40.

Figures XLIV and XLV show the patterns of signed errors in relation to standard error controls. In practice the charts would be used dynamically, and management intervention would prevent the large deviations shown in

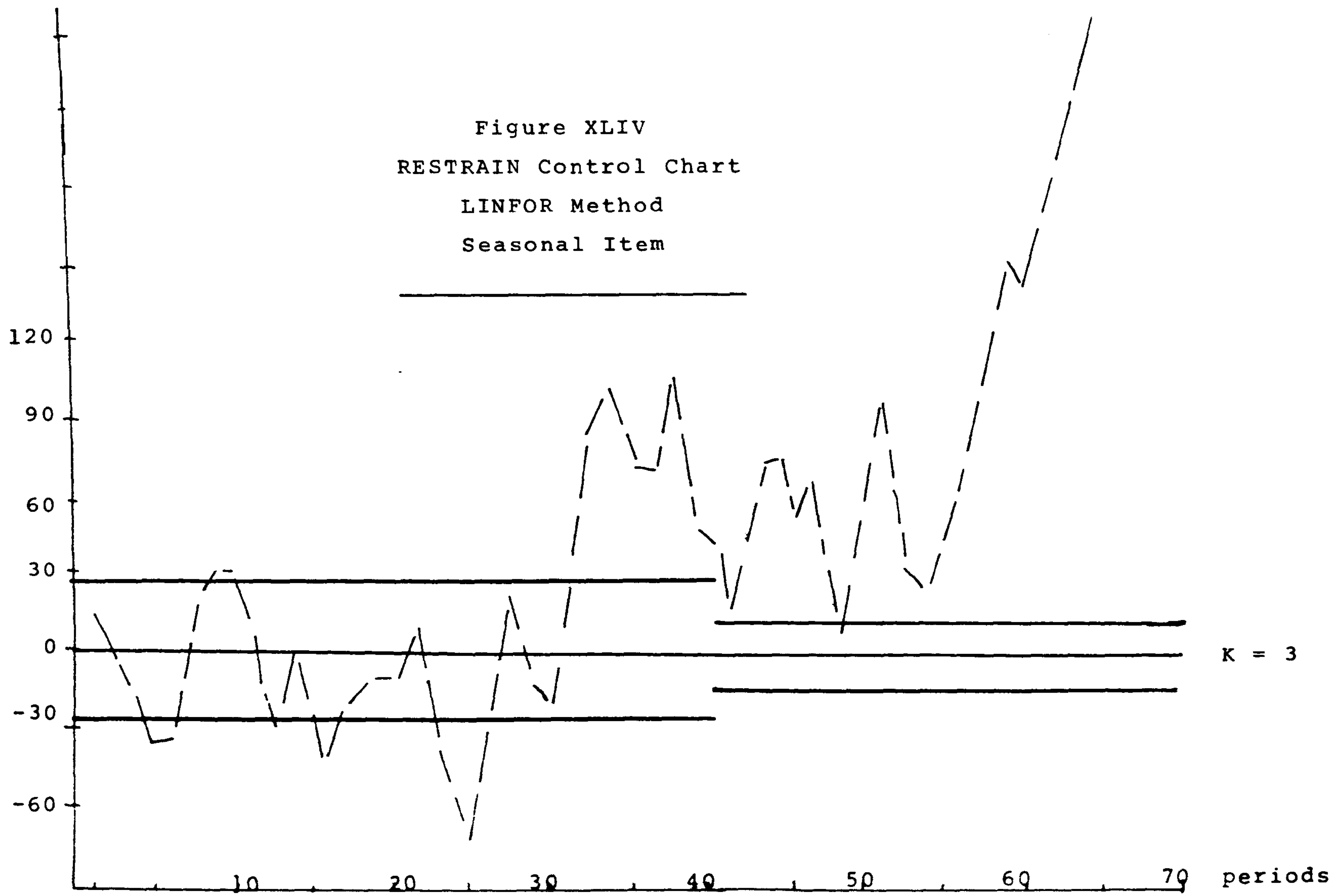


Figure XLIV

RESTRAIN Control Chart

LINFOR Method

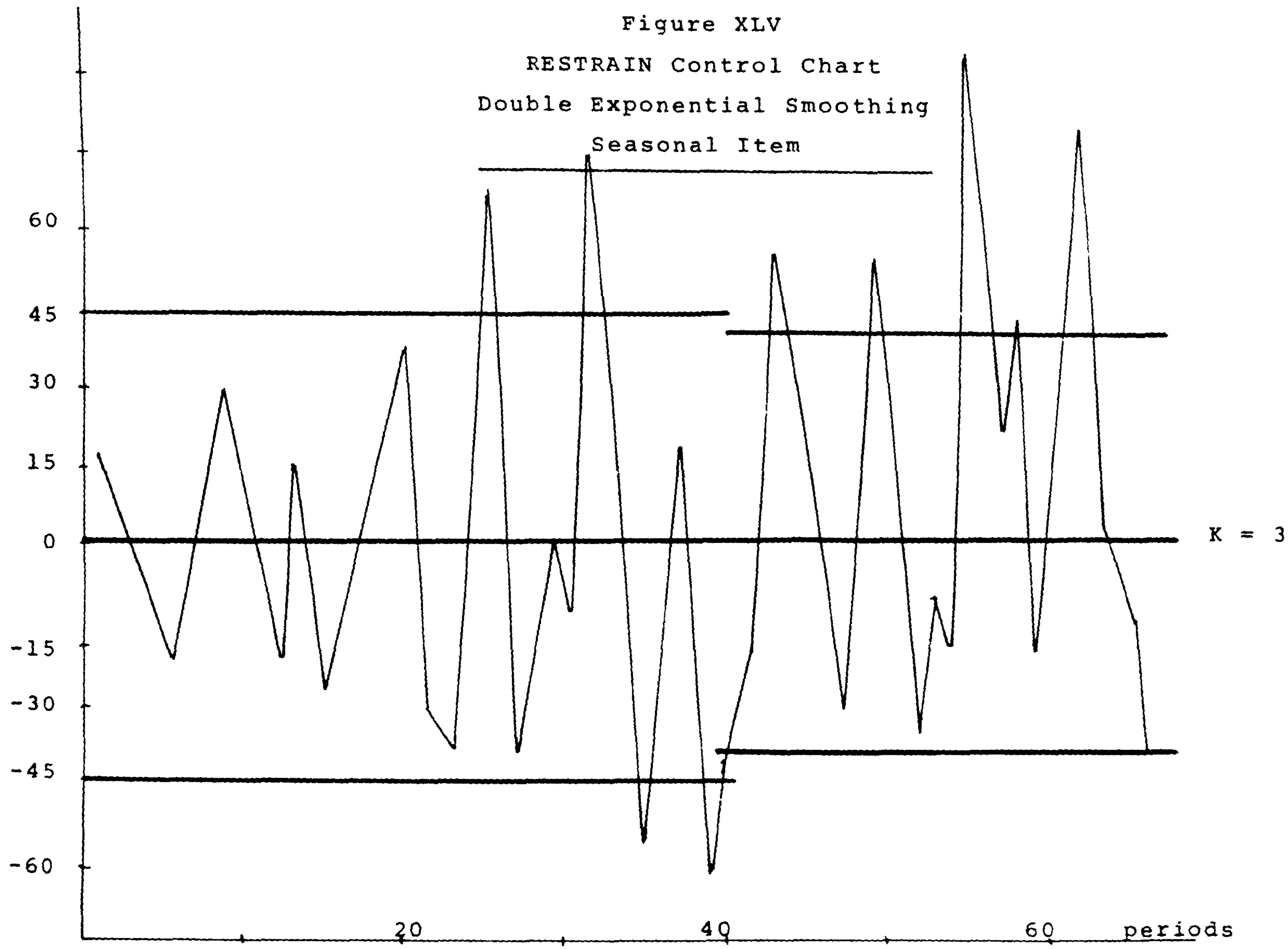
Seasonal Item

Figure XLV

RESTRAIN Control Chart

Double Exponential Smoothing

Seasonal Item



these charts.

In figure XLIV the erratic pattern of errors arising from the LINFOR method are clearly demonstrated. In contrast, figure XLV shows the more regular pattern of errors from double smoothing, contained by the three standard error limits. In this chapter, the method serves to emphasize differing capabilities of various methods of forecasting.

When a study was undertaken of the entire sample, it was discovered that almost 50 percent of the lowest average cumulative signed errors arose from use of moving average methods. Double and triple exponential smoothing performed well although less than twenty percent of the items were identified as being influenced by trend. Of all series of 26 data points or more, only eight showed evidence of seasonal regularity. From this and other experience gained through examination of stores records in several hospitals, it is considered that an appropriate forecasting method should have the facility of coping with trend and seasonal patterns, but should be most suited to regular, erratic demand data.

Analysis of the three forecasting effectiveness tests confirmed that moving average and double exponential smoothing methods performed best of all the experimental methods.

INVENTORY SENSITIVITY AND DEMAND FORECASTS

Although most Canadian hospitals lack data processing facilities needed by even a basic inventory management system, planning must be undertaken on the assumption that such requirements would be made available upon proof of need. Health care costs and benefits are concerns of high political profile in 1977 in Ontario. Joan Hollobon (1975) wrote: "determining true hospital costs is impossible because the health system has no cost accounting similar to industry's . . . an economist said that detailed cost accounting virtually went out the window when hospital insurance came in. While hospitals can tell costs overall, they have difficulty differentiating between different types of patients."

Despite the above accurate observations, an attempt is made to assess the effect of forecasting methods upon the system. This writer designed the programme INVENT as a simple means of studying the effect of each component upon the others, namely costs, economic order quantity and reorder point (including safety stocks). The programme and output is found in the appendix.

The first procedure is an analysis of economic order quantity, using annual demands based on the monthly forecasts generated by different methods, each extended to a yearly basis. Table 53 shows the effect of these demands upon total annual inventory costs (excluding discounts). Certain assumptions are made:

(a) if there would be a shortage due to an inadequate demand forecast, this is expedited at a premium of twice the usual line order cost;

(b) if a surplus of an item is maintained in stock, additional holding costs are charged, based on average demand and number of months involved.

Basic assumptions are: holding cost of 24 percent; ordering cost of $20 and purchase price per box of face tissues of $1.19.

LASTAVE, moving average and triple smoothing have similar costs to those arising from perfect knowledge (actual demand). Most extreme penalties were incurred by Box-Jenkins and SIMPAVE methods.

A similar analysis was conducted for item 2129, and presented in table 54. Holding cost of 24 percent, order cost of $20 and price of $12.75 were used in the programme.

The data is seasonal. Single exponential smoothing and moving average methods approximate to actual costs; Winters and exponential seasonal methods show greatest discrepancies. If a hospital stores contained many items affected by seasonal demand, greater efforts would be required than have been possible in this study, to produce a forecasting method that would track actual demand more effectively.

An analysis was undertaken using INVENT, of item 43: Gypsona bandage, using actual demand and nine forecasting methods. Holding and ordering costs used, were 24 percent and $10, and the purchase price was $6.80.

Actual demand data was erratic to period 30, with a slow but definite upward trend to period 60. All trend

Table 53

DEMAND FORECASTING, E.O.Q. AND COSTS

FACE TISSUES

Method	Forecast (Annual)	E.O.Q.	No. of Orders	$ Order Cost	$ Holding Cost	$ Shortage Costs	$ Overage Costs	$ Total Cost
Actual	30218	2121	14.3	285	285	--	--	570
SIMPAVE	20389	1742	11.7	234	234	226	--	694
LASTAVE	30796	2141	14.4	288	288	--	2	578
MOVETREND	30691	2137	14.4	288	288	--	2	578
Box-Jenkins	37563	2364	15.9	318	318	--	90	726
Single Sm.	29514	2096	14.1	282	282	40	--	604
Double Sm.	28825	2071	13.9	278	278	40	--	596
Triple Sm.	30211	2120	14.3	285	285	--	--	570
BRUSIM:								
No trend	27532	2024	13.6	272	272	80	--	624
BRUSIM:								
Adaptive	30063	2115	14.2	284	284	40	--	598

Table 54

DEMAND FORECASTING, E.O.Q. AND COSTS

ITEM 2129: SEASONAL PATTERN

Method	Forecast (Annual)	E.O.Q.	No. of Orders	$ Order Cost	$ Holding Cost	$ Shortage Costs	$ Overage Costs	$ Total Cost
Actual	1191	88.2	13.5	135	135	--	--	270
SIMPAVE	795	72.1	11.0	110	110	100	--	320
LINFOR	889	76.2	11.7	117	117	80	--	314
MOVAVE	1047	82.7	12.7	127	127	40	--	294
Single Sm.	1023	81.8	12.5	125	125	40	--	290
Seasonal	856	74.8	11.4	114	114	80	--	308
Regression	1053	83.0	12.7	127	127	40	--	294
Winters	1370	94.6	14.5	145	145	--	46	326
BRUSIM:								
No trend	988	80.4	12.3	123	123	51	--	297
BRUSIM:								
Trend	997	80.7	12.3	124	124	48	--	296

Table 55

DEMAND FORECASTING, E.O.Q. AND COSTS

GYPSONA BANDAGE

Method	Forecast (Annual)	E.O.Q.	No. of Orders	$ Order Cost	$ Holding Cost	$ Shortage Costs	$ Overage Costs	$ Total Cost
Actual	108	36.4	3.0	29.60	29.60	--	--	59
MOVAVE	99	34.8	2.8	28.40	28.40	20	--	77
MOVETREND	110	36.7	3.0	30.00	30.00	10	--	70
LINFOR	94	33.9	2.8	27.70	27.70	20	--	75
Single Sm.	103	35.5	2.9	29.00	29.00	12	--	70
Trend Sm.	107	36.2	2.9	29.55	29.55	--	--	59
Double Sm.	108	36.4	3.0	29.68	29.68	--	--	59
Seasonal	124	39.0	3.2	31.80	31.80	--	30	93
BRUSIM:								
Trend .3	107	36.2	3.0	29.55	29.55	--	--	59
BRUSIM:								
Adaptive	106	36.0	2.9	29.40	29.40	10	--	69

adjusted methods (except MOVETREND) were effective; the highest cost was incurred by seasonal forecasting.

Important 'subjective' difficulties would be involved in a decision as to the preferred forecasting system, including:

(a) the effect on health care and medical efficiency caused by unexpected shortages of medical/surgical supplies;

(b) losses due to expired usage dates, and obsolescence caused by over-stocking.

Most hospital managers 'choose' to overstock, indicating that alternative (a) is regarded more seriously than (b).

The second INVENT routine deals with the reorder level, and is intended to show the variability in this caused by changes in desired service levels. Holding and order costs are held constant, and single exponential smoothing used. The reorder point method used is that of R. G. Brown, using an approximation of Parr (1972) corrected by Crowe (private correspondence, 1972). Parr's method gives rather tighter results than Brown's interpolation method.

The programme permits incorporation of a variety of lead times, and in practice the stores manager would be required to maintain a record of recent lead times. The effect of several lead times is displayed in the computer output.

The concept of service level causes difficulties, and this programme is intended to assist understanding, by means such as figure XLVI. Although extended lead times require higher reorder points, safety stocks may be

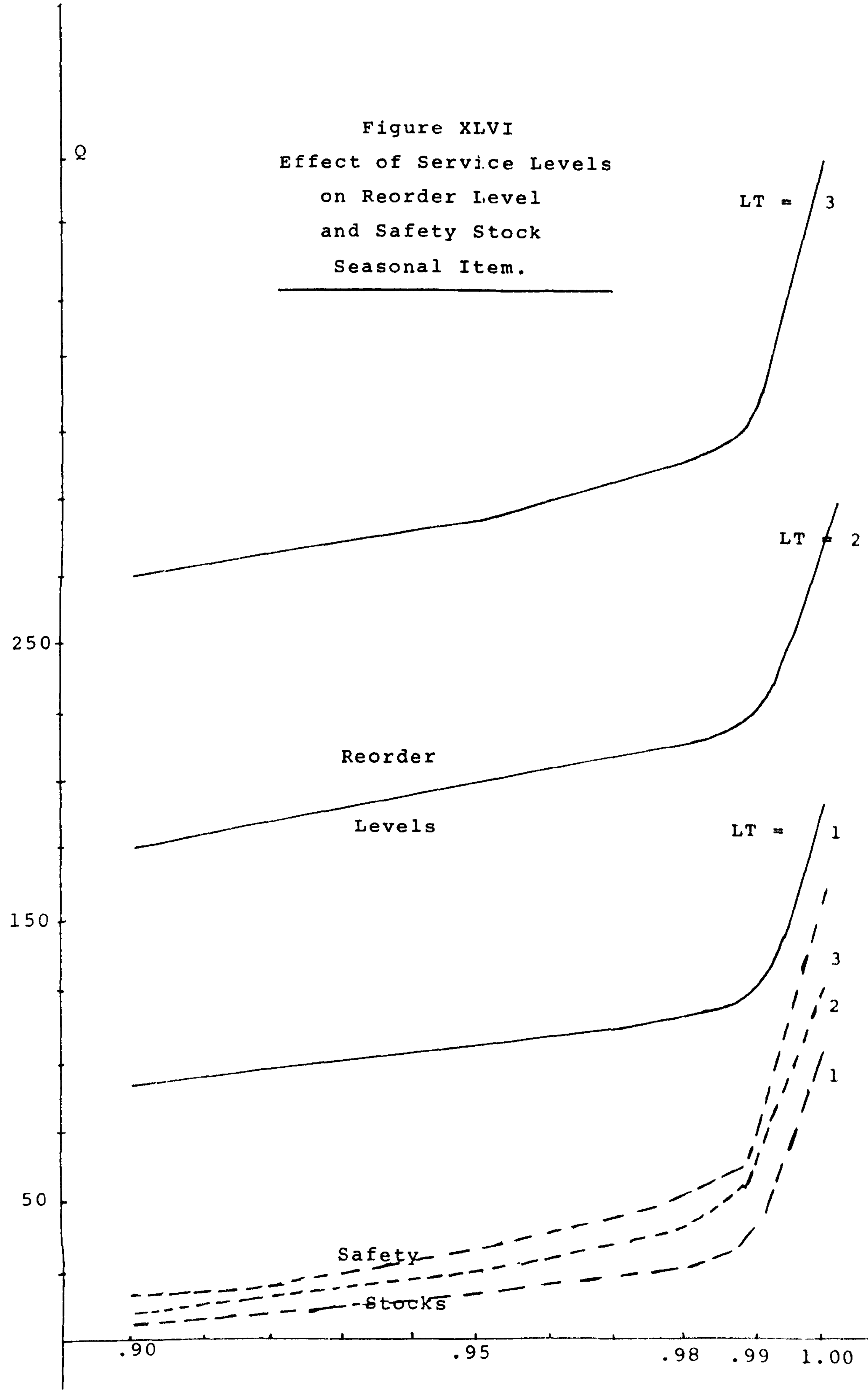


Figure XLVI
Effect of Service Levels
on Reorder Level
and Safety Stock
Seasonal Item.

kept low. However, once 98 percent or higher service levels are demanded, quantities involved rise rapidly.

Section three of INVENT is based upon fixed lead time, holding and order costs; economic order quantity and reorder point calculations are made using a variety of forecasting techniques.

Tables 56 and 57 are excerpted from the programme to show the effect on safety stocks and reorder point of different forecasting methods.

Table 56

DEMAND FORECASTS AND SAFETY STOCKS

FACE TISSUES

Method	Annual Demand	E.O.Q.	M.A.D.	Safety Stock	Reorder Point
Actual	30218	2121	0	0	2517
SIMPAVE	20389	1742	479	400	2099
LASTAVE	30796	2141	353	109	2676
MOVETREND	30691	2137	229	0	2515
Box-Jenkins	37563	2364	578	416	3546
Single Sm.	29514	2096	291	34	2493
Double Sm.	28825	2071	363	136	2538
Triple Sm.	30211	2120	319	66	2584
BRUSIM No trend	27532	2024	355	133	2428
Adaptive	30063	2115	300	43	2548

For these tables, lead time is assumed to be 1.5 months, holding cost 24 percent and service level 95 percent. Safety stocks range from zero (MOVETREND forecasting) to highs of 400 and 416 for SIMPAVE and Box-Jenkins, for face tissues. The latter would cause much higher reorder levels, without providing improved service. Satisfactory safety stocks would arise from use of adaptive methods, single and triple smoothing.

Table 57

DEMAND FORECASTS AND SAFETY STOCKS

SEASONAL PATTERN

Method	Annual Demand	E.O.Q.	M.A.D.	Safety Stock	Reorder Point
Actual	1191	125	0	0	99
SIMPAVE	795	102	25	18	85
LINFOR	889	108	25	17	91
MOVAVE	1047	117	28	20	107
Seasonal	856	106	24	15	86
Single Sm.	1023	116	29	22	107
Regression	1053	117	27	18	106
Winters	1370	134	29	18	132
BRUSIM No trend	988	114	29	22	104
Trend	997	114	30	23	106

Similar results are shown in table 57, seasonal pattern. Best performance is given by seasonal exponential smoothing, LINFOR, and Regression; least satisfactory are BRUSIM Trend and Single smoothing. Winters seasonal method requires low safety stock but reorder point is high due to large annual demand forecast.

The range of reorder points due to different service levels is shown in table 58, for face tissues.

Table 58

REORDER POINT SENSITIVITY

TO SERVICE LEVELS

	0.90	0.95	0.98	0.99
Actual	2517	2517	2517	2517
SIMPAVE	1750	2098	2466	2708
LASTAVE	2387	2676	2990	3179
MOVETREND	2313	2515	2743	2881
Box-Jenkins	3113	3546	4005	4300
Single Sm.	2248	2494	2765	2928
Double Sm.	2245	2538	2856	3049
Triple Sm.	2318	2583	2875	3049
No trend	2142	2428	2738	2927
Adaptive	2296	2548	2826	2993

SUMMARY AND CONCLUSIONS

The above analyses will assist in the selection of suitable forecasting methods. Anyone, with the current exception of Box-Jenkins, can be incorporated into the BRUFICH system. This, in turn, could become a subroutine of an entire inventory management and supplies system of a large hospital or health sciences centre.

Although demand patterns differ, analysis by this researcher suggests that seasonal regularity is uncommon; and trend movements affect few demand items. Results of analysis and effectiveness measures indicate that moving averages and double smoothing give most satisfactory results when judged by error size. Since the moving averages involve storage of complete history of demands for each item, and calculations of some complexity every month, it is recommended that double exponentially smoothed averages be most commonly used, with seasonal method available for items thus identified.

In general, hospital supplies managers do not use statistical forecasting, nor are computer facilities easily available to them. Materials managers arrive at most inventory decisions by use of experience and judgment. Rules of thumb take on an aura of scientific method, and the more elaborate, mathematically-based procedures are ignored or resisted, unless they can be adopted at reasonable cost and without substantially enhanced effort.

It can be argued that managers need not be aware of its technology to use modern processes. The response is that no system can be relied upon unless the manager has insight into, and an appreciation of the objectives and restraints appertaining to the models. It cannot be held that hospital environments are unconducive to modern technology. Clinical and commercial applications of computers have been welcomed and developed by many health institutions. Every hospital executive requires information, in order to evaluate the costs and benefits of alternative strategies; it is being realised that complex systems can satisfactorily enhance the decision process, and assist in the control function.

There exists no comprehensive and coordinated management information system for health service institutions. Its objectives would require careful definition, but would certainly include procedures to ensure that the impact of high cost activities were reduced. This would include more effective patient monitoring and control over length of stay; properly designed and widely disseminated medical records, and improvements to waiting list control and patient scheduling. Better methods of supplies management would be a required feature of such an M.I.S. Housley (1974) observed that: "in recent years there has been an increasing interest in the utilization of supplies and services in the hospital. In the past, too much emphasis was placed on just having supplies on hand, without regard for the method, volume, price paid or utilization process. With more and more controls being placed on hospitals, there is realization of a very definite need to scrutinize the entire acquisition, utilization and disposition cycle to decrease or maintain costs in this highly inflationary area."

It is believed that this research makes a worthwhile contribution to health management development in Canada. Forecasting methods that are simple to understand, and easy to incorporate within the supplies routine, facilitate control of the economic order quantity, discount decisions and reorder level management. Based on experience within actual hospitals, and on the results of experiments with real data, it is considered that the efforts involved in the design, testing, implementation and adoption processes are beneficial and advantageous; BRUFICH will raise standards of performance of the Canadian hospital materials manager.

REFERENCES

Adam, E.A., Berry, W.L. and Whybark, D.C. 1972. Forecasting Demand for Medical Supply Items Using Exponential and Adaptive Smoothing Models. Paper 381. Krannert Graduate School of Industrial Administration, Purdue University.

Adam, E.A., Berry, W.L. and Whybark, D.C. 1974. The Hospital Administrator and Management Science. Hospital Administration. 19(1):30-41.

American Production and Inventory Control Society. 1974. State of the Art Survey: A Preliminary Analysis. Production & Inventory Management. 15(4):1-11.

Ammer, Dean S. 1975. Purchasing and Materials Management for Health Care Institutions. Lexington: D.C. Heath.

Anderson, O.D. 1976. Review of M. Kendall, Time Series (Griffin). The Statistician. 25:309.

———————. 1977. The Interpretation of Box-Jenkins Time Series Models. The Statistician. 26:127-145.

Anderson, T.W. and Darling, D.A. 1952. Asymptotic theory of certain goodness of fit criteria based on stochastic processes. The Annals of Mathematical Statistics. 23:193-212.

Baer, J. 1967. "An Inquiry into Computers in Hospitals." Unpublished doctoral thesis, New York University.

Batty, M. 1969. Monitoring an Exponential Forecasting System. Operational Research Quarterly. 20:319-325.

Benton, W.K. 1972. Forecasting for Management. Reading: Addison-Wesley.

Berman, H.J. 1968. "Ratio Analysis: A Technique for Financial Management in Hospitals." Unpublished M.H.A. thesis, University of Michigan.

Berman, H.J. and Weeks, L.E. 1971. The Financial Management of Hospitals. Ann Arbor: University of Michigan Press.

Bodenham, K.E. and Wellman, F. 1972. Foundations for health service management. London: Oxford Universities Press.

Box, G.E.P. and Jenkins, G.M. 1962. Some Statistical Aspects of Adaptive Optimization and Control. Journal of the Royal Statistical Society, B. 24:297-343.

______________. 1964. An Analysis of Transformations. Journal of the Royal Statistical Society, B. 26:211.

______________. 1968. Some Recent Advances in Forecasting and Control. Applied Statistics. 17:91.

______________. 1970. Time Series Analysis, Forecasting and Control. San Francisco: Holden-Day.

Briscoe, G. and Hirst, M. 1972. An Appreciation of Alternative Sales Forecasting Models: recent techniques based on historical data. Paper 32. Centre for Industrial, Economic and Business Research, University of Warwick.

Brown, R.G. 1959. Statistical Forecasting for Inventory Control. New York: McGraw-Hill.

______. 1963. Smoothing, Forecasting and Prediction of Time Series. Englewood Cliffs: Prentice-Hall.

______. 1967. Decision Rules for Inventory Management. New York: Holt, Rinehart & Winston.

______. 1971. Management Decisions for Production Operations. Hinsdale: Dryden Press.

______. 1973. "Short Term Forecasting." Lecture given at the London Graduate Business School, October 30, 1973.

Buchan, J. and Koenigsberg, E. 1963. Scientific Inventory Management. Englewood Cliffs: Prentice-Hall.

Canada, Government of. Ministry of National Health and Welfare. 1970. Task Force Reports on the Cost of Health Services in Canada: Volume 2, Hospital Services. Ottawa.

Canada, Government of. Health Division, Statistics Canada. 1976. Hospital Statistics. Ottawa.

Canada, Government of. 1976. Report of the Superintendent of Bankruptcy for the year ended March 31, 1975. Ottawa.

Careless, J.M. 1965. Canada, a Story of Challenge. Toronto: MacMillan.

Carter, L.R. and Huzan, E. 1973. Practical Approach to Computer Simulation in Business. London: Allen & Unwin.

Chase, R.B. and Aquilano, N.J. 1973. Production & Operations Management. New York: Irwin Dorsey.

Chatfield, C. and Prothero, D.L. 1973. Box-Jenkins seasonal forecasting: problems in a case study. Journal of the Royal Statistical Society, A. 136:295.

Chen, M.M. and Bush, J.W. 1976. Maximizing Health System Output with Political and Administrative Constraints Using Mathematical Programming. Inquiry. 13(3):215-227.

Chen, M.M., Bush, J.W. and Zaremba, J. 1974. "Effectiveness Measures," Operations Research in Health Care, ed. L.J. Shuman et al. Baltimore: The John Hopkins University Press.

Chow, W.M. 1965. Adaptive Control of the Exponential Smoothing Constant. The Journal of Industrial Engineering. 5:314-317.

Collier, D.A. 1975. Lead Time Analysis for Purchased Items. Production & Inventory Management. 16(1): 25-34.

Conover, W.J. 1971. Practical Nonparametric Statistics. New York: Wiley.

Craddock, J.M. 1967. An Experiment in the Analysis and Prediction of Time Series. The Statistician. 17(3): 257-268.

Crowe, W.R. 1973. The Management and Control of Inventories in Hospitals. Hospital Administration in Canada. 18:36-37.

__________. 1976. Modern Hospital Inventory Management: How Modern? Hospital Administration in Canada. 18: 36-37.

Dalrymple, D.J. 1975. Sales Forecasting Methods and Accuracy. Business Horizons. 18 (December):69-74.

D'Amico, P. 1971. Forecasting System uses Modified Smoothing. The Journal of Industrial Engineering. 11:15-20.

Dancer, R. and Gray, C. 1977. An Empirical Evaluation of Constant and Adaptive Forecasting Models for Inventory Control. Decision Sciences. 8:228-238.

Davis, E.D. 1966. "Forecasting the Demand for Surgical Gloves." Hospital Industrial Engineering. ed. H.E. Smalley. New York: Reinhold.

Dickie, H.F. 1951. A.B.C. Analysis shoots for dollars. Factory Management and Maintenance. 109:92-94.

Draper, N.R. and Smith, H. 1966. Applied Regression Analysis. New York: Wiley.

Duke, J.D. 1973. How much does it really cost? Hospitals, J.A.H.A. 47:114-119.

Duncan, I.B. and Norwich, H.S. 1973. Opportunity Costs and Elementary Inventory Theory in the Hospital Service. Operational Research Quarterly. 24(1):27-34.

Edmands, C.D., Schutta, A. and Daly, D. 1976. Processing for a Multi-unit Hospital Complex. Hospital Topics. 54(2):25-29.

Farid, A. 1974. Computerized inventory control . . . is it worth it? Hospital Administration in Canada. 16(1): 52,56.

Fearon, H. 1969. Inventory Management: Survey and Analysis of Current Practice in 55 Hospitals. Hospital Progress. 40:85.

Fox, K.A. 1968. Intermediate Economic Statistics. New York: Wiley.

Gandy, P.W. 1971. "Scientific Inventory Management for Hospitals." Unpublished M.H.A. thesis, Washington University.

Garrett, R.D. 1973. Hospitals - a systems approach. New York: Petrocelli.

Geoffrion, A.M. 1962. A Summary of Exponential Smoothing: Comparative System Analysis. Operational Research Quarterly. 25:421-435.

Gibbons, J.D. 1971. Nonparametric Statistical Inference. New York: McGraw-Hill.

Gleason, J.M. 1971. A Computational Variation of the Wagner-Whitin Algorithm: an alternative to the E.O.Q. Production & Inventory Management. 12(1):15-22.

Great Britain. 1966. Committee on Hospital Supplies Organization, Report. London.

Great Britain. Central Health Services Council. 1954. Final Report of the Committee on Hospital Supplies. London.

Gronogo, A.W. and Woodgate, D.J. 1971. Index for Measuring Health. The Lancet. 7732:1024-1026.

Gue, R.L. and Freeman, J.R. 1975. "Information Systems," Operations Research in Health Care, ed. L.J. Shuman et al. Baltimore: The John Hopkins University Press.

Hadley, G. and Whitin, T.M. 1963. Analysis of Inventory Systems. Englewood Cliffs: Prentice-Hall.

Hollobon, J. 1975. Editorial. The Globe and Mail (Toronto), October 2, 1975, p. 4.

Holt, C.C. 1957. Forecasting Seasonals by Exponentially Weighted Moving Average. O.N.R. Memorandum 52, Carnegie Institute of Technology.

Holt, C.C., Modigliani, F. and Simon, H.A. 1960. Planning Production, Inventories and Work Force. Englewood Cliffs: Prentice-Hall.

Hospital Administration in Canada. 1975. What's Ahead in Purchasing? Hospital Administration in Canada. 17:39-45.

Housley, C.H. 1974. Provocative Approaches to Material Management. Dimensions in Health Service. 51(10):32.

Hughes, P.A.B. and Morgan, N.B. 1967. The Use of Computers in Forecasting. The Statistician. 17:283-284.

Hyman, S. and Day, P. 1970. Hospital Supplies and Suppliers. London: Kingston Polytechnic.

I.B.M. 1967. Basic Principles of Wholesale IMPACT - Inventory Management Program and Control Techniques. Report E20-8105.1. New York: International Business Machines.

I.C.I. 1965. Short Term Forecasting. Statistical Monograph 2. London: Oliver & Boyd.

Ingrando, D. 1972. "An Investigation into the effects of Exponential Smoothing and Economic Order Quantity on a Hospital Inventory Investment." Unpublished thesis, Trinity University.

Jones, T.A. 1969. Skewness and Kurtosis as criteria of normality in observed frequency distributions. Production Research Report 69-5. London: Esso Limited.

Kaimann, R.A. 1968a. The Fallacy of E.O.Q.'ing. Production & Inventory Management. 9(1):82-87.

———. 1968b. Revisiting a Fallacy of E.O.Q.'ing. Production & Inventory Management. 9(4):12-19.

———. 1969. E.O.Q. Revisited. Journal of Purchasing. 5:62-72.

———. 1970. Choosing between E.O.Q. and Dynamic Programming for Purchasing. Journal of Purchasing. 6:44-51.

———. 1974a. A Comparison of E.O.Q. and Dynamic Programming Purchasing Models with Safety Stock Considerations. Journal of Purchasing. 10:41-54.

———. 1974b. A Comparison of E.O.Q. and Dynamic Programming Inventory Models with Safety Stock and Variable Lead Time Considerations. Production & Inventory Management. 15(1):1-9.

Kendall, M.G. 1976. Time-Series. London: Griffin.

King Edward Hospital Fund for London. 1952. Report on Costing Investigation for the Ministry of Health. London.

King, W.R. 1968. Probability for Management Decisions. New York: Wiley.

Kline, A. Burt. 1975. Will shortages of raw materials and rising prices hurt our chances for better health care? Public Health Reports. 90:3-9.

Knopp, J.F. 1971. "The Impact of Scientific Inventory Management Rules on Inventory Costs in Hospitals." Unpublished M.B.A. thesis, Xavier University.

Konnersman, P.M. 1969. Forecasting production demand in the dietary department. Hospitals, J.A.H.A. 43 (Sept.):85-87.

Kourie, D.G. 1976. A Length of Stay Index to monitor efficiency of service to General Surgery In-Patients. Operational Research Quarterly. 27:959-970.

Labelle, J. 1968. "Means of Attaining Economic Procurement in Hospitals." Unpublished M.H.A. thesis, University of Ottawa.

Lee, A.M. 1976. New Paths for Operational Research. Operational Research Quarterly. 27:177-184.

Letouze, D. and Sutherland, R.W. 1974. A Report prepared for the Canadian Union of Public Employees, Hospital Workers Section. Ottawa.

Lewis, C.D. 1970. Scientific Inventory Control. London: Butterworth.

Lilliefors, H.W. 1967. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. Journal of the American Statistical Association. 64:387-389.

Lilly, R.T. 1967. Inventory Management Simulator/360. New York: International Business Machines.

Lowerre, W.M. 1975. Lot Size Rules: A One Act Play. Production & Inventory Management. 16(2):41,49.

McGibony, J. 1969. Principles of Hospital Administration. New York: Putnams.

McKenzie, E. 1974. A Comparison of Standard Forecasting Systems with the Box-Jenkins Approach. The Statistician. 23:107-116.

McNerney, W.J. et al. 1962. Hospital and Medical Economics. Chicago: Hospital Research and Educational Trust.

Martin, A.V. 1965. Hospital Management Planning and Equipment. Hospital Supplies and Services. 622-624.

Massey, F.J. 1951. The Kolmogorov Test for Goodness of Fit. Journal of the American Statistical Association. 46:68-78.

Milne, J.F. and Chaplin, N.W., eds. 1969. Modern Hospital Management. London: Institute of Hospital Administrators.

Naylor, T.H., Seaks, T.G. and Wichern, D.W. 1972. Box-Jenkins Methods: an alternative to econometric models. International Statistical Review. 40:123.

Nelson, C.R. 1973. Applied Time Series Analysis. San Francisco: Holden-Day.

Newbold, P. 1975. The Principles of the Box-Jenkins approach. Operational Research Quarterly. 26:397-412.

Newbold, P. and Granger, C.W. 1974. Experience with forecasting univariate time series and the combination of forecasts. Journal of the Royal Statistical Society, A. 137:131.

Niland, P. 1970. Production Planning, Scheduling and Inventory Control. New York: Macmillan.

Office of Health Economics. 1972. Hospital Purchasing. London: O.H.E.

Ontario, Ministry of Health. 1972. An Implementation Plan for the New Orientation and Structure of the Ministry of Health. Toronto.

O'Toole, A.L. 1964. Elementary Practical Statistics. New York: The Macmillan Company.

Parr, J.O. 1972. Formula Approximations to Brown's Service Functions. Production & Inventory Management. 13(1):84-86.

Parry, E. 1969. A Check on Product Forecastability. The Journal of Industrial Engineering. 1(8):38.

Pearce, L. 1976. Hospital Supplies - has the service improved? Hospital and Social Services Journal. 86:1305-1306.

Philippakis, A.S. 1970. The cost of using E.O.Q. with variable demand items. Journal of Purchasing. 6: 65-73.

Phillips, D.T. 1972. Applied Goodness of Fit Testing. Atlanta: American Institute of Industrial Engineers.

Queen's University, Ontario. 1972. Auto- and Partial Correlations: APCORR and TYMPAC: Estimation of Parameters in Linear Time Series Models. Kingston: Queen's University.

Raitz, R.E. 1964. "The effect of using an Economic Order Quantity and Exponential Smoothing to reduce hospital purchasing costs." Unpublished thesis, University of Minnesota.

Reid, D.J. 1969. "A Comparative Study of Time Series Prediction Techniques on Economic Data." Unpublished doctoral thesis, University of Nottingham.

Reilly, D.P. 1975. Box-Jenkins for the Layman. New York: Celanese Corporation.

Revans, R.W. 1964. Standard for Morale: Cause and Effect in Hospitals. London: Oxford Universities Press.

Robinson, G.A. 1966. Hospital Administration. London: Butterworth.

Rosser. R.M. and Watts, V.C. 1972. The Measurement of Hospital Output. International Journal of Epidemiology. 1:361-368.

Rothe, J.T., Naidu, G.M. and Kleimenhaugen, A.K. n.d. The Sales Forecasting Audit: Prescription for Forecasting Problems. Whitewater: University of Wisconsin.

Scarborough General Hospital. 1974. Annual Report. Scarborough.

Schulz, W.M. 1969. Inventory Management in the Hospital. Hospital Financial Management. 23(3):11-14, 22.

Shapiro, S.S. and Wilk, M.B. 1965. Analysis of Variance test for normality (complete samples). Biometrika. 52:591-611.

Shapiro, S.S., Wilk, M.B. and Chen, H.J. 1968. A Comparative Study of Various Tests for Normality. Journal of the American Statistical Association. 63:1343-1372.

Shepley, D.J. 1972. Harnessing Hospital Computing. Hospital Administration in Canada. 14(4):21-22.

Shone, M.L. 1967. Viewpoints. Operational Research Quarterly. 18:318.

Siegel, S. 1956. Non-Parametric Statistics. New York: McGraw-Hill.

Smith, A.G. 1973. Centralisation of Hospital Service Stores. The Hospital and Health Services Review. 69: 49-52.

Smith, D.E. 1974. Adaptive Response for Exponential Smoothing: Comparative System Analysis. Operational Research Quarterly. 25:421-435.

Snyder, R.D. 1973. The Classical Economical Order Quantity Formula. Operational Research Quarterly. 24:125-127.

Spencer, J.A. 1967. Management in Hospitals. London: Faber and Faber.

Sposato, D.P. and Spinner, A.H. 1970. Forecasting by a Modified Exponential Smoothing Method. Health Services Research. 5:141.

Sullivan, W.G. and Claycombe, W.W. 1977. Fundamentals of Forecasting. Reston: Reston Publishing Company.

Tersine, R.J. 1974. Time Series Analysis. Journal of Systems Management. 25(7):34-41.

Thamara, T. 1968. "Exponential Smoothing with Automatic Weight Assignment." Unpublished paper presented at the TIMS/ORSA meeting, San Francisco.

Theil, H. 1961. Economic Forecasts and Policy. Amsterdam: North-Holland Publishing Company.

Thompson, H.E. and Tiao, G.C. 1971. Analysis of telephone data: a case study of forecasting seasonal time series. The Bell Journal of Economics and Management Science. 2:515-541.

Trenn, M.J. 1971. "Development and significance of a 'standard inventory per bed' criterion for the assessment of the adequacy of inventory levels." Unpublished M.H.A. thesis, Xavier University.

Trigg, D.W. 1964. Monitoring a Forecasting System. Operational Research Quarterly. 15:271-274.

Trigg, D.W. and Leach, A.G. 1967. Exponential Smoothing with Adaptive Response Rate. Operational Research Quarterly. 18:53-59.

Trux, W.R. 1968. Data Processing for Purchasing and Stock Control. London: McGraw-Hill.

Tuite, M.F. and Anderson, W.A. 1968. A Comparison of Lot Size Algorithms under fluctuating demand conditions. Production & Inventory Management. 9(4):20-27.

Uhrich, R.V. and Noart, A.J. 1971. Production Demand Forecasting. Hospitals, J.A.H.A. 45:106.

Wagle, B.V. 1965. A Review of two Statistical Aids in Forecasting. The Statistician. 15:191-195.

Wagner, H.M. and Whitin, T.M. 1968. Dynamic Version of the Economic Lot Size Model. Management Science. 5:89-96.

Wheelwright, S.C. and Makridakis, S. 1973. Forecasting Methods for Management. New York: Wiley.

Whybark, D.C. 1973. A Comparison of Adaptive Forecasting Techniques. The Logistics and Transportation Review. 9:13-26.

Winters, P.R. 1960. Forecasting Sales by Exponentially Weighted Moving Averages. Management Science. 6: 324-342.