IoT SYSTEM ENGINEERING APPROACH USING AI FOR MANAGING SAFETY PRODUCTS IN HEALTHCARE AND WORKPLACES

By

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Abstract

The Internet of things (IoT) has been widely used in life support facilities, especially in the healthcare sector. The management of health and safety (H&S) devices is an indispensable factor in guaranteeing human life. Thus, many companies and organisations have ensured the safety of their workplace from any overwhelming risks, such as fire, damage and accidents. The problem is that companies that have thousands of employees also have hundreds of health and safety systems in continuous use and Building Service Managers do not know which devices need maintenance or replenishment and require a significant amount of time to continuously check that their health and safety systems are maintained according to legislation requirements.

The consequences of companies not meeting their health and safety obligations are serious and expensive if any of their employees are seriously injured as a consequence of the health and safety products not being in their original, immaculate order for use. Furthermore, insurance companies will refuse to pay compensation for injury to employees if it has been shown that the health and safety products are not in their original, immaculate order for use. Therefore, it makes economic sense to design and use an Internet of Things based monitoring system to record the state of health and safety products within companies. This thesis presents the design and prototype of an IoT-based health and safety (H&S) products monitoring system using artificial intelligence (AI) and image processing. The thesis aims to present a real-time control and monitoring system to determine the status of consumable hospital devices, such as first aid boxes, earplug dispensers, life jackets and fire extinguishers by using Zigbee sensors to read the measurement of the weight, and image-processing (sensor in a micro digital camera with affixed laser light) to determine the level.

The proposed design is a dynamic (real-time) system that can monitor and predict the status of any equipment in hospitals or workplaces and notify the building service managers when any facilities need to be updated. Therefore, the proposed system can reduce hospitals' and companies' time, money and workforce requirements compared with previous manual maintenance approaches that are time-consuming and require more efforts and higher costs. Artificial intelligence infrastructure based on Ant Colony, Traveling Salesman Problem TSP and Genetic Algorithm GA is proposed to be implemented in optimisation algorithm to support salesmen in selecting the shortest path and latest time in maintaining and replenishing critically low devices at different locations in an appropriate time. Artificial neural networks are used to predict the optimal performance and the correlation between effective input factors and

performance output. The achieved AI accuracy results is 96% of the proposed system which are proven to be reliable and can be used to manage many consumable H&S products in different district hospitals and companies as compared with the other approaches i.e. (Genetic, Ant-colony and TSP) that have been used at the same application whilst meeting regulatory requirements. The efficiency of the proposed system is validated because it reduces time, costs, efforts and workforce resources compared with previous manual maintenance approaches.

Publications

Journal Papers

- Smart Health and Safety Equipment Monitoring System for Distributed Workplaces. Jabbar Al- Dulaimi, John Cosmas and Maysam Abbod. November 2019, Computers journal (MDPI).

Conference Papers

- Smart Safety & Health Care in Cities. Jabbar Al-Dulaimi*, John Cosmas - The 6th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare (ICTH 2016). Surrey University – Uk- London- ScienceDirect. Elsevier.

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Dedication

I dedicate this work to

My mother and father for their sacrifices and support to help me achieve the best life and education possible.

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Nomenclature

AAs	Administrative authorities	**ITS**	Intelligent transportation system
ACK	Acknowledgement	**IoT**	Internet of Things
ACO	Ant colony algorithm	**ISM**	Industrial–scientific–medical
AI	Artificial intelligence	**LED**	Light Emitting Diode
ANNs	Artificial neural network	**LTE**	Long Term Evolution
BRT	Bus rapid transit	**M-ESB**	Mobile enterprise sensor bus
CDSS	Clinical decision support system	**MDRP**	Multimodal disease risk prediction
CIM	Computer-integrated Manufacturing	**M2M**	Machine-to-machine
CNN	Convolutional neural network	**MLP**	Multilayer perceptron
CoAP	Constrained application protocol	**MSE**	Mean Squared Error
CSO	Chief Science Office	**NFC**	Near-field communication
CT	Computerize technology	**O/D**	Origin destiny
DDL	Doubly linked list	**PHDs**	personal healthcare devices
DOACs	Direct oral anticoagulants	**PSS**	Power system stabilisers
ECG	Electrocardiograms (Electrical activity of the heartbeat)	**PT**	Public transportation
HER	Electronic health records	**REST**	Representational state transfer
EU	Europe Union	**RFID**	Radio frequency identification
FMS	Flexible manufacturing system	**RNN**	Recurrent neural network
GA	Genetic algorithm	**SHS**	Smart hospital system
5G	Fifth generation broadband	**SHT**	Smart home technologies
GUI	Graphical user interface	**SMS**	Short message service
GPS	Global positioning system	**SOA**	Service oriented architecture
HAS	Health and safety authority	**SOM**	Self-organising map
H&S	Health and safety	**SQL**	Structured query language
HSH	Health Smart Homes	**SNs**	Sensor networks
ICTs	Information and Communications Technologies	**SVM**	Support vector machine
ID	Identity address		
IT	Information technology network	**TSP**	Travelling salesman problem
UML	Unified modelling language	**Wi-Fi**	Wireless networking
WBAN	Wireless body area network	**WSN**	Wireless sensor network

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1. Chapter One: Introduction

Technology has rapidly developed, and the world has entered a new era of interconnection advancement with the intelligent use of an innovative technology called the Internet of Things (IoT). This concept includes conditions where 'Internet' refers to a technique that is used for communicating information, and 'Things' refers to any devices that use wireless sensors, software, electronics, actuators and connected network. IoT enables these objects and everyday items to collect and exchange information ubiquitously with minimal or no need for human intervention [1]. IoT is the interconnection of concrete devices through a network to make them smart. In other words, changing the nature of 'things' enables the connected products to be smart [2]. Physical and computational systems can send and receive data with high combination and coordination between them by using the IoT-based infrastructure. The interconnected objects can be monitored, detected and managed remotely by an existing network system to exchange information for fulfilling the tasks of the users. This process alters the technique that governments used to interconnect and establish everyday industry and production procedures [3].

New world people have requested the continuous development of high-quality assistance within their living environment. Therefore, many organisations and companies have investigated the benefits of IoT applications in developing a new network of intercommunicating objects in consumers' everyday life. Thus, all sectors of industrial advancement are required to maintain a regular pace based on these requirements to address the global progression in people's living standard [4]. The health industry is a vital requirement for world safety because it directly addresses human life. Thus, health systems across the world have experienced unprecedented financial, social and environmental challenges. The use of innovative IoT technologies can improve the healthcare industry [5].

The advancements of IoT, such as the cloud and sensors with mobile technologies, are considered the best solution for overcoming various limitations related to data processing, storage, accessibility, security and distribution [6]. Although IoT has not been used in monitoring health and safety (H&S) products, it has been used in many aspects of the healthcare industry, such as in monitoring patients' health, blood pressure and electrocardiogram (ESG) equipment [7]. Thousands of H&S products in the healthcare field must be regularly inspected by facility managers. H&S company managers have to continuously evaluate every device by themselves because they do not know when and which equipment is used. Moreover, process consumes considerable amount of time, efforts, cost and intensive workforce.

An innovative monitoring system based on IoT infrastructure should be used to overcome all these shortcomings whilst keeping the equipment compliant to regulatory requirements. Thus, healthcare IoT is used to solve these kinds of obstacles by remotely constructing, operating and controlling H&S products via a network to analyse and exchange data with the help of the cloud. The use of IoT is considered a simple, fast and low-cost solution in the healthcare industry [2], [8]. Therefore, healthcare organisations around the world have transformed into efficient, interoperable and coordinated systems. Companies can reduce maintenance costs, avoid equipment failures, and keep them compliant with regulatory requirements through the data analytics in the application of IoT to provide H&S facilities and improve business operations. This adoption has proven suitable for sectors that manage a large number of assets and coordinate complex and distributed processes.

To address novel IoT technologies and their importance role in the healthcare sector, the proposed software is modified to make this technology practical in this field. This dynamic software is based on (real – time) application that can monitor the status of equipment i.e. (Active, low and critically low) and predict the location of any equipment in the workplace that need a maintenance or replenish after a period of time and then notify the building service manager when any facilities need to be updated.

This approach measures the change in weight, level and battery status to guarantee that these devices are suitable for continuous daily use based on regulatory requirements. The collected data are stored and analysed in the cloud to decide. Smart sensors are used to collect data from the devices that are used to monitor the status of different facilities. Companies have been increasingly required to observe the critical conditions of their devices in the workplace to ensure that they meet the regulatory requirements. Thus, a maintenance system is required for the early detection of devices with critically low state.

Therefore, the proposed smart monitoring system can monitor the equipment in different workplaces simultaneously, thereby enabling building service managers and customers in most hospitals to benefit from these improvements. On this basis, information and communication technology (ICT) should act as the centre point in accomplishing efficiencies and improving H&S facility systems to fulfil various and regular update requests. Benefiting from the IoT structure, building service managers will secure contracts for different facilities to ensure that all equipment is available for use at any time and avoid any confusion in daily life work. Thus, customers will obtain good service without delay. Hospitals can reduce the risks and can ensure the safety and lives of their patients and staff by identifying the number of H&S devices that are critically low and uncompliant with regulatory requirements.

This thesis presents a system called 'Smart Health and Safety Monitoring System', which is a novel maintenance system used for the early detection of critically low H&S devices in various facilities by using smart sensors for data collection and status monitoring. This thesis aims to monitor the status of consumable items within a first aid box, including plasters and sterile wipes, by monitoring the total change in the box weight; the level of an earplug dispenser; or the weight change of a fire extinguisher. The battery state (i.e. the remaining charge) is also required because H&S monitoring systems use smart sensors which require batteries as power source. The proposed prototype enhances the efficiency of system performance by using genetic algorithm (GA), ant colony (ACO) and travelling salesman problem (TSP) algorithms, in which the shortest path can be found in the least time to access the locations with critically low-status devices that require maintenance or replenishment.

ANNs is used to predict the optimal performance and the correlation between effective input factors and performance output. ANNs can be defined as a computational model based on the structure and functions of biological neural networks (called artificial neurons or nodes) comprised of densely inter-connected adaptive simple processing elements that can perform characteristics relevant to nonlinear, high parallel, fault and noise tolerance, and learning computations for data processing and knowledge representation [9]. The results demonstrate that the proposed software can be used to manage a large number of H&S products in different hospitals and companies in various health districts simultaneously by using IoT to identify consumable H&S devices that are critically low and to enable salesmen to replenish these devices to meet regulatory requirements. The system's effectiveness is validated because it reduces time, costs, efforts and workforce resources compared with previous manual maintenance approaches

1.1 Motivation

Organisations should prioritise occupational H&S because of the increasing number of accidents and injuries at workplaces, such as dangerous equipment, electricity, toxic substances, fire or any other kinds of working hazards. The importance of H&S at the workplace is deduced from the importance of human resources because human loss is priceless and unbearable for families and organisations. H&S management in the workplace is important to protect workers' lives because their productivity and loyalty increase when they are healthy and happy. Therefore, decision makers in all industries should focus on the H&S conditions in the workplace by minimising accidents that continuously occur on a daily basis to promote the wellness of employees and employers. Accidents that resulted from lack of safety conditions force employees to be absent from work and lead to huge losses [9].

H&S products should be prioritised when managing workplace accidents because they save the lives of workers who are exposed to such accidents and hazards at work. First aid boxes should be prioritised because it directly helps save peoples' lives. Any item that is missing from the first aid box to aid an injured person may lead to fatal loss. Fire extinguisher is another imperative safety product because its absence could cause huge damage to people, buildings and the organisation's wellbeing. Another product is ear plug dispenser, which has a special importance in protecting employees who are exposed to long periods of high-level noise that could cause hearing loss.

Traditionally, monitoring the H&S data is manually accomplished every week, month or year, in which the status of the equipment, such as leak or damage, might change. In this way, the building service manager cannot update the information to maintain equipment compliance. The manual checking of H&S products requires high wages for several employees to continuously check these products. All the aforementioned reasons are the motivations of this study.

1.2 Injuries in the Workplace

Health and Safety Authority (HSA) reports indicate that more than 200 people are killed each year because of different kinds of accidents that occur in the workplace. The number of injured people has increased to more than 1 million in the past few years. In 2015, HSA stated that the number of nonfatal injuries in employees increased to approximately 96%. This percentage was inferred by comparing the number of injuries between 2014 and 2015, which was 7,443 and 7,775, respectively. In other words, the rate of employment injuries increased from 3.7 per 1,000 to 3.8 per 1,000 in 2015. Economically, these industrial accidents caused organisations considerable losses in time, effort, production, money and the health and lives of experienced workers. The Chief Science Office investigation in 2014 indicated that 18,796 workplace injuries resulted in the absence of injured workers from work for more than four days, thereby causing huge losses because of the delay in production and full payment for the injured workers (Table 1.1) [10].

Therefore, reducing occupational risks and avoiding workplace accidents have been mainly prioritised by legal authorities and industrial firms. H&S products, such as first aid boxes, fire extinguishers and others, should be readily available anywhere and anytime. This condition can be fulfilled by benefitting from IoT ubiquitous computing systems that can play an interesting and important role in ensuring the safety of occupational workplaces.

Table 1.1 Numbers of injuries 2008–2018 [11]

Non-fatal accident	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	8072	7007	7594	7112	6828	7045	7550	7928	8622	9282	9199

1.3 IoT Challenges

IoT provides solutions to numerous demands, such as exchanging information and communicating through sensing devices, energy efficiency, remote monitoring, controlling of physical properties and enhancing productivity through applications. However, its rapid development has led to many challenges in security and privacy, maintenance, interconnectivity, standard and protocols, big data and their integrity, scalability and heterogeneous connection. Many researches have focused on the benefits of IoT in terms of global welfare. Firstly, privacy and security are significant challenges in IoT. With the increasing number of connected IoT devices that receive and send data in real time, the probability to maliciously exploit these devices has increased because of the weaknesses of data standards and protocols. The poor design of these connected devices can enable user information to be hacked, especially when data streams are unprotected. In other words, the data should meet the protection requirements in terms of integrity, confidence, privacy and confidentiality. The lack of ownership makes the data susceptible to risks. These factors enhance the threats of database hackers. In healthcare, healthcare authorities, such as doctors, nurses, specialists and emergency services, have to access patient's data any time to provide them with the required health treatments. However, the privacy of patient's sensitive health data should be ensured, otherwise, any malicious disclosure of patient's health data can expose the patient to negative consequences, including patient's identity and record theft, which may affect insurance claim or patient's health [12].

Secondly, maintenance is another challenge in applying IoT. The integration and maintenance of a huge number of devices are major issues that confront IoT. Massive devices that belong to different unknown users make the maintenance of these devices difficult. Many users ignore upgrading their devices to the latest stages and solving security and other problems in their devices. The lack of maintenance challenges the overall performance of the device, that is, this deficiency can be easily attack and affect the performance of the entire IoT system.

Thirdly, the interconnectivity of a heterogeneous device is considered a main challenge of IoT, although connecting these devices increases the productivity of any system by generating advanced applications and facilities. IoT is increasing in many diverse directions, with many different technologies challenging to become the standard. This condition would cause problems and require the distribution of additional hardware and software when connecting devices. At present, the IoT infrastructure provides sufficient interconnectivity amongst these devices, although the number of devices and networks will increase and the deficiency of interconnectivity between them will become a bottleneck. In healthcare, the sensors must send accurate signals in real time using IoT signal database when tracking patients' health to avoid the probability of disconnections from healthcare services when patients are out of mobile phone signal to prevent data loss [13].

Fourthly, networking challenge is another issue that confronts IoT application. The development of IoT technology requires multi-communicational networks when transforming heterogeneous devices from traditional to smart ones. This condition indicates that the IoT system uses various network protocols to generate and increase the rate of data standards. Thus, building a networking protocol is a complex task because the requirements of the entire system in terms of simplicity, usability, efficiency, cost and performance should be met. Network compatibility with the protocol is another issue. Networking compatibility is the suitable choice for wireless communication in smart environments. Therefore, different communication protocols and network technologies are important issues that should be solved.

Fifthly, big data generated from the IoT system and data integrity are considered crucial challenges. The IoT system combines enormous devices that generate massive amounts of data, thereby causing great difficulty in the analytical storage and processing of data because of their capacity, speed and diversity. Therefore, cloud computing is used to enable the storage of huge data for a long time period. However, the performance of different applications makes the management of massive amounts of data a considerable issue. Data integrity is an important issue related to big data because it affects the quality of service and its security and privacy aspects. Cloud computing is used to store large amounts of information. Therefore, it is used in medical services, particularly in storing patients' medical history, which requires a large database.

The sixth challenge is the scalability of IoT system. The number of connecting IoT devices has increased daily with new world demands. The IoT structure should meet scalability condition to adopt to the world's advancement. Scalability refers to the IoT system's efficiency in coping with any condition to meet the changing demands of people's interests, which can increase with the development of the world and technology.

Finally, heterogeneity is a central challenge experienced by the IoT system because it involves multi-heterogeneous devices, network, platforms, functional structures and services that exist and might be used to afford innovative applications for enhancing the quality of life. Managing large number of interconnected devices via diverse types of networks through various communication technologies remains difficult because dealing with various devices with different features makes connectivity and facilitating problematic [11], [14]. All the aforementioned crucial challenges need to be addressed to fill the gap for reaching the potential applications of IoT.

1.4 Neglect the Importance of H&S Products

Healthcare organisations, such as medical clinics, hospital administrators and specialists, are responsible for high-quality management in the healthcare domain to ensure that all patients receive excellent care, medication and treatment. Most previous studies have focused on patients' chronic diseases, implanting medical body sensors and monitoring patients inside or outside the hospitals. Other researchers have implemented different systems to call ambulance or paramedical specialists in assisting during first aid and remote medical practitioners or police officers to promptly respond in real time. [7], [15].

The healthcare sector is mainly prioritised amongst all the authorities because of its direct relation to human lives and global welfare. Occupational workplace H&S products, such as fire extinguishers, first aid boxes and safety jackets, are important in healthcare treatment. However, these products have not been prioritised by researchers and authorities, although they are considered lifesaving. Therefore, the main focus in this study is to highlight the importance of H&S products in workplaces, such as hospitals and companies, by implementing a novel system to monitor and manage these products to keep them available for use anytime and anywhere. This system would contribute in reducing many fatal and nonfatal accidents for workers during their work inside and outside their workplaces.

1.5 Aim and Objectives

The aim of this thesis is to design a system for monitoring the status of health and safety products at workplace in real-time and plan the maintenance/replenishing at an optimal path and minimum time to reduce cost and improve quality.

The main objective of our system is to enhance the H&S of occupational personnel by

- Develop monitoring system for medical equipment using IoT with wireless connection and utilise the cloud for data storage and analysis.

- Design a graphical user interface (GUI) system for monitoring and planning.
- Design a prediction system to dynamically monitor medical equipment in the workplace in real time.

1.6 Author's Research Contributions

- In this thesis, the proposed smart H&S equipment monitoring system for distributed hospitals with GUI can play a major role in enhancing the existing healthcare sector and industrial companies by providing programmability, flexibility and ease of network management for data. The contributions of this work are described as follows:
- Present a novel maintenance system for the early detection of critically low H&S devices in various facilities by using smart sensors to collect data from them to monitor their status.
- Enhancing the efficiency of system performance by using GA, ACO and TSP algorithms, in which the shortest path and least time can be determined to access the locations with critically low-status devices that require maintenance or replenishment.
- The results demonstrate that the proposed software can be used to manage a large number of H&S products in different hospitals and companies in various health districts simultaneously by using IoT to identify H&S consumables that are critically low and enabling salesmen to replenish them to meet the regulatory requirements. The system's effectiveness is validated because it reduces time, money, efforts and workforce resources compared with previous manual maintenance approaches.
- Implementing a prediction algorithm to enhance the system performance and support hospitals in replenishing consumables that will expire in different times in the near future.

1.7 Research Methodology

Although IoT has been applied in many aspects of the healthcare industry, it has not been used in the proper monitoring of H&S products. The increasing number of accidents and injuries at workplaces causes heavy losses in global production and has triggered the authorities to develop measures in prioritising H&S devices at occupational workplaces. Thus, companies have been required to observe the critical situation of their devices in the workplace to ensure that they meet the regulatory requirements for reducing fatal and nonfatal accidents. Therefore, given the importance of IoT-based services, various changes are made to build a prototype of an IoT-based H&S monitoring system with GUI.

The proposed design is a dynamic software system called 'Smart H&S Equipment Monitoring System for Distributed Hospitals', which is a real-time controlling and monitoring system that can monitor, predict and access any consumable equipment in hospitals to notify administrators when any services requires updating. This method measures the changes in weight, level and battery status for guaranteeing that these devices are suitable for continuous daily use based on the regulatory requirements. Then, the collected data are stored and analysed in the cloud for decision making. Smart sensors are used to collect data from devices that are used to monitor the status of different facilities.

The maintenance system requires the early detection of devices with critically low state. Thus, an AI infrastructure based on ACO used because it's very efficient path planning, TSP It's a standard and GA it is a global search method to support salesmen in finding the shortest route and up-to-date time for maintaining or replenishing critically low devices at different locations in an appropriate time. ANNs is used because more efficiency and accurate to predict the optimal performance and find the correlation between the effective input factors and performance output. In this way, the proposed smart monitoring system can monitor the equipment in different workplaces simultaneously, thereby enabling building service managers and customers in most hospitals to benefit from these improvements by reducing hospitals' and companies' time, money and workforce requirements compared with previous manual maintenance approaches that consume considerable time, efforts and costs.

1.8 Thesis Organisation

This thesis consists of six chapters. It begins with an introductory chapter to outline the reason behind the research, challenges and the methodology. Each chapter begins with an introduction and ends with a summary. The chapters are independent, and the readers are advised to follow the proper order to completely understand the presented ideas. The remainder of this thesis is organised as follows:

Chapter 2: In the previous chapter, the aim and objectives of this thesis are presented. Chapter 2 explores the background of IoT, H&S products in smart cities, H&S products for doctors, H&S products for patients at home, H&S products for patients in hospitals, IoT for smart factories, IoT for smart homes and IoT for smart transportation. Further, it provides a literature review of AI in the healthcare sector, investigates the major challenges experienced by the healthcare sector, and presents the main benefits in using AI in the healthcare domain.

Chapter 3: This chapter discusses the network modelling system, H&S product infrastructure in hospitals and briefly describes the simulation system loop in MATLAB software. The use case and components of the system are explained in detail on the GUI software.

Chapter 4: This chapter presents the 'Smart H&S Equipment Monitoring System for Distributed Hospitals', which is a novel maintenance system for the early detection of critically low H&S devices in various facilities by using smart sensors for data collection and status monitoring. The efficiency of system performance is enhanced by using GA, ACO and TSP to support large number of hospitals with large and limited sales force to determine the shortest routing path in latest time.

Chapter 5: This chapter presents the third contribution of the research. A prediction algorithm is proposed to predict the consumable equipment that will expire in the future. The major issues are identified to define the devices that may be critically low in the future.

Chapter 6: This chapter described the conclusion and a future work.

2. Chapter Two: Literature Review Technical Background of IoT

2.1 Introduction

From the inception of the Internet, the world has entered a new era of interconnection where myriad data are generated, connected and transmitted via network web pages. The innovation of advanced IoT technology has accelerated the rate of data generation where various heterogeneous physical objects and devices are connected to the Internet. This condition has allowed the remote access and management of devices anytime, anywhere and from any network. IoT transforms these physical objects into ubiquitous and smart ones by enabling them to interact, perform jobs, share information and manage results using innovative infrastructure.

Consequently, large amounts of data have constructed efficient organisations by converting them into useful information and have made intellectual estimates by using this information. Thus, IoT exhibits a promising solution to make the world smart (smart devices, smartphones, smart cars, smart homes, smart cities) by transforming the operation and the role of many existing systems. IoT can play a significant role in other aspects and domains and improve the quality of human's lives, such as transportation, healthcare, industrial mechanisation and environmental monitoring and prediction where rapid decisions to natural or man-made disasters must be taken. IoT services and big data analytics have enabled smart city initiatives worldwide. IoT infrastructure can be applied to these sectors:

2.2 IoT for Smart Cities

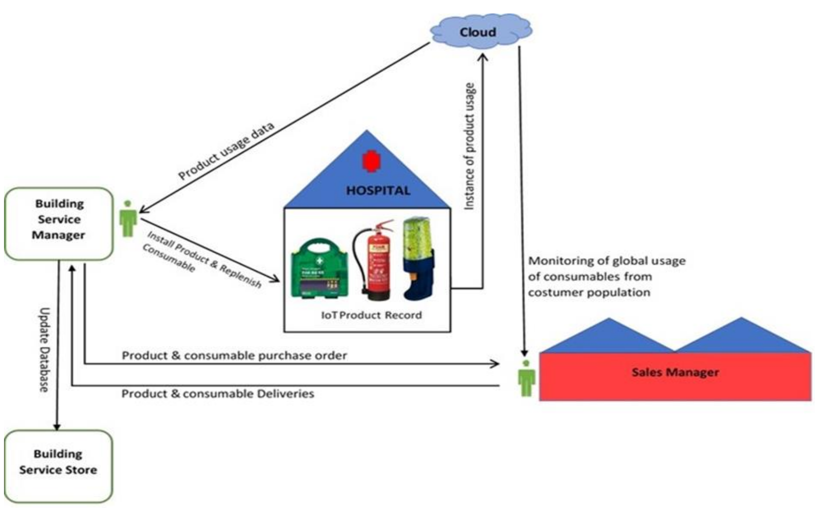

Figure 2.1 Smart safety & Healthcare in cities

In figure (2.1), the world enters a new era of overpopulation in urban places. This condition requires suitable facilities and services to guarantee the wellbeing of city residents. The use of innovative IoT technology has presented the new age of heterogeneous IoT data to smart cities. Thus, the probable value of data should be invested for the wellbeing of people and their lives by using the various aspects of IoT-based applications. A smart city can be characterised as a multifaceted ecosystem. Authorities have to intensively use ICT to make cities sustainable and unique for safe and innovative living. Therefore, IoT systems require application developers, service providers, citizens, government and public service providers, the research community and platform developers to play a vital role in the deployment of extensive heterogeneous infrastructure. These services transform cities by improving infrastructure and transportation systems, reducing traffic congestion, providing waste management and improving the quality of human life. Therefore, several and different studies have been conducted to enhance the citizens' quality of life in cities.

[16] Presented a complete design of developing a smart city in accordance with Melbourne City councils to ensure the provision of essential services and high quality of life for residents. They adopted an innovative framework based on ICTs to develop smart cities. This framework relied on an existing cyber-physical system that encompasses sensors, networking structures, data management and cloud-based integration. A new method for existing operations that can be adopted for the improvement and transformation of significant city services is demonstrated by applying this framework to noise mapping measurement for the health of citizens. In this context, the key IoT building blocks of smart cities have been identified, and the approaches and resolutions have been provided to meet the communication and computation requirements. Considering that smart cities are equally important as technological advancement, investigations on this topic can be categorised as an environmental example for the creation of a smart city [17].

[18] Scrutinised a specific application domain of the urban IoT system, which is designed to support valuable services for the government and citizens of smart city, based on advanced communication technologies, protocols and architecture. They presented a comprehensive survey of the architectures, protocols and IoT-based services of the Padova smart city plan in Italy. They evaluated and clarified the technical solutions and professional procedural strategies that aim to monitor street lighting, air quality and identification of other crucial issues. Although they presented a comprehensive survey on the fundamental IoT elements in

realising smart cities, they did not provide examples of using a system to sense things in a city [19].

[20] Investigated the different functionalities, structures and characteristics of IoT systems and their utilisation as effective motivations to enhance and develop the daily activities of citizens in smart cities. They explained the combination of IoT infrastructure with other intelligent systems in providing smart and widespread applications, such as smart homes, smart parking lots, weather and water systems, vehicular traffic, environmental pollution and surveillance systems. IoT is based on intelligent systems and sensors that preserve the rights of smart city's citizens by providing a mechanism to overcome crucial challenges, such as the privacy rights of citizens.

[21] Presented a comprehensive system that contained multi-sensors system, including smart home sensors, vehicular networking, weather and water sensors, smart parking sensors and surveillance objects. This system combined IoT-based infrastructure to develop a smart city and used big data analytics for urban planning. The system architecture consisted of four tiers, namely, bottom tier-1, which is responsible for IoT sources and data generation and collection; intermediate tier-2, which is responsible for all types of communication between sensors, relays, base stations and the Internet; intermediate tier-3, which is responsible for data management and processing using a Hadoop framework; and top tier-4, which is responsible for the application and usage of data analysis and generated results.

The complete system was developed by using Hadoop technologies with Spark to achieve real-time processing. Several steps, which started from data generation and transfer to collection, aggregation, filtration, classification, pre-processing, computing and decision making, were taken in implementing the system. For urban planning or city future development, offline historical data were analysed on Hadoop by using MapReduce programming. This system aided inhabitants and the government by providing them the facilities to make smart and fast decisions for smart cities and citizens. System efficiency was evaluated in terms of processing time and throughput. The system provided efficient results on large data sets. The system results increased with the data size [22].

2.3 IoT for Healthcare and Safety Products of Doctors

The healthcare sector is an essential requirement for global welfare because it directly deals with human life. Poor healthcare organisations mainly affect the welfare of the continuously growing population because of different factors, such as the shortage of qualified doctors in dealing with the increasing population, insufficient number of healthcare facilities and insufficient timely diagnostic equipment of illnesses. The pioneering IoT technology is used to improve the healthcare industry. The convergence of IoT with cloud technology provides a complete solution for many applications in terms of storage, processing, accessibility, safety, interacting service and devices in addition to the advancement of mobile technologies, resulting in the flexibility of this solution. Therefore, many venues, especially in the healthcare sector, have benefitted from this advanced framework to overcome the shortage of expert physicians, difficult transportation of patients and other medical problems.

Benefitting from the Android application in patient's smartphone, the system timely updates the patients' medicines and automatically notifies them to take their correct medicine at the right time. Consequently, the medication history in the hospital webpage is automatically updated. Using this platform helps in moving the medication procedures from hospital centric to home centric, reducing the burden for patients, doctors and hospitals. Patients can check their prescriptions, make appointments and are informed to take the medicine easily with minimal cost. Doctors can direct observe their patient's details by receiving SMS alerts when any vital sign is noticed. The chat option provided in this application helps patients and doctors to have close communication [6]. The so-called 'Internet of medical things', such as clinical wearable sensors, mobile devices and remote monitoring equipment, will enable health workers and patients to receive the advantages of digital innovation for wellbeing and quality healthcare [5] as showing in the figure (2.2).

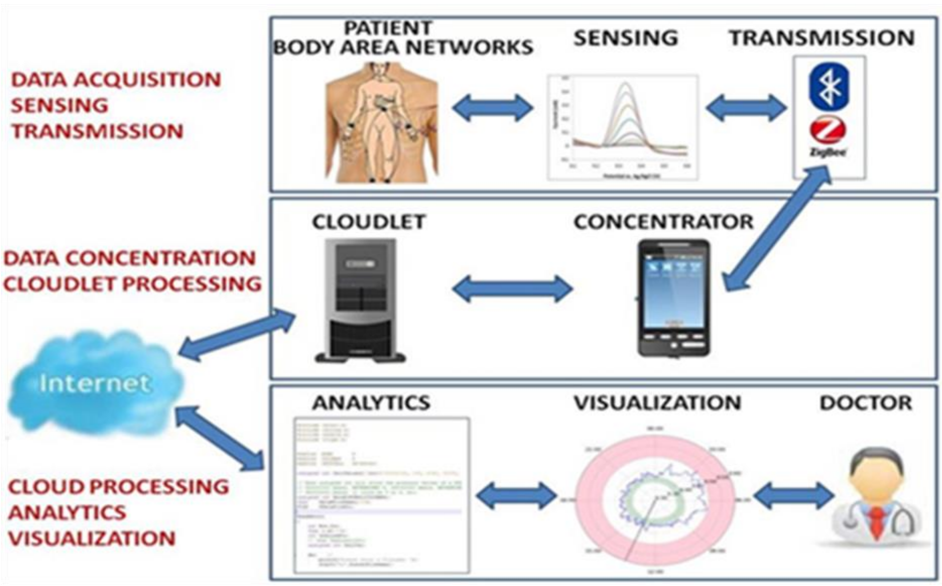

Figure 2.2 IoT for doctors [23]

[6] Discussed and proposed the voice pathology monitoring of patients based on IoT–cloud technology. Their project consisted of an IoT-based monitoring system where voice signals are detected and sent to a hosting device (smartphone) that sends them to the cloud accordingly. The medical doctor received the processed data after cloud verification for analysis and decision making. The authors developed the voice pathology monitoring system inside their framework by using a local binary pattern on a Mel-spectrum representation as a feature of the voice signal and an extreme learning machine as a classifier to detect pathology. The proposed monitoring system achieved high detection accuracy and was easy to use.

[24] Presented a modified healthcare monitoring system model that can remotely and timely monitor the patients' vital data, such as heart beat, blood pressure, body temperature and glucose level. The proposed system was called 'mobile health monitoring system', which contained several wearable sensors that could communicate with the cloud and automatically place requests for assistance whenever needed. They constructed the system on two fundamental stages to facilitate its implementation. In the first stage, the sensors transferred the collected data to an Android application, which was developed to act as a communication interface between the sensors and LTE cell networks. In the second stage, the patient's collected data were sent to the LTE network by using a new dynamic scheduling technique depending on the sensitivity of the patient's condition. This strategy sent the data based on the priority of the application's class and served the sensors based on the applications' requests, such as quantity, postponement and container damage rate.

[5] Proposed a platform that helped hospital administrators to monitor and diagnose their patients remotely and remind them to take their medications on time using smart health home, which was based on a wireless connected medicine box with an Android application. The proposed platform included an intelligent medicine box that is wirelessly linked with the hospital administration and an installed Android application on the patients' and doctors' smartphones. The box was provided with different sections and a LED on top of each section to signify the correct box. The LED will glow during the intake time of medication, and a buzzer will be activated when a wrong section is opened [5].

Similarly, a new era of fifth generation (5G) broadband technology has provided tremendous opportunities to improve various sectors in the world via its superfast connectivity, intelligent device management and cloud-based data capabilities. 5G represents an evolution of transformative heterogeneous network system that processes data efficiently from billions of devices and manages to move them to the right device using the suitable processing architecture.

Increasing the platform capacity will enable minimum devices to intelligently accomplish complex computations and rapidly link to the power processor. This process will nurture the developments in all human welfare sectors, such as medical healthcare, education, transportation, agriculture and many business managements. Therefore, the fast speed and intelligent design of 5G systems have introduced considerable opportunities to improve the healthcare sector by creating new applications and devices that can transform health diagnosis and treatment. Thus, healthcare consumers and providers will experience substantial advances in medical treatment.

West [22] demonstrated how these developments enable healthcare systems to help people to obtain quality care through improvements in imaging, diagnostics, treatment and data analytics using 5G advanced network. He indicated that using 5G networks and connected medical services can provide an advancement in telemedicine diagnosis, treatment services and high-resolution video conferencing at affordable prices.

[25] Study on '5G and e-Health' investigated the innovative trend of 5G generation and its impact on the new world era of technological communication. He proposed that 5G could integrate human-type communications with machine-type communications (MTC) to design the first radio communication system that easily enables IoT. 5G can increase the performance of mobile technologies, promote the conjunction of different applications on one wireless network and provide new flexible radio interfaces for the new spectrum and existing mobile bands. The innovative 5G technology is used to efficiently and effectively enable new means of providing therapeutic approaches for enhancing the healthcare domain worldwide. Telecommunication healthcare technologies can bridge the gap between urban and rural healthcare by enabling healthcare authorities' access to patients' medical data in real time anywhere.

5G technology assists hospitals and healthcare service users by decreasing the numbers of outpatient appointments and helping patients achieve a high degree of self-management independently in their well-being and illness. This system supports a physician–patient interaction that reduces the clinicians' efforts with the help of efficient medical decision-based system and facilitates the access to the medical use for the patients, their family members and other service users. However, the main socioeconomic requirements in developing the healthcare sector are the affordable cost of healthcare distribution and the improvement of health treatment and quality [25].

2.4 IoT for H&S Products for Patients at Home

Figure (2.3) shows that the significant growth of the elderly population, especially in advanced countries, such as the UK, USA and Japan, has revolutionised the entire health system by using innovative IoT-based health smart homes (HSHs). On this basis, Mano and his team used cameras as a means of developing the HSH system and providing comfort to aging people and patients during their treatment outside the hospital. This platform was constructed by combining smartphones, which could deliver notices to certain people when required, and wireless sensor networks (WSN), which were distributed everywhere in the house and linked to cameras that snap the patients' faces. This application was easily and economically implemented by using IoT technologies. [26] Developed an IoT infrastructure prototype based on the images and emotions of patients who believed in the psychologists' view that emotions play a decisive role in curing the patient from different kinds of diseases. They considered emotions the central feature to be measured whilst nursing patients.

Images were used to identify and confirm that the exact person was traced in the house to ensure that the specific kind of medication was provided and to help nurses or caregivers to aid patients who needed timely assistance. They conducted many experiments on several individuals to distinguish each person and identify his emotions based on his own facial expressions. They used facial expressions to classify people's emotional states and determine their emotional health. They indicated that such facial expression was used as a vital symptom to diagnose certain illnesses, such as autism, schizophrenia, bipolar disorder and depression. After conducting the experiments, the suitability of this approach was validated through the precise and accurate statistical analysis of its performance [26].

[27] Demonstrated and built an IoT-based system for the remote monitoring of patients in smart home environments. This system can help medical workers to easily monitor their patients at home by receiving various biomedical data from personal healthcare devices (PHDs) that are attached to the patients. PHDs are electronic portable devices that notify and control patients' biomedical signals to inform health staff that their patients are experiencing conditions that require urgent attention. The healthcare IoT monitoring system is based on one machine-to-machine (M2M) communication protocol. The system operates through a protocol conversion process between ISO/IEEE 11073 protocol and one M2M protocol to monitor patients at home

desirable and operable on ordinary IoT networks. A multiclass data communication scheduling scheme is implemented on the basis of the urgency of biomedical data delivery to medical workers. To protect the patients' privacy, the system is based on strict authorisation via two security schemes, namely, the scheme where the patient's biomedical data are stored in parts and Buddy-ACK (acknowledgement) authorisation scheme, where the patient's biomedical data cannot be accessed unless the acknowledgement (or consent) of the buddy (patient and the related medical staff) is obtained. The constructed system is evaluated through several experiments in an authentic work environment [27].

Figure 2.3 IoT monitoring for patients at home [28]

2.5 IoT for Healthcare and Safety Products of Patients in Hospitals

The use of IoT solutions for connecting medical devices enables healthcare staffs to monitor patients in real time. This process demonstrates that there is needless of unnecessary physician visits to the hospital because of the efficiency in collecting and managing data. Furthermore, this will lead to better patient experience. Another advantage of using IoT in healthcare sector is implanting medical devices which are used to substitute a lost biological organ, boost an injured biological organ or improve an existing biological organ. This can be clarified in implantable infusion pumps and other medicine delivery strategies, cardiac pacemakers, implantable neuro stimulator systems and glucose monitors [29] as showing in the figure below (2.4).

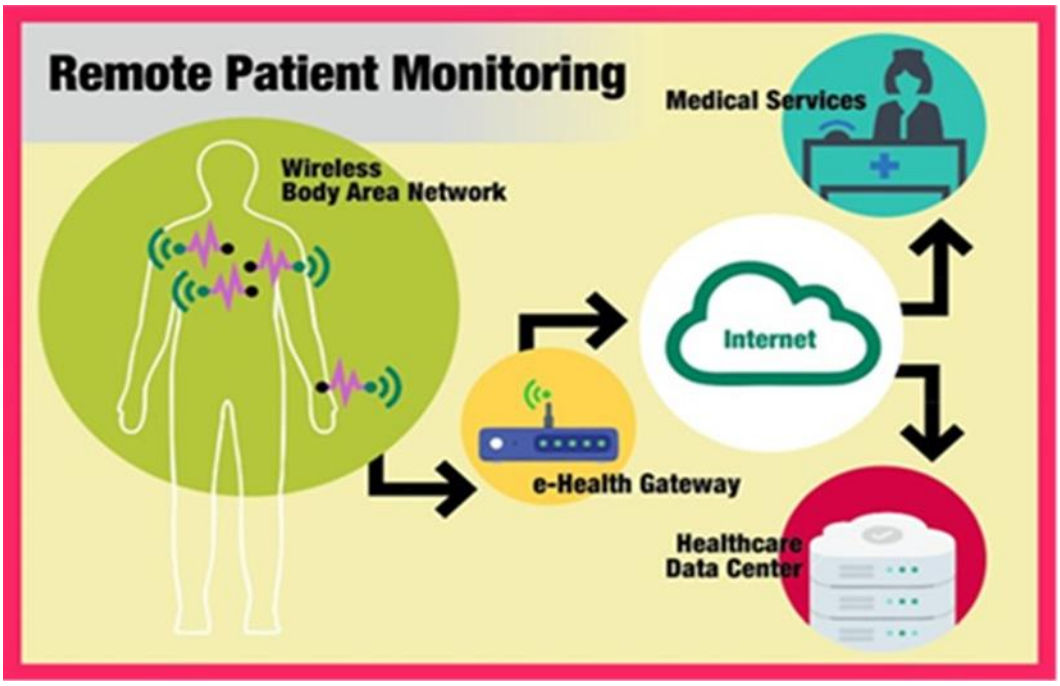

Figure 2.4 IoT monitoring for patients in hospitals [23]

[30] Developed a smart hospital system (SHS) architecture to automatically detect and control patients, employees and biomedical devices in hospitals and nursing organisations by relying on the awareness of innovative IoT technology. SHS is based on radio frequency identification (RFID), WSN and smart mobile technologies that interoperate with one another through a constrained application protocol (CoAP)/IPv6 under low-power wireless personal area network (6LoWPAN)/ to provide a representational state transfer (REST) network infrastructure. SHS can detect and gather the real-time variation of any serious patients' physiological data with their environmental conditions Utilising an ultra-low-power hybrid sensing network (HSN) composed of 6LoWPAN nodes integrating UHF RFID functionalities, Local and remote users can easily access these sensed parameters, which are delivered to a control centre by a modified REST web service. Thus, the author demonstrated the capabilities of the proposed SHS system in identifying and tracing the patients, staff, and biomedical equipment within hospitals and nursing institutes and providing power-effective remote patient nursing and fast managing of emergencies [31].

[32] Presented a real-time controlling and monitoring system to access and scrutinise patients' healthcare information for providing quality patient care and prevent avoidable deaths by applying IoT technologies for improving the healthcare industry IoT (Health-I-IoT). The

proposed Health-I-IoT system was based on various functional strategies, such as interconnected technologies, sensors, devices, apps and health specialists who can access, store and analyse patients' data anywhere in real time to continuously monitor and track the patients. The suitability of this approach was validated through experimental assessment and simulation. Health-I-IoT data (e.g. ECG signals) were collected by mobile devices and sensors and securely sent to the cloud to be securely accessed and monitored by healthcare professionals. On this basis, the authors utilised different analytical approaches, such as signal enhancement and healthcare data watermarking, before the data were sent to the cloud for secure, safe and high-quality health monitoring to avoid identity theft or clinical errors.

The increasing number of elderly population and people with chronic diseases has stimulated. [30] Advocated the indispensability of the use of IoT in the healthcare environment. They suggested an independent location framework based on IoT, interconnected sensors and WBAN (wireless body area network) to remotely monitor the patient's health condition in real-time. Monitoring patients remotely in outdoor hospital locations requires the improvement of IoT competences with cooperation amongst other applications. Connecting WBAN to a computing cloud by using smartphones for managing the health status of patients can be processed through various data distribution applications. Although the actual assessment of sensor lifetime, energy consumption and existing costs validated the system performance compared with normal WBAN, it did not guarantee data privacy and security.

[33] Conducted a comprehensive survey of different aspects of IoT-based healthcare technologies that are supposed to be beneficial for any health experts and professionals who work in the IoT and healthcare domains. An extensive insight into the recent and continuous advances in sensors, devices, Internet applications and other technologies was provided to enhance practical medical devices and combined them with the IoT-based healthcare services. They introduced various innovative IoT-driven healthcare services, applications and network architectures/platforms, such as vast data, environmental intelligence and wearables to enable medical data transmission and reception. Their study explained the use of IoT-based healthcare in dealing with paediatric and ageing care, chronic disease observation, special health and fitness supervision. The research provided numerous IoT and eHealth procedures and protocols across the world to determine how they can maintain the development of economies and societies. They evaluated several security and privacy features and necessities, such as security requirements, threat models and attack problems in the healthcare sector, to present an intelligent design that can reduce the security risks of IoT healthcare.

2.6 IoT for Smart Factories

Industry and manufacturing are significant domains that have benefitted from IoT in all their aspects and fields. Physical and computational machineries of manufacturing systems can send and receive data for a high combination and coordination between them by using the IoT-based infrastructure. IoT is used for smart connections between physical things and for various interactions of IT tools within the digital factory to build a smart factory (real-time data). The digital factory, which can be integrated with the real-time data of smart factory to deduce information and statistics, is a real factory used for designing, planning and operating.

[34] Investigated several methods and approaches to guarantee data reliability when the digital factory is integrated with IT machines and IoT in a diverse IT manufacturing environment. The IoT platform of virtualised factory was integrated with the PLM platform of the digital factory by using semantic web technologies and Open Services for Lifecycle Collaboration. The authors developed a cloud based IoT platform that can store real-time data; retrieve data; and enable users to connect, produce, analyse and experience things. They presented three layers, namely, data transfer protocols, data presentation and representation and semantics and understanding of data, to achieve the interoperability between a smart factory and a digital factory. Each layer required many examined approaches, technologies and data models to achieve its interoperability. However, certain strategies were required to select the appropriate ones to identify the best solution for integration.

The world has experienced a new trend of a highly sophisticated and competent manufacturing called the fourth industrial revolution (4.0 or Smart Factory). Benefitting from the recent advancement in ICTs, the current industry model can be transformed through digitalisation and smart solutions to meet the modern market requirements. High level of data processing, modelling, simulation, controlling, optimisation and capacity building are required to design and manage modern manufacturing systems. Three essential transformations, namely, flexible structures and strategies (scenarios), AI approach (smart solution) and integration through digitalisation, should be considered to build a smart factory. [35] Presented a smart solution for complex system called INTSCHED, which was an integrated approach that could produce added value for all smart factories. Various advantages, such as the efficient scheduling and controlling of the entire system and local subsystem, the flexible link with external databases that helped integrate forecasting and planning with scheduling and worked as a real-time optimiser for dynamic scheduling and intelligent control, were obtained using the INTSCHED system. To maintain the advancement and growth in the capacity of buildings for Industry 4.0 for countries in economic transition, such as Kosovo, the University for Business and Technology has become a small ecosystem by its investigation, knowledge and invention programmes [36].

[35] Presented a software package that is used as an interactive support to control the platform software in Flexible Manufacturing Systems (FMS). This intelligent module consisted of various inputs, outputs, communication and analysing modules, which worked as an optimiser of dynamic scheduling and administration in FMS. This optimiser was developed to support and help the operator of the control platform to improve his decisions in difficult problems by inserting genetic procedures and experiential methods. This module provided and projected the alternative working scenarios to find solutions in crucial and realistic situations. It was built on a structure of priority of orders (each order has a priority). The installation of the selected order was determined on the basis of the appropriate relative options of the system. The implementation of this module was verified on real flexible manufacturing, assembly and transport systems as a part of computer-integrated manufacturing factory solution.

The fourth stage of industrialisation (Industrie4.0) must emerge to improve the industry for dealing with the global progression in people's standard of living. Wang et al. believed that the emergence of IoT, big data, cloud computing and AI technologies helps the application of the smart factory of Industry 4.0, which produce advanced business models and maintain products to survive with global challenges. The author proposed an outline system that integrates manufacturing wireless networks, cloud and terminals with smart things, such as machines, products and conveyors. They projected three essential features to implement the flexible and reconfigurable smart factory of Industry 4.0. Firstly, a horizontal integration through value networks to facilitate inter-cooperation. Secondly, vertical integration and networked manufacturing systems, indicating the implementation of hierarchical subsystems inside the smart factory to create a highly FMS. Therefore, the smart factory competently and commercially produced modified products. Thirdly, the end-to-end digital integration of engineering across the entire value chain support product customisation. This self-organised reconfiguration was implemented on the cloud and big data analytic-based management to describe the operational mechanism of the smart factory. The researchers outlined the main technical structures and advantageous outcomes and provided a prototype design scheme in detail. They concluded that the smart factory of Industries 4.0 can be implemented progressively by applying the qualifying technologies whilst actively dealing with technical advancements [37] as showing in the below figure (2.5).

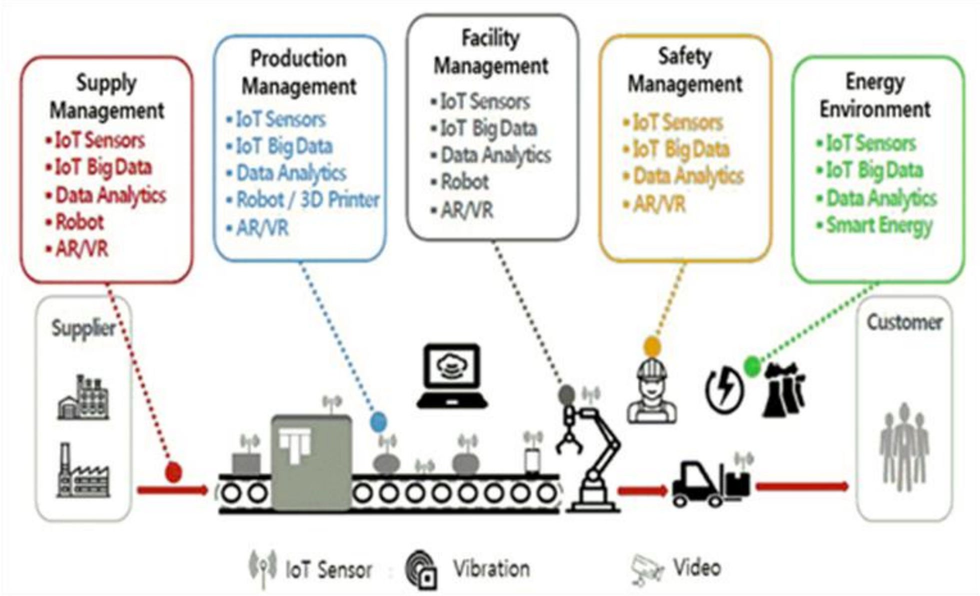

Figure 2.5 IoT for smart factory [38]

2.7 IoT for Smart Home

With the requirement of continuous development of high-quality of living environment, the advancement of homes should maintain the regular pace with these requirements. On the basis of IoT services for smart home, Risteska suggested a holistic framework that integrates different components from IoT constructions to professionally interconnect smart home devices in a cloud-centric-based IoT. This fundamental IoT framework was confined to the smart home application domain. As the central element in the system, the cloud worked to collect and store data and functioned as a solid base in developing applications for interested third parties. Biljana proposed that WSNs are the essential technology in improving the IoT by integrating the devices inside a smart home. WSN solutions had two limitations, namely, they were separately operated, and the data were used for resident optimisation, presuming a completely automated home and was an expensive solution for most households. Therefore, combining all available data of the smart home within a self-learning machine was the best solution to create modified recommendations for all users, regardless of the level of automation presented at their homes. This solution did not require any additional cost for consumers because it did not require the use of any specific hardware. Fog and edge approaches were used to improve energy saving inside the IoT network by reducing the number of transmissions amongst IoT devices. Thus, Biljana produced a model with a set of certain tasks performed at each level to meet the requirements of smart home management system [39].

Wilson highlighted the benefits and risks of smart home technologies (SHT). He indicated the merits of various implementations of SHTs, including the management of energy use, domination of the resident environment and development of security. The valuable assumption for SHTs relied on cost, management and suitability. Therefore, smart homes were the main domain of strategic energy planning and national policy. Wilson outlined the main risks of SHTs, in which they consumed energy either by demanding new services or by intensifying the existing ones.

Thus, the demand of SHTs to apply energy management depended on their design and usage. He expressed certain consideration towards some social risks of relinquishing self-independence and autonomy in the household for improving technological control. These widespread sociotechnical shortcomings were conceived more strongly than the privacy and data security apprehensions that influenced the smart pattern rollouts in Europe. Wilson provided possible solutions to these shortcomings. The observation was that politicians can provide an important procedure to alleviate these perceived risks and sustain the energy management of a smart home future. This procedure was designed to support positive system outcomes and market development from widespread adoption of SHTs, including operating standards, guidelines on data and privacy, quality control and research programmes [40].

[41] Proposed that a smart home system can be monitored and controlled from anyplace around the world by using the IoT and low-power wireless technology (ZigBee). Different sensors, such as temperature sensor, motion sensor, air flow sensor, ultrasound sensor and actuators, can be used to control a smart home system. These sensors are linked to the ZigBee components, which are interconnected with Arduino boards and wireless networking (Wi-Fi modem), wherein the observed data are stored in the Internet server. The control of electronic devices in smart home can be achieved by updating all the obtained parameters (signal-to-noise ratio and bit error rate) in the Internet server and accessing it through a developed Android application.

Aiming to renovate old homes built in 1938 into a smart home with the help of sensing technology, [42] Developed a smart home approach and implemented it in different home environments to monitor the activity of an inhabitant for wellness detection. They produced and improved interconnected sensor systems to predict and measure the individual’s health in smart home cities. These sensors were based on wireless networking technological nodes to build reliable, efficient, flexible and economical sensors. These nodes generated real-time data related to the individuals' wellness and movement inside the home where necessary care can be provided at the time of need.

In this context, wellness refers to the efficiency of someone to stay fit in the home environment and perform his or her daily routine to live a long healthy life. They extended their research of smart homes to intelligent buildings and designed model issues that were related to system performance and reliability. Industrial–scientific–medical band interference and attenuation losses were used to detect the effectiveness of wireless communication and placement of wireless nodes without compromising top system performance [43] figure (2.6).

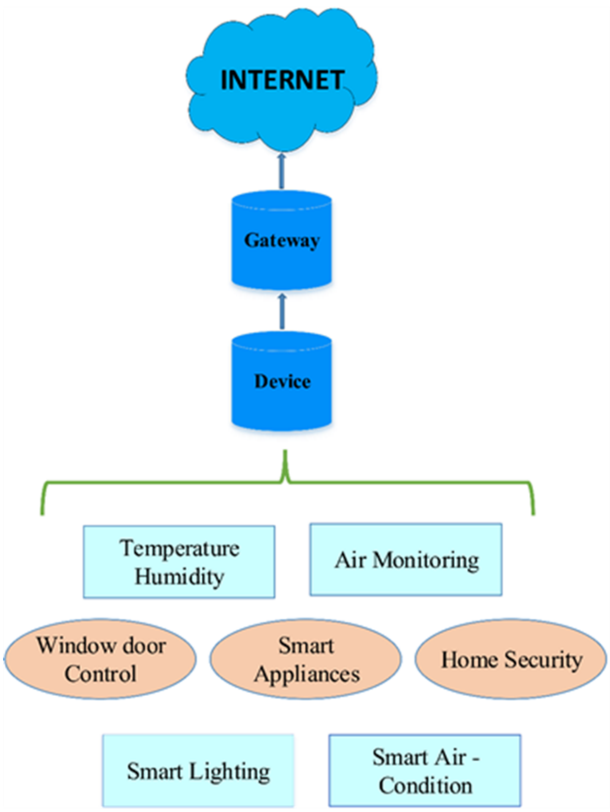

Figure 2.6 IoT for smart home [44]

2.8 IoT for Transportation

The recent growth of population, especially in large urban cities, such as London, Tokyo, New York and other big cities around the globe, has caused many problems that require innovative solutions. Public transportation (PT), which is an evident sign of the urbanisation of smart cities, is one of these problems because the increasing number of citizens leads to the increase in transportation means, especially private cars on the road.

This kind of urbanisation may cause a considerable increase in air pollution, spoiling of roads, overcrowding and other traffic issues. These problems require urgent solutions of air conditioning, vehicle safety status and road monitoring. IoT technology has provided exceptional solutions to existing problems in most transportation systems. IoT is used to create an intelligent transportation system (ITS) that enables transport specialists to track and monitor each vehicle and predict any possible road traffic. ITS is considered the main factor in developing smart cities.

Obviously, the conventional approach of using fixed roadside cameras for city monitoring has provided limited coverage and considered expensive. Cities and their transportation should be transformed by making them smart via using active, digital and autonomous-work devices with the help of net web for data storage and control. [45] Proposed the requirements and architectural design of public transport buses called mobile enterprise sensor bus service in China, which can support urban physical environment monitoring and road traffic condition detection by using a data exchange interface to feed a data cloud computing system on-board SNs.

Thus, a road vehicle was used as a complex smart mobile device and as a smart environment supporting smart interaction between the embedded multiple devices. As part of a wide system called ITS, the data were transferred in real-time via the GSM network or intermittently uploaded by a vehicle to a network structure at local area bus stops and stations. They provided a new marketplace management prototype for the bus company that can deploy sensors on PT buses and host the data sharing interface to sell sensing data to those who are interested to perform data processing and become a new service provider to act as a virtual mobile service operator for reducing the costs of deployment and operation of the mobile environment sensor systems. The proposed system was validated through pre-deployment testing. India is similar to most advanced countries, where many commuters, whether living in urban or rural areas, use buses as a main source of travelling in PT because of their availability and affordable prices.

[46] Demonstrated and developed a prototype for building an ITS based on the IoT infrastructure. The proposed ITS structure had three fundamental components, namely, a sensor system, which is responsible for tracking the location, commuter and ambience in the bus through its temperature and humidity sensors, global positioning system (GPS) and near-field communication (NFC). Secondly, the monitoring system is used to collect data from the database sensors and transform them into a meaningful context to provide information to the bus driver. Thirdly, the display system is used to present the context data of the bus and transport to all travellers in the bus stop.

Thus, this system can easily follow a vehicle through GPS, check the payment of tickets, analyse the crowd inside the bus through NFC and measure the environment inside the bus through the temperature and humidity sensors. All the data collected from the sensors are sent via a GSM network and processed by the monitoring system to make useful decisions and send them to the display system. The system's initial results are validated as a complete solution that contains hardware prototypes and manageable software application through field trials [47].

Some governments and public organisations have used new technology approaches based on IoT system to build new ITS infrastructure to reduce energy consumption and traffic congestion. [48] Proposed an ITS smart sensor model that contains an IoT-based platform and Big Data methods to accomplish the ITS cloud services for helping administrative authorities in cities, such as Bogota in Colombia, to achieve an appropriate transportation planning for bus rapid transit (BRT) systems.

The ITS smart sensor prototype can detect numerous Bluetooth signals of several devices and can create the origin/destiny (O/D) matrix for several BRT routes. The proposed prototype can serve as an affordable device that can fulfil the tasks performed by several devices, such as computers, servers and sensors. The researchers combined two approaches, namely, SOA as a successful paradigm for integrating system implementation and NoSQL method, which processes massive amounts of data and integrate them into IoT-enabled devices. The proposed system is validated in terms of its flexibility, reliability, versatility and easy access of the IoT approach that guarantees the reduction of time and cost in deploying ITS solutions [48].

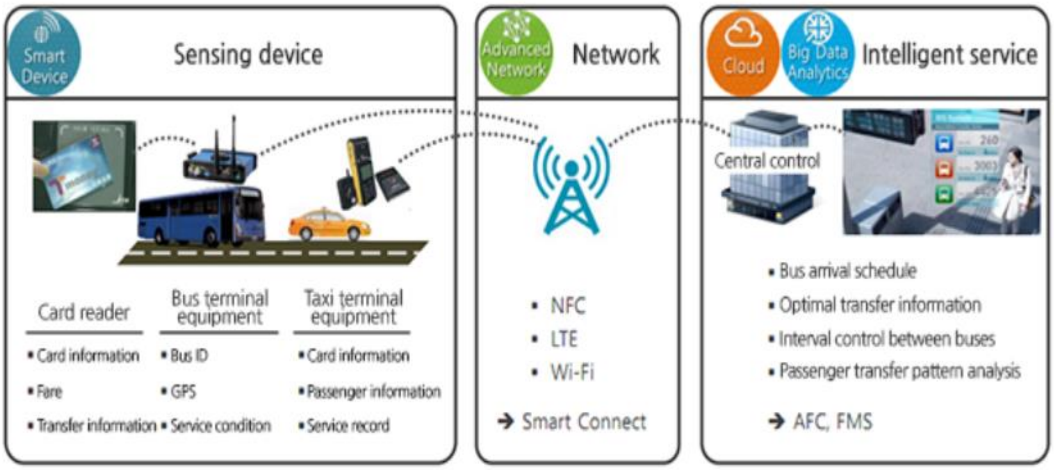

Figure 2.7 IoT for smart transportation [44]

2.9 IoT for Sustainable and Environmental Issues

The concept of sustainability has sparked an increasing interest amongst researchers. Closed-loop supply chain (CLSC) is a sustainable design that attracts considerable attention due to the increase in environmental concerns and important economic impact of customer returns. CLSC is an effective means to collect customer returns and recycle used items. Secondary markets are important channels to sell these products.

[49] aimed to design sustainable supply chain systems in the current business environment. They proposed a CLSC to solve a location–inventory problem (LIP) by considering the used products in the secondary market and the sales of new ones in the primary market. LIPs are NP-hard. Thus, the aforementioned authors developed a new heuristic approach by introducing an effective self-adaptive mechanism into differential evolution to solve the above-mentioned problem efficiently.

A mixed-integer nonlinear programming model was developed to optimise facility location and inventory management decisions jointly, and the logistics flows between the two markets were modelled precisely. Sustainability numerical experiments were conducted to validate the solution approach and provide valuable managerial insights. Results show that the algorithm is robust and effective and has better finance performance of the closed-loop system than Lingo. This work fills the gap in the existing literature on CLSC by incorporating the secondary market into the study of CLSC. This work is also beneficial in improving the sustainability and efficiency of modern supply chains. Sustainable supply chain networks (SSCNs) are attracting considerable attention as a means of dealing with various environmental and social issues. Environmental and social issues are important aspects of the design of SSCNs because they involve complex decisions that are related to strategic design and tactical operation within a dynamic and uncertain environment.

[50] studied SSCN planning under uncertain atmosphere to consider economic costs, environmental impacts and workplace hazard parameters. They used an interactive multi-objective fuzzy programming approach that combines the two-phase stochastic and fuzzy multi-objective programming in the design of an SSCN for measuring social objectives. The numerical analyses indicate that the proposed approach is a promising multi-objective problem under uncertainty decision environment. This approach can provide un-balanced and balanced efficient solutions for decision makers with compromise of the conflicting objectives. The proposed model aims to maximise social benefits whilst minimising economic costs and environmental impacts by helping in decision making in the following aspects: selecting production technology materials and determining the number of locations of production, distribution centres and quantity of products to be transported between facilities.

Two-phase stochastic variables were used to deal with the uncertainty related to customer demand, whilst fuzzy number programming was utilized to handle the overall costs, carbon emissions, job opportunities and detrimental effects of the resulting solutions. However, this approach strongly relies on the preferences of the decision maker for parameters (e.g., the compensation coefficient of objectives) and their confidence level to deal with flexible constraints (e.g., the a-cut level in selecting the final preferred compromise solution). Numerical analysis demonstrates the efficacy and efficiency of the proposed model in solving large-scale problems due to its computational advantages. However, the model is suitable only for designing SSCNs with a single product and environmental and social impacts. The performance of the model also highly depends on the capacity of facilities opened on the network [50].

Open-shop scheduling problem (OSSP) is a popular topic with vast industrial applications and is an important issue in the field of engineering. OSSP is NP-hard and has a wider solution space than other basic scheduling problems, namely, job-shop and flow-shop scheduling. Thus, OSSP has attracted considerable attention from many researchers over the past decades. Numerous algorithms have also been proposed for OSSP.

[51] investigated the effects of the selected crossover and mutation operators on the performance of genetic algorithms (GAs) in solving OSSP. They found that the operators greatly influence the efficiency of the GA. In other words, the performance of the proposed GA (EGA_OS) in solving the OSSP is largely dependent on the type of crossover and mutation operators used. The use of suitable crossover and mutation operators in EGA_OS results in a goal-oriented dispersion of the chromosomes in the problem space and leads to better solutions. The proposed algorithm (EGA_OS) was evaluated by comparing it with other existing algorithms. The results show that hybrid selection of genetic operation type greatly influences the quality of solutions for OSSP. The use of the one-point crossover operator along with the displacement mutation operator also finds better solutions at a short time. The proposed algorithm can find highly optimal solutions for all kinds of problems at a shorter computational time with higher objective values than the other developed algorithms. However, applying different operators increases the time complexity of the proposed solution method compared with those of state-of-the-art methods.

[52] Proposed a hybrid metaheuristics algorithm to solve a job-shop scheduling problem (JSSP). This algorithm integrates three metaheuristic algorithms, namely, shuffled frog leaping (SFLA), intelligent water drops and path relinking (PR) algorithms. They proposed a random multi-neighbourhood-based SFLA with PR (RMN-SFLA-PR) by developing a simulation model. The authors firstly tested on the test data of traveller salesman problem (TSP) and then on real-world production lines to solve the problem of minimum needed workers at the production line.

The proposed RMN-SFLA-PR includes two different neighbourhood structures with random size block operation, namely, a random structure size and applied order of the multi-neighbourhood-based local search strategy and a PR-based local search guiding strategy. The proposed RMN-SFLA-PR was tested on a set of four benchmark instances (dj38) of the TSP to solve the JSSP using two software environments, namely, MATLAB and Simio. The obtained results are reliable, robust and tangible.

The computational results show that the new proposed RMN-SFLA-PR algorithm converges to the optimum at nearly 10 times faster than individual algorithms. The algorithm is also highly effective in solving combinatorial optimisation problems, especially in the cases of low dimensions. Theoretically, one worker is sufficient to complete all the machine checks in one shift for case C. However, the Simio simulation shows that the efficiency of the machine is only 85% in consideration of unexpected situations that may occur during the operation of the production lines. Therefore, case C should employ two workers instead of one to check the machines in one shift for solving the aforementioned problem [52].

2.10 Review of AI Techniques in the Healthcare Sector

AI is a general term that implies the use of intelligent machines to work and respond similar to humans by imitating human mental functions. Intelligent machines have increased human's efficiency and are expected to replace them in various domains that basically aim to enhance the welfare of the population in many areas. These machines are considered intelligent because of a subfield of computer science called AI. This term was first coined by John McCarthy in 1956 because it is concerned with making computers behave similar to humans by exhibiting the ability of the machines to think analytically.

AI has more advantages compared with natural intelligence because it is more reliable, affordable, permanent, can be documented, it also has the ease of repetition and distribution and can perform certain tasks much faster and better than humans. In other words, AI is the study of developing intelligent machines to enable them to learn, gather information, reason, communicate, manipulate and observe objects in solving complex problems. AI in medicine has two main branches, namely, virtual and physical.

The virtual branch comprises a study of information processing and computer science that includes the learning of health information management and controlling of health management systems, such as electronic health records EHRs and active guidance of treatment decisions for doctors. The physical branch is embodied in applied health devices, such as robots that are used to support elderly patients and robots that join the physicians. This branch is directed towards a unique and new drug delivery system called 'nanorobots'.

AI can be applied to a broad range of healthcare devices and data, such as medical diagnosis, medical manufacturing, medical statistics and human biology. In medical diagnosis, AI can be applied in different areas of any disease, such as early detection and diagnosis, treatment, outcome estimation and prognosis evaluation. Major disease areas that use AI devices include cancer, neurology and cardiology [12].

2.10.1 The Advantages of Using AI-based Healthcare System

AI applications have tremendous contribution in improving various areas, such as science, engineering, business, medicine and weather forecasting in addition to the increase in the quality and efficiency of the performance of the manufacturing and service systems. AI technologies have promising and profitable results in several practical applications, such as expert systems, natural language processing, speech understanding, robotics and sensory systems, computer vision and scene recognition, intelligent computer-aided instruction and neural computing. Whereas, the uses of AI techniques in computer games are described to solve the common problems and provide features to the games. In the banking databanks, AI helps in reducing their problems and increases the accounting accuracy and efficiency.

In the healthcare sector, AI applications have provided perfect amendments to the healthcare systems by improving the processing of healthcare data and empowering their analytical techniques. One of the most effective uses of artificial intelligence AI-based healthcare systems is optimising the clinical process. For instance, AI-based mobile apps can ask patients about their symptoms and provides easy-to-understand information on their health. In this way, the system uses (1) natural language processing to provide an extensive experience and (2) machine learning algorithms to create a map of patients' condition, thereby providing personalised experience [53] .

Moreover, AI is beneficial in monitoring patients' vital signs in real time. The treatment and prevention of dangerous diseases depends on the timely detection of symptoms. In various cases, early diagnosis can result in complete cure, whereas late or wrong diagnoses can have damaging results. Humans have difficulty making reliable decisions. AI algorithms can rapidly ingest billions of samples in short order and collect useful patterns. By contrast, machine learning algorithms can be used to generate the knowledge bases used in expert systems and in the predictive analysis of data.

Hence, an AI-based healthcare system is beneficial for patients and doctors. In hospitals, for example, nurses conduct rounds and visit each bed every few hours to manually measure and record patients' vital signs. However, the patients' condition may deteriorate between the time of the planned visits. This situation means that physicians often respond reactively to this type of problems, but an early visit may have improved the patients' wellbeing. The latest wireless sensors can capture and transmit patients' vital signs more often than the traditional methods. Furthermore, these measurements can be streamed using various new technologies. Real-time alerts can also be generated, and physicians can use these signals to respond more rapidly to unexpected changes [54].

2.10.2 AI and Historical Correlation in Healthcare

Obviously, innovative AI applications in various areas have triggered most authorities to restructure the healthcare sector for matching the technological advancements. This condition would be achieved by adopting decision support systems in routine clinical practices to support the healthcare personnel who rely heavily on patients 'medical information and healthcare environment to address the cost and quality problems of healthcare. Many researchers have used AI in various healthcare purposes, including disease detection, management of chronic conditions, delivery of health services and drug discovery. [55] Evaluated the application domain and usage of AI technology in the power system stabilisers model to maintain system consistency and assess the power system fluctuations caused by interruptions to provide high-quality performance.

[55] Investigated the importance of AI technique in network intrusion detection to protect the network from intruders and hackers by increasing the safety protection of the computer and communication systems. In the medical sector, AI is used to enhance medical image classification and develop hospital patients' care and therapy. [56] Studied thoroughly investigated the heterogeneous infrastructure and attained the best results for reducing medication costs by using tree and simple path cases for heterogeneous systems. Patients' disease history, test results and statistical data were recorded in the HER to enable health organisations in identifying potential data-centric solutions to reduce the costs of medical case studies. [57] Examined the influence of clinical decision support system (CDSS) in improving clinical practice and patients' care quality by minimising errors. They presented the major challenges experienced in the implementation of CDSS (including economic, moral, practical and public issues) and healthcare issues in Saudi Arabia. They addressed the requirements in implementing a successful CDSS with a real example. They discussed and explored the integration of CDSS by the health ministry in Saudi Arabia in the health area. They explained the needs for leading an effective CDSS integration. Similarly, this study mainly provides the requirements for a successful CDSS integration that are divided into three parts, namely, 1) CDSS content and knowledge, 2) incorporating CDSS with HIS, 3) value of idea provided by CDSS [58].

Scientifically, anticoagulation therapy can only be implemented by medication adherence. Currently, direct oral anticoagulants (DOACs) are a suitable alternative to warfarin. These medications comprise a wide therapeutic space, few medications, nutritional connections and fixed dosing without the need for laboratory monitoring. Although DOACs have reduced the need for regular monitoring, they have caused pressure on patients to self-manage in addition to their shorter half-life that makes treatment adherence a huge concern. Laboratory tests used to screen vitamin K antagonists are either sensitive or insensitive to DOACs to act as reliable measures of adherence. Consequently, suboptimal rates of adherence to DOACs are unobserved, causing patients to be at an augmented risk of stroke and bleeding. [59] Proposed a novel AI infrastructure to increase the medication adherence of existing diagnosed ischemic stroke patients. They used mobile devices to reduce the risk of nonadherence on anticoagulation therapy for those patients.

Their project was the first randomised controlled trial to compare the adherence rates of all 3 DOACs (dabigatran, rivaroxaban and apixaban) and warfarin through daily real-time monitoring against a control group and verified by plasma sampling. They highlighted the major limitation of existing approaches in measuring the adherence, such as studies that relied on claim data and patient self-reports to measure adherence, which were unreliable and other studies that used electronic medication set and provided a date and time stamp although they have limited effect on adherence, or studies that used adherence interventions (therapy, instructive, text messages and electronic nursing), which provided mixed results. They observed that all these approaches do not validate drug supervision, interpersonal differences, logistics and cost, making them inappropriate in routine clinical practice. Although blood levels are considered the best standard in previous methods, AI (AiCure, New York, NY) structures have the potential to accurately monitor medication ingestion on smartphones by visually automating a direct observed therapy using AI to change patient behaviour [60].

2.10.3 AI for Hospitals and Medicine

- In medicine, AI is divided into two sectors, namely, virtual and physical sectors. AI effectively guides medical practitioners in their treatment decisions. Virtual sector involves informatics medical approaches from learning data management to the regulation of health management systems and EHRs.
- Elderly patients receive assistance by using robots or attending specialists. Nanorobots are used as a unique new medicine delivery system. In this sector, nanorobots are used as a special new medicine delivery system, and this implementation requires additional reflection, confirmation of their medical usefulness, economy and the development of interdisciplinary strategies for their application.

- AI applications are useful to consumers because of the huge amount of data availability, combined with progresses in normal language processing and social consciousness algorithms. In particular, these applications are important in the healthcare and medicine sector where many information are obtained from patient medical records and data by using wearable health sensors [59].
- AI applications contribute to the development of inpatient care in many sectors, such as clinical decision systems. They assist in the early detection of tumours in medical images and diagnosis of different kinds of cancer and inborn heart defects.
- AI techniques and tools play an important role by reducing the error rates in diagnosing medical images to enable specialists for assessing the disease prevalence in the body of patients [58].

2.10.4 AI Challenges in the Healthcare Sector

Healthcare is a promising sector for AI because it has enormous abilities to connect and identify the patterns in large capacities of patient histories, medical images, epidemiological statistics and other data. AI can help doctors to improve their diagnoses, forecasts the diseases and provide treatments through remote monitoring and transforming of patients' chronic diseases. Healthcare administrations have experienced challenges in handling such huge amounts of information because of the rapidly increasing data production from sensors, smart devices and public networks. Certain requirements should be met to bridge the gap between the available techniques to data experts and real-world management problems. These requirements include:

Adoption

A major issue experienced by AI in the healthcare sector is common clinical adoption. This factor requires investment to build the workers' competencies in understanding the use of AI data systems and in trusting them during decision making. Healthcare providers must provide workers with the knowledge and skills required to use, sustain and operate AI systems by utilising AI capabilities. This process requires the changes in skills, mentalities and philosophy of the staff, such as data specialists and technicians who have to be well trained for management, team development, problem solving, and other monitoring skills. Education and training systems should be arranged to develop technology skills, and the workforce, such as AI developers and engineers, must be retrained to become acquainted with potential healthcare data systems. Technologies and applications and their benefits should be demonstrated.

2.10.5 Training Specialist and Patients

The use of AI technology in training doctors and patients is another crucial issue. Although AI technology can support doctors to improve their diagnoses, predict the diseases and modify treatments, some healthcare staff are not qualified enough to use this technology. Others consider learning the use of AI techniques or trusting them in decision making. These issues remain as huge challenges. Moreover, not all patients trust the information given by a machine or are afraid of their confidentiality. To address this issue, doctors, nurses and other medical professionals should be acquainted to work with the support of AI devices by trainings and updating their skills. Therefore, healthcare providers could improve their capacity by using AI applications to optimise data security and protection. These kinds of applications can significantly affect the physicians' and patients' ideas on using this technology. In other words, doctors and patients can overcome their doubts and learn how to accept AI technology through education.

2.10.6 Regulations

Conformity to legislation is a major challenge for applying AI in healthcare industries. Regulators would not accept the risk of an incorrect computer decision that affects a patient to prevent repeating a situation. Although AI tools have less probability to make mistakes than individual human physicians, powerful AI tools, such as profound NNs, remain a serious issue. Furthermore, existing agreement procedures are likely to control AI hardware rather than the data. Thus, authorities are required to support and protect the doctors and patients to ensure that they benefit from AI-powered digital services. Some legislation, such as the General Data Protection Regulation, which is a legal guideline for the collection and processing of personal information from individuals, should be enacted. The approval from the Food and Drug Administration (FDA) is required before applying the AI techniques in the healthcare sector. Therefore, medical AI data protection with the validation from the FDA poses a new regulatory challenge for the healthcare industry [61].

2.10.7 Big Data, ANN, and Machine Learning

With enormous amount of computational power, machines can analyse large sets of data points and apply real-time and predictive correlation modelling. Machine learning, deep learning and cognitive computing are various steps leading to a high degree of AI, although they are different from one another. Deep learning is a subset of machine learning that uses artificial neural networks (ANNs) to simulate and 'train' human brain connections, thereby providing answers to questions with nearly 100% accuracy. AI is the intelligence that makes machines intelligent. Machine learning is the process of implementing the computing methods that support this process. AI algorithms can predict post-discharge results, thereby reducing readmissions and optimising patient flow. That is, physicians can use these solutions to provide rapid, precise and manageable medical diagnostics. For a caregiver, identifying a pattern is the first step in further addressing a complicated treatment process. In this situation, AI and machine learning will perform the same tasks. Companion diagnostics will facilitate the determination of the gaps in the current data resources and lead towards a truly personalised medicine.

2.10.8 Machine Learning

Machine learning is defined as a process that involves computers using machine learning algorithms to analyse large sets of non-linear data, identify patterns and generate predictions that can be tested and confirmed. Supervised machine learning is available at a high level, in which outcomes will be predicted from available data and information from previous outcomes. In unsupervised machine learning, unknown patterns of outcomes will be predicted from the data. Machine learning can be used in health care by increasing efficiencies, saving money and saving lives.

All types of machine learning in health care can be divided into the proactive and reactive categories. Reactive healthcare involves reacting to an adversarial disease, injury, disorder or symptom. If patients suffer from fever and body ache, then they may react by visiting a doctor. Depending on the diagnosis, doctors may recommend antibiotics to help the body fight infections. In this situation, patients and doctors react to the symptoms [32]. By contrast, proactive healthcare performs the necessary actions before symptoms become observable. Patients can take a proactive approach towards their health (without waiting for a health problem) by boosting the immune system with vitamin C and antioxidants and by drinking plenty of fluids. Healthcare can be reactive if it satisfies the four basic principles of a reactive system, namely, responsive, resilient, elastic and message driven.

A responsive healthcare system refers to the achievement of the proper results of the prescribed medicines in all circumstances. A resilient healthcare system requires the engagement of all system components. An elastic system is scalable, whereas a message-driven system refers to the request–response messages for exchanging patient details across different hospitals. The latter provides the best of in- and out-patient service integration within and across healthcare systems. As an example, CT scan data can be analysed and cross-applied to patient records to identify those most at risk for diseases. Physicians can predict post-discharge outcomes to reduce readmissions and enhance patient flow, as well as provide rapid, accurate and accessible curative diagnostics.

2.10.9 Big Data and Data mining techniques

Big data technology has the potential to accurately influence machine learning capabilities. Moreover, real-time decision-making capability facilitates the improvement of the overall operating efficiency and reduction of unnecessary costs. In health care, machine learning plays a big role by understanding various parameters and correlating them with diseases. Whereas, data mining techniques have been widely used by health organisations because they provide healthcare authorities with significant knowledge towards a decision. Different data mining techniques, such as clustering, classification and regression, have been utilised by researchers in the healthcare domain to discover new perceptions by grouping patients and providing them efficient medications. In a project presented by Santhanam et al., they used evolutionary algorithms and clustering algorithms. They implemented K-means to remove noisy data, GA to find the optimal set of features, and support vector machine (SVM) to classify the diabetes dataset in India. The experimental results showed that the proposed model achieves an average accuracy of 98.79% for the reduced dataset of Pima Indian Diabetes from UCI repository. The proposed method attained better results compared with the modified K-means clustering using data preparation method with SVM classifier (96.71%), as described in literature [53].

In the same way, analysed the existing clustering approaches and proposed an effective genetic K-means clustering algorithm that uses a self-organizing map (SOM) to overcome the problem of finding the number of centroids in traditional K-Means and mechanically discovering the optimal number of sections in the data. In an NN viewpoint, the SOM data visualisation and clustering technique is efficient because of its unsupervised learning and topology preserving properties. [62] Used SOM in two-staged clustering algorithm to produce the prototypes in the first stage and used them in the second stage to create clusters. They applied a cluster accuracy metric in two healthcare datasets to evaluate the performance of the algorithm. The analysis showed that proposed method is accurate and improves the clustering performance along with valued perceptions for each cluster. The proposed method can be applied to various domains because of its supervision and scalability. [56] Presented an optimal big data sharing algorithm to manage the complicated data sets in telehealth with cloud techniques. Intelligent healthcare is applied to identify high-risk patients. This process can be utilised to minimise medical costs because most high-risk patients frequently require expensive healthcare.

2.10.10 ANNs based on Cloud Service

Innovative IoT applications combined with cloud-based network have provided tremendous advancements in all aspects of a new human's life. In particular, the healthcare domain has benefited from the cloud based IoT technique by enabling the medical services to competently access and manage the health service records from distant places. These mobile healthcare (m-healthcare) applications have provided a new platform to the public by acquiring regular health assistance to lead a healthy life. Medical specialists can efficiently diagnose the disease at an appropriate time before reaching the severe condition by timely collecting and managing the required data using IoT-centric healthcare applications. These medical applications enhance the accessibility and secured storage by using the cloud computing technology.

Many previous studies have been conducted in this direction. [63] Developed and implemented a new Cloud and IoT-based Mobile Healthcare application to monitor, predict and diagnose the levels of serious diseases based on their severity for providing better services to the patients. The new efficient approach was used to evaluate diabetes and related medical data, which involved three stages, namely, collecting the necessary data from IoT devices, UCI repository and medical records, storing the medical records securely on cloud database, and predicting and diagnosing the disease severity level of affected people.

The proposed system based on a new machine learning algorithm was called Fuzzy Rule-based Neural classifier, which was responsible for diagnosing the disease and reducing its severity. The results of the experiments on the standard UCI Repository dataset and real health records from various hospitals illustrated that this system outperforms the existing systems for disease prediction. [64] Proposed a new system for monitoring and diagnosing the disease level by using IoT with the cloud infrastructure. The proposed system was primarily used to predict the disease severity and to address student health. Key terms were extended to discover the computational science concept for producing client-based health measurements. They applied various classification algorithms to predict various diseases. Systematic health data were generated by using the standard UCI Repository and sensors. This framework can be used in medical field to predict various diseases that affect students with different severity levels. They used parameters, such as F-measure, specificity and sensitivity, to calculate the prediction accuracy of the system. The reliability of the proposed framework was verified by comparing it with the existing schemes in terms of prediction accuracy.

With the generation of huge quantities of medical data of patients, the access of medical specialists to these data is a common challenge in healthcare. Therefore, intelligent clinical decision support is a major factor that assists in predicting the patients' and providers' needs. EHRs signify the longitudinal experience of patients and doctors and are currently used in U.S. healthcare. In this context, [65] Developed a Doctor AI system, which is a common predictive model that uses the supervised medical conditions and medication usage by leveraging large historical data in EHRs.

The chronological system of Doctor AI is based on recurrent NNs (RNNs) that can learn efficient patient representation from a large amount of longitudinal patient records and predict future events of patients. Although the Doctor AI may degrade the patient's health, the reliability of Doctor AI is that it mimics the predictive power of human physicians and provides diagnostic results that are clinically meaningful. [66] Proposed a new convolutional neural network (CNN) based on multimodal disease risk prediction (CNN-MDRP) algorithm was using structured and unstructured data from hospital. They updated machine learning algorithms to accurately predict chronic disease eruption in disease-frequent communities. They used an inactive factor model to rebuild the lost data for overcoming the obstacles of incomplete data.

Their experiment was conducted on a local chronic disease of intellectual infarction. The modified prediction models were used to evaluate the real-life hospital data collected from central China in 2013–2015. The results showed that the proposed algorithm was more reliable and faster than that of the CNN-based unimodal disease risk prediction algorithm because its prediction accuracy reached 94.8% with a convergence speed. It is obvious that smart health applications are the most vital domains that extensively transform the daily lives of populations in new era of smart cities. Using IoT wearable computers by personal devices with the connection to the cloud infrastructure, body smart sensors, such as vital signs heart rate and temperature can be continuously traced for real-time health management and long-term health statistics.

Although these smart health sensors and applications enable patients to access the doctors' instructions and medicine records, their security and privacy requirements have increased. Physiological signal-based biometric human identification should be considered to protect sensitive patient data and confidential biomedicine results.[67] Proposed an innovative wavelet domain multiresolution convolutional ANNs for biometric human identification applications to overcome the existing challenges of signal processing and feature engineering. The challenges of signal processing and feature engineering are data dependent, complex, time consuming and require suitability of specific datasets. Therefore, this project conducts blind biological signal selection for user identification purpose to effectively avoid complicated and data-dependent signal event identification (e.g. ECG R peaks) for enabling a data-independent and highly generalisable signal processing and feature learning process.

The process would lower the algorithm engineering segmentation effort and exceedingly increase the generalisation capacity of the algorithm suitable to other quasi-periodical biometric signal-based user identification applications, such as Photoplethysmogram, ballistocardiograph and body movements (walking, running, etc.). Furthermore, the random chosen signal segment is transformed from the time domain to the wavelet domain through autocorrelation where multiresolution time-frequency representation is achieved to enrich the time-frequency data representation and remove the phase difference causes by blind segmentation. [67] Introduced a parallel 1D-CNN to automatically learn multiscale hierarchical features from the wavelet domain raw data, which can significantly perform the ECG-based user identification task by the effect of many wavelet and CNN topologies.

The effectiveness of the proposed algorithm is extensively evaluated on eight ECG datasets with diverse behaviour, such as with or without severe heart diseases and with different sensor placement devices and compared with existing advanced algorithms. This study demonstrates that the proposed blind signal processing and deep learning techniques can effectively identify human subjects from randomly selected signal segments and without heavy feature engineering efforts and provide a good generalisation ability for biometric human identification applications.

2.11 Summary

This chapter presents representative examples from a comprehensive survey of various studies that demonstrate numerous manipulations of the integration of IoT, cloud computing and mobile core network with the help of the promising 5G technology. This integration is anticipated to provide promising solutions for generating a smart world. In the literature review, several experts have highlighted the capability of the IoT in connecting a plethora of digital devices with several sensors, actuations and computing capabilities with the Internet, which will offer new diverse services in the context of a smart city.

Therefore, IoT is used by diverse specialists in numerous scenarios of multifaceted services, such as medical care, transportation, industrial mechanisation and environmental monitoring. Hence, most authorities believe that IoT can play a significant role in rendering various applications in daily and social lives and improve their quality. Although numerous works have investigated the significance of the advancement of medical devices to enhance the required level of performance and guarantee their accuracy and reliability, only a few works have highlighted the importance of revolutionising the old-fashioned maintenance approaches that remain applicable in healthcare systems and services.

For example, many previous studies have focused on IoT related to healthcare systems, but studies related to the management of health and safety products are unavailable, apart from one research. This research mentions that companies experience pressure from clients, insurance companies and regulatory bodies in terms of transparency. Moreover, technologies are increasingly being introduced into industrial workplaces to promote health and safety, prevent liability risks and improve auditing and verification. Consequently, most healthcare administrations have faced the challenge of detecting critically low equipment, which would have been improved if efficient real-time monitoring equipment is available.

The proposed architecture, which is based on IoT real-time monitoring framework, confirms the comprehensive prominence into H&S devices and provides the capability of predicting possible failures. Furthermore, this chapter provides a generalised framework for personalised healthcare that influences the advantages of remote monitoring, cloud computing, big data and machine learning. The framework provides a systematic approach to support the rapidly expanding data of people with severe diseases by simplifying the task of physicians and not overwhelming them with false alerts by using IoT-based cloud computing in predicting diseases. It also highlights and explores the historical relationship between AI and the healthcare sector and illustrates the benefits of AI in the healthcare domain, such as cost reduction, prediction and diagnosis of disease, doctor assistance in many complex areas in healthcare. The use of AI in the healthcare sector significantly influences the monitoring, management and decision-making of patients and clinical staff members. Moreover, several factors affect the decision-making on the use of AI in system learning and predictive ANN.

Where AI algorithms can collect big data in short order and time, machine learning algorithms can be used to generate the data bases used in expert systems and in the predictive analysis of data. Hence, in this proposed system, the benefit of the AI-based healthcare applications, such as ANNs, general algorithms, and ant colony optimisation, include the generation of the effective solutions. Similarly, these algorithms can support the 'salesman' in identifying the critically low health and safety equipment in the shortest route and least time

3. Chapter Three: Network Modelling of H&S Infrastructure in Hospitals

3.1 Introduction

The remote interconnection amongst patients and general practitioner centre provides considerable advantages to patients and therapeutic centres. Patients can obtain rapid response and guidance in appropriate time to reduce the number of patient reviews and entry and exit visits to therapeutic centres [60].

This chapter discusses the network modelling system (H&S) product infrastructure in hospitals and its simulation system loop in MATLAB software. This chapter describes the use case components, design, system interactive components and communication interfaces of the system. AI is used to support salesman operations, such as short path routing and clustering into regions. The structure, operations and functionality of the main system interface and battery state are illustrated in the H&S product usage modelling.

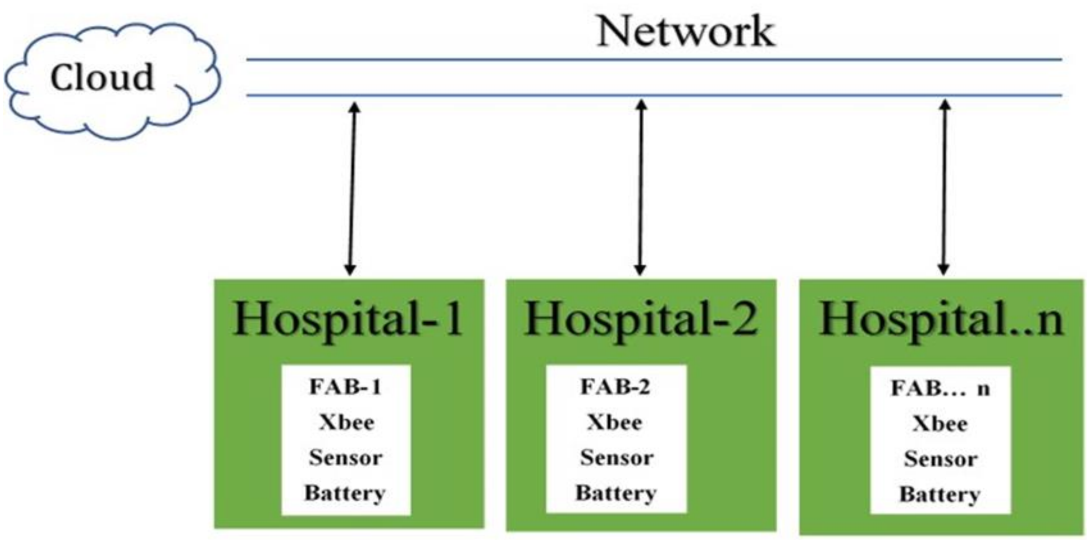

Figure 3.1 Network H&S products infrastructures in hospitals

3.2 Probability of Accidents in the UK per Day

Companies experience considerable nonfatal injuries of employees at work every day. In Table I, the statistics indicated that approximately 340 accidents per day occur in different locations of companies in the UK [68] (Table 3.1). The first aid box needs to be immediately available, indicating that the first aid box might be used 340 times per day and requires being available in case people or employees experience an accident. A roulette algorithm can be used to find the probability of the location in which an accident occurs within companies in London in proportion to the population size of the company.

Table 3.1 Probability of the number of accidents in the UK per day

Employees Number / Company	**Av Employees / Company**	**Total Av of Population / Area**	**Number of Companies / Area**	**Probability of person working for a size of company**	**UK Accidents / day**
1–4	2	3276310	1638155	0.168545519	57.44682
5–9	7	520065	74295	0.02675407	9.11882
10–19	15	2045625	136375	0.105234525	35.86799
20–49	35	2566725	73335	0.132041839	45.00496
50–99	75	1737375	23165	0.089377004	30.46313
100–249	175	2334500	13340	0.120095325	40.93312
250–499	375	1614375	4305	0.083049428	28.30645
500–999	750	1571250	2095	0.080830919	27.5503
1000+	1500	3772500	2515	0.19407137	66.14702
Total		19438725			340.8386

3.3 Roulette Wheel Method

Roulette wheel selection, also known as fitness proportionate selection, is a common genetic operator used in the GA to determine the possibility of an individual chromosome, which is directly related to fitness. This fitness level is used to associate a probability of selection with each individual chromosome. Fitness level was first proposed by Holland [69], who assumed that the selection is similar to a roulette wheel game, in which the selection probability depends on the central angle of the roulette wheel where each individual obtains a portion of the wheel, and more fit ones obtain larger portions than less fit ones. Systematically, this approach is the simplest where all chromosomes (individuals) in the population are positioned on the roulette wheel slots based on their fitness values. Each individual is given a section of roulette wheel, in which its size is equal to the fitness value of the individual. The roulette wheel stops on the section where the individual is selected, and the recurrence of this process determines the preferred number of individuals are selected. Individuals with high fitness have high probability of selection. Similarly, parents are selected based on their fitness. The better the Chromosomes have high chances of being selected when they are of good quality [70]. The limitation of this selection is the bias towards high fitness individuals, leading to the possible missing of the best individuals of a population. Good individuals may not find their way in the next generation. Thus, the roulette wheel selection depends on the utilisation of this approach. By applying this approach, the probability of locations that accidents might occur in the UK per day can be determined.

Official reports indicate that many daily accidents occur in different workplaces in the UK. The use of roulette method provides huge benefits and assists in determining the probability in which locations an accident might occur. This process supports the emergency team to present the optimal service in helping and ensuring the safety of injured people. Another advantage is that is enable companies and ambulance car team to establish a good plan to move the injured employees from the accident location to the nearest hospital in a short time and way for providing first aid to the injured employees. The distribution probability of the number of accidents depends on the company size and its number of employees.

3.4 System Simulation Loop

In the system simulation, the mean interarrival time is calculated by using the following formula:

$$T_{mean} = -\frac{\log(1-p(x))}{t_m} \qquad (4.1)$$

where T_{mean} is mean interarrival time, $p(x)$ is the probability, and t_m is mean duration An object for First-Aid-Box (FAB) and an event list for Open and Close are created, each open and close events are inserted with the increasing order of time, the source identification address (ID) for next event, simulation time and type of start node are obtained, where the Type is 'Open', the next start packet event is created and inserted in the event list, and the parameters of next event are obtained and inserted into the event list.

3.4.1 Running the Simulation

As shown in figure (3.2) during the simulation, the application read information from database to obtain the previous state of all shelves and battery state. The simulation time and threshold are set in the GUI. The open and close times of the nodes are calculated at the beginning of the simulation by using the class Event-Node. The time is calculated to close the shelf when the node is opened, and the next node is inserted. The battery state is read, and the opened shelf is determined.

The node remains active when the battery charge is higher than the limit. The change in weight of the shelf determines which toolbox is removed from the shelf. The reduction in weight is sensed by the sensor and updated in the database. Simulation time set in a minutes or seconds, If the simulation time less than 200 the application will get next event ID, and type then, event timer will check if the box is open, then record simulation time for close will get ID of next event and buttery state then, iterate same process for n box. While, if box is closed, sensor sense number of items taken from change in weight, calculate energy consumption and get battery state. Furthermore, if the simulation time more than 200 store the information in the database and end the simulation.

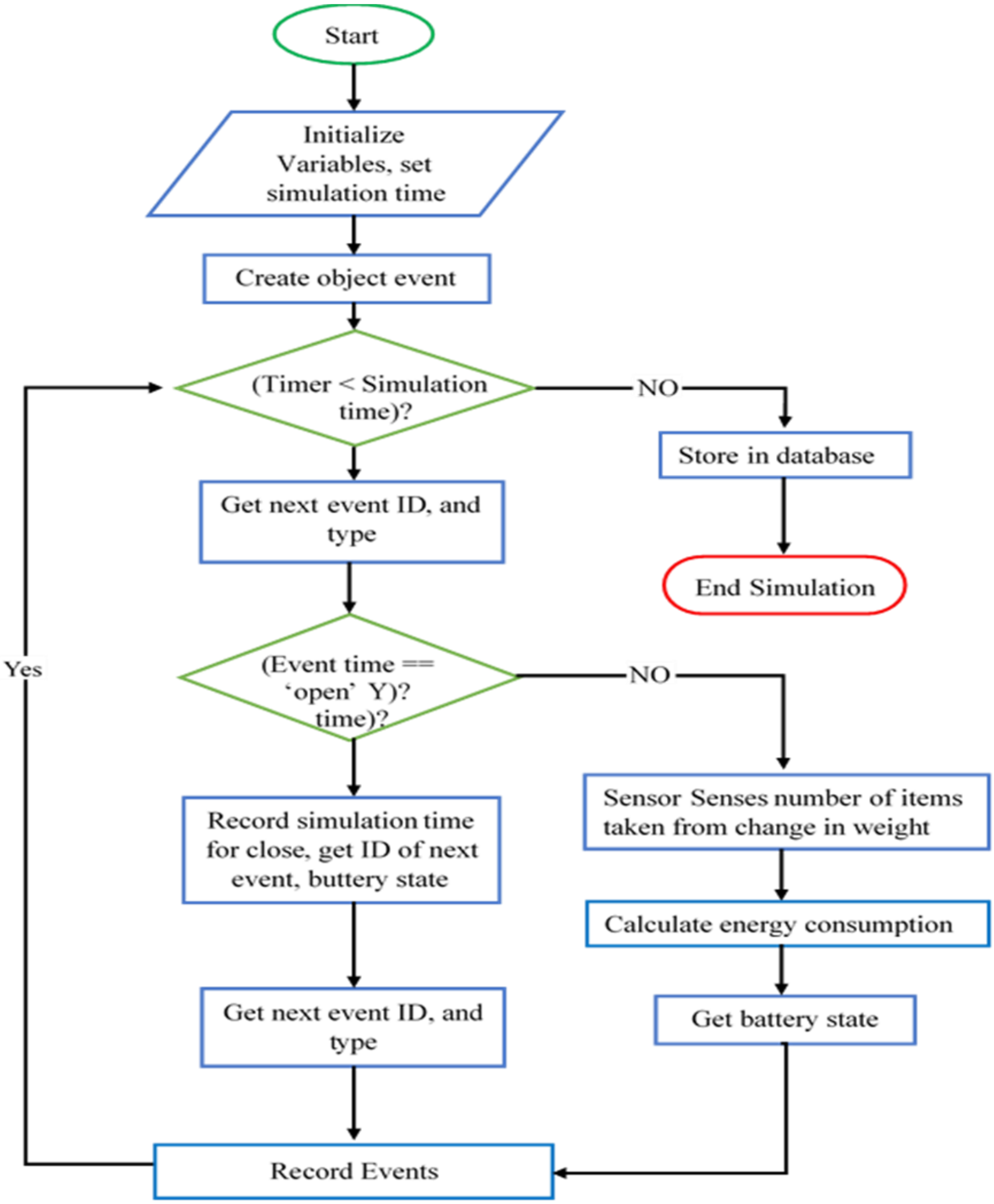

Figure 3.2 IoT operation (algorithm simulation)

3.4.2 Event List Design and Operation

An event list is designed by using a doubly linked list (DLL) and has two references, namely, the next and previous nodes.

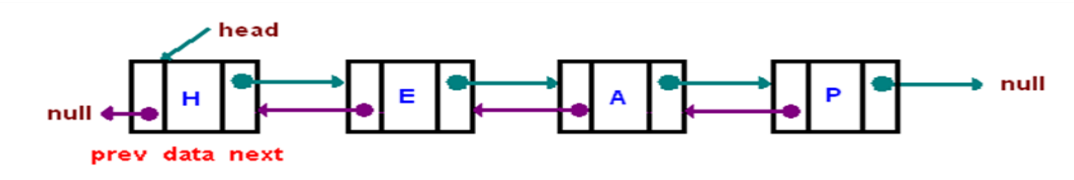

Figure 3.3 Design of linked list

3.4.3 Linked List Operations

- Add first: A node is created and added at the beginning of the list.
- Inserting After: Find a node that contains ‘key’ and insert a new node after it.

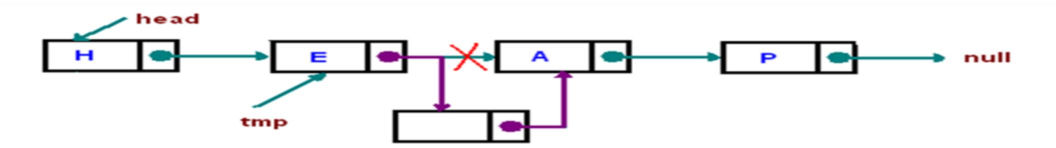

Figure 3.4 Insert node after

The below diagram explains how to find a node that contains “The key” and insert a new node before the current one.

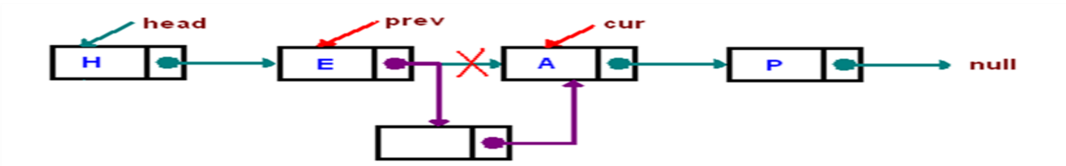

Figure 3.5 Shows the node inserted before current

The following diagram shows how to delete nodes that contain “The Key”

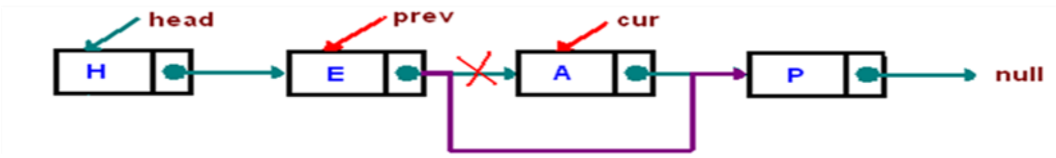

Figure 3.6 Expresses how to delete nodes from the simulated software

The algorithm is similar to insert ‘before’ algorithm. Two references, namely, prev and cur, are used. The two references are shifted when it is moved along the list, in which prev is maintained one step before cur. It continues until cur reaches the node that needs to be deleted.

3.5 System Design and Use Case Interaction

In this modern era of advanced technology, most commercial administrations have experienced several adversities in their businesses. Therefore, most of these organisations have benefitted from this technological advancement and transformed their manufacturing procedures from the traditional labour-intensive to an up-to-date high-tech process. Software modelling system is a new consistent electronic system that helps professional businesses in their process. It plays a crucial role in manufacturing sectors and has a radical impact on any organisation's future. Unified Modelling Language is an eminent software that is recognised and manipulated as a standard language by most industrial organisations. It is a powerful standardised graphic modelling language used in system analysis to classify, clarify and arrange system requirements. It is also used to enable designers to specify, visualise, construct and document items of a software system to make them scalable, protected and robust in their performance. The improvement of technology has stimulated businesses to change their style from manual to IT for developing their manufacturing processes.

3.5.1 Components of the Use Case Diagram

1. Actors: they generally represent the users, organisations and external systems related to the application or system.
2. Use Case: it exemplifies specific tasks performed by one or more actors to accomplish a goal.
3. Boundary: it describes a particular system related to the world around it.
4. Scenario: it refers to the specific arrangement of activities and connections between actors and the system.
5. The connections amongst the actors and the components of use case system consist of many interconnected components in which the system can be operated and monitored, as illustrated in figure (3.7). The actor is responsible for managing the system. Each component is responsible for performing a specific task [71].

3.5.2 Use Case and Main UI Description

The system consists of many interconnected components in which the system can be operated and monitored as shown in figures (3.7) and (3.8). The actor (service manager) is responsible for managing the system, each component has a function to perform a specific task as follows:

- Inter order Edit-Text box is enabled to select the simulation time order for running the system in minutes or seconds.
- Calculate interval time Edit-Text allows the user to run the system and has to selections, namely, 1) Motorway and 2) Non-rush hours. The salesman takes considerable time in rush hours and town area when their times are different.
- View Database Button type is enabled to display all the information related to the equipment state, such as active, low and critically low, and equipment location. The threshold value is set to 10% by default but can be changed to any value between (0 and 100), setting the minimum value of the battery in which it cannot operate and enters into a critically low state. Insert object button allows adding a new object to the database.
- Add Toolbox button in the interface will display a window that the equipment name required to be added with its initial weight/level and quantity is obtained, and the new equipment added will show in the list of the main interface by pressing the add button. The kind of equipment, such as first aid box, fire extinguisher and earplug dispenser, required to run it is selected,
- Salesman button will display new window to show the equipment locations, its state and a grand chart showing the percentage of equipment in each location.
- Run button type will start to run the system when it is pressed. Pressing Pause temporarily stops the code simulation and pressing the Ok button to continue running again.
- Radio button (Diagnostic panel). Type radio on/off button provides diagnostic information in a list box when pressed. No diagnostic information is generated, such as first aid box ID, type, and time when off, and the weight or level and equipment status, such as available, low and critically low and its location, are obtained when the first aid box opens and closes. The other part of the use case interaction system allows the add and delete processes through the system interface.
- Add New Location is used to add a new location. It takes the name of the location, longitude and latitude as input and updates the location in the database named location.xlsx and panel interface by typing the name of the location required to add it to the interface and database.
- Typing the longitude and latitude and pressing the add button shows that the new location is displayed in the interface.

- Delete Location: Any location on the database can be deleted using this button. Pressing the pop-up menu displays all the location in the list, and the desired location can be selected for deletion.
- Edit Location: Allows the location to be edited. The three parameters of location, namely, name, latitude and longitude, can be edited and updated in the database.
- Google Earth button enables to find the distance and time in miles between the locations.
- View location: The name of the location and its latitude and longitude can be viewed in a tabular format.
- Refresh type button: It is used to refresh and update the changed contents. Clustering type button shows the locations distributed to the groups, for example, make each 10 locations in one group (cluster) and display the cluster-ID and latitude and longitude of the location.
- Roulette button: It is used to find the probability of a workplace having an accident to support companies when employees experience injuries during daily working hours and to find the time spent between the injury workplace and hospital. Time and Distance button enables to determine the distance and time between two sources in miles and time in minutes.

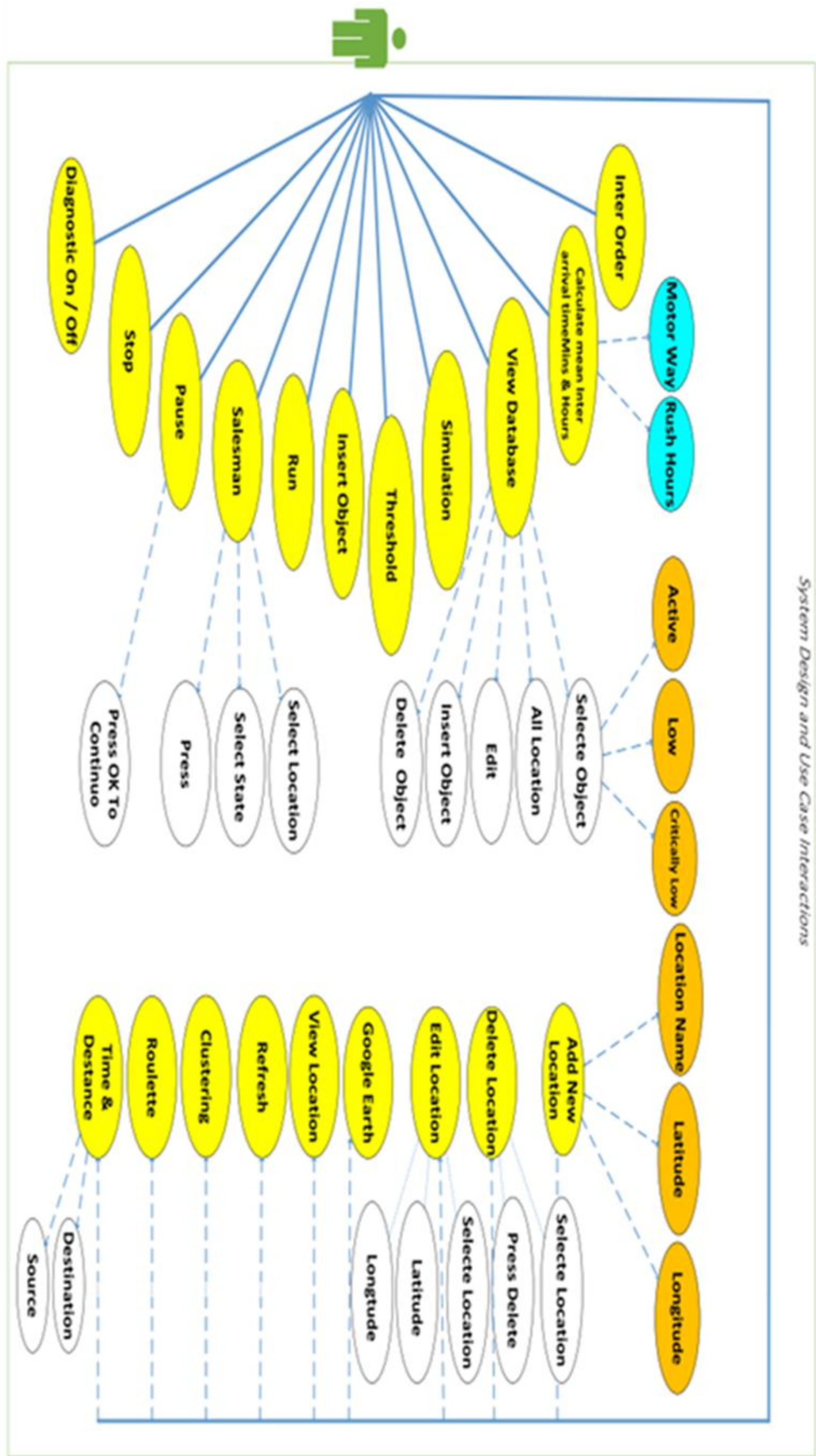

Figure 3.7 System design and use case interaction framework represent the system components distributed according to the component task connected, and the actor is responsible for controlling the system

3.6 Main User Interface (MUI)

As illustrated in figure (3.8), the main interface system contains many components to enable the user responsible for managing the system to apply many processes, such as add, delete and edit on the user interface and database. As described in page 48, the learning and prediction button type plots the salesman traveling path in visiting all locations under critically low state and requires maintenance or replenishment. The text box displays all the information related the locations, such as location name, first aid box ID, date, time shelf ID and battery state.

Figure 3.8 Main interface system

3.7 Event Nodes and Class

The system simulation consists of many classes and event nodes. Each class obtains a method.

3.7.1 Definition of Terms

A class is a set of things having similar property or attribute and quality.

Event Node: Class represents a DLL node. Each node contains a piece of data and provides access to the next and previous nodes. It consists of public and private variables as showing in the figure below (3.9).

Public variables are variables that can be accessed by objects of the class outside the class, and private variables can be only accessed within the class.

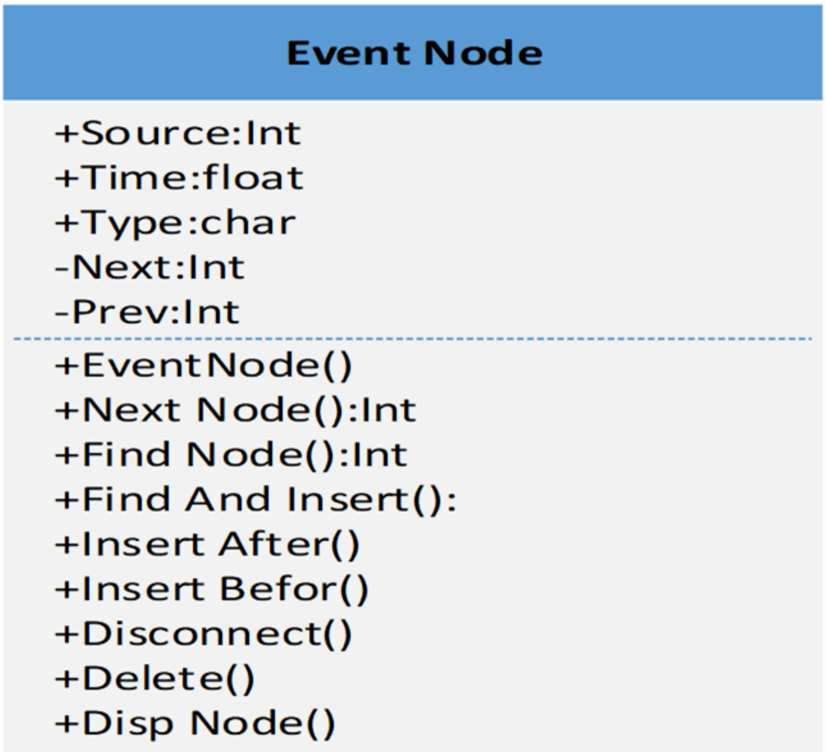

Figure 3.9 Event node class and method

3.7.2 First Aid Box Class

In the main interface (First Aid Box. m), the locations for all nodes are created, a uniformly distributed random value is generated to assign the probability for each node, mean arrival time is calculated, an object is created for First Aid Box class, and an object for Event Node is created to model the opening and closing times of the shelf.

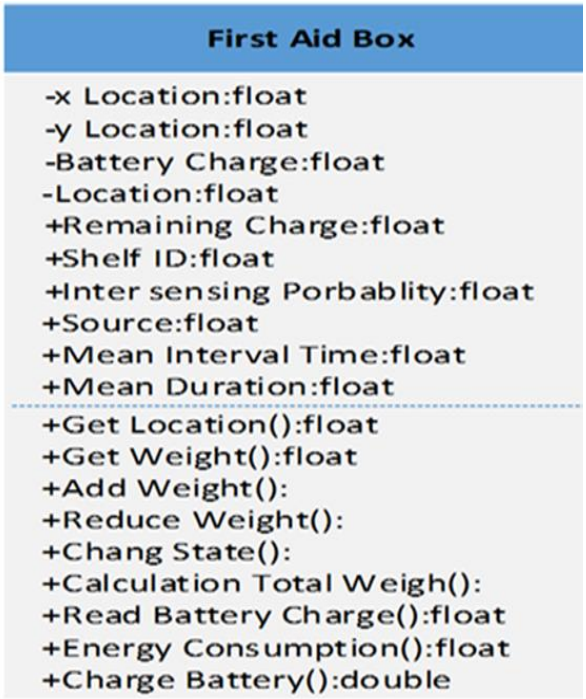

Figure 3.10 First aid box class and method

3.7.3 Database and Data Querying

The database can be searched based on location, battery state and database name. The states of all shelves and battery are displayed for the selected location. Likewise, the database can be searched depending on battery state.

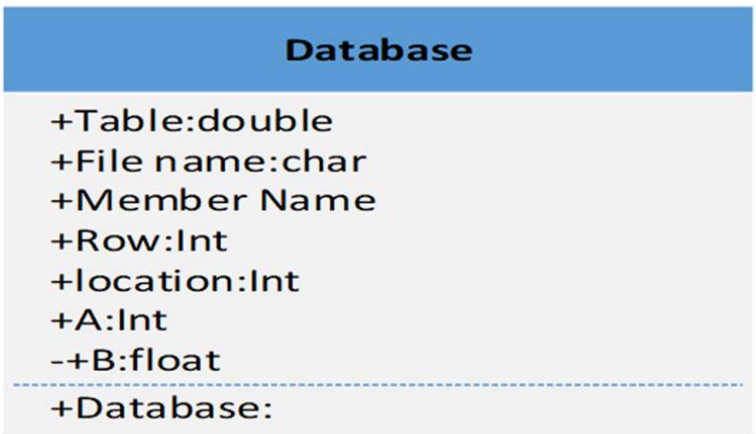

Figure 3.11 Database class and method

3.7.4 First Aid Box Inheritance Diagram

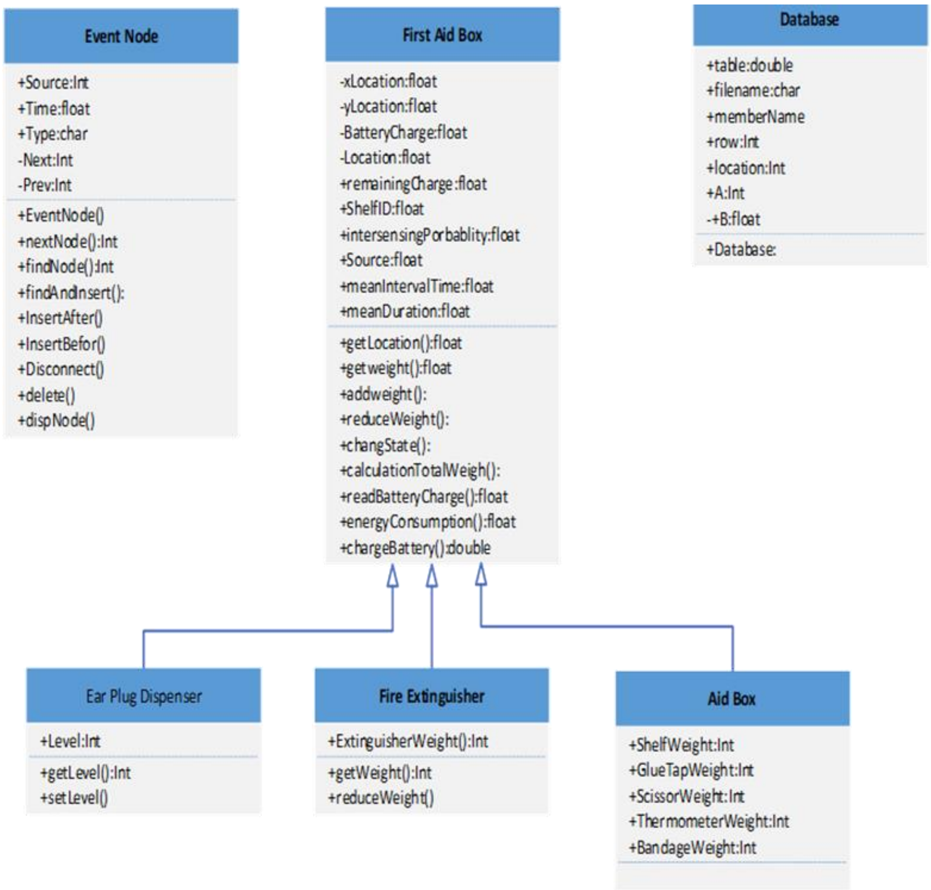

Figure 3.12 First aid box inheritance

Inheritance can be defined as the ability of one class (offspring class) to inherit the same functionality of another class (main class) in addition to its own functionality. This property is considered to be a significant concept in object-oriented design

3.7.5 Database GUI

The interface system (GUI) plays an important role in interacting with the database and allows communication amongst personal computer applications and databases [72]. It enables the building service manager to access and manage the data for easy monitoring. Another advantage is that the client does not need special experience regarding database languages, such as SQL. The manager controls who can access and edit the data [73].

The database button in the main interface system is enabled to display a new window that contains all the information related to products or locations, such as hospitals or companies. It enables the building service manager to access and edit the data and to perform many processes, such as insert new location, add new object, delete location or object and edit location or object as showing in the figure below (3.13).

Figure 3.13 Database information

3.7.6 Functions of the Main Interface Buttons

The function which is used to insert a new shelf at the selected location and is automatically updated in the database is “insert. m”, while the “delete data. m” function This function is used to delete the node from a given location and is automatically updated in the database.

3.7.6.1 Menu

Insert is a button type to insert objects, such as first aid box (FirstAidBox.xlsx), fire extinguisher and earplug dispensers, in the database.

Delete is a button type to enable the user to delete objects, such as first aid box database (FirstAidBox.xlsx), fire extinguisher and earplug dispensers, in the database.

3.7.6.2 Panel

Pop up Menu (Select Location): type Select Location to display in the table.

State (pop up menu): type select the state enable to display in the table.

Select (Push Button): type Click select pushbutton to display on the table

Edit Database (Push Button): type that enables the user to edit the information in the database ((FirstAidBox.xlsx)

Refresh (Push Button): type that refreshes the database.

3.7.7 Operations in the Database

Database operations enable the users to perform many functions in updating the database information in real time. Users can perform many operations, such as adding, deleting and editing information, in the database.

3.7.7.1 Adding, Editing and Deleting Hospital locations

3.7.7.1.1 Add New Location:

Location (Edit Box): This type allows to input the location name.

Latitude (Edit Box): This type allows to input the latitude of the new location.

Longitude (Edit Box): This type allows to input the longitude of the new location.

Add (Push Button): Clicking this button stores the new location in the database.

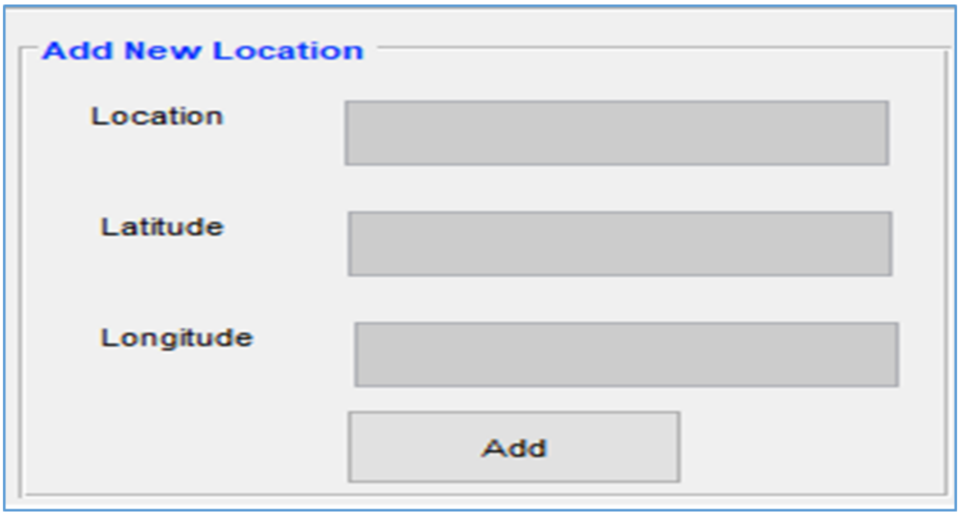

Figure 3.14 Adding location to the database

3.7.7.1.2 Delete Location:

Pop up menu shows all the locations in the database.

Delete (Push Button): This button deletes the selected location.

Figure 3.15 Deleting location in the database

3.7.7.2 Edit New Location using coordinates

- Latitude (Edit Box) allows to edit the latitude by typing the new latitude.
- Longitude (Edit Box) allows to edit the longitude by typing the new longitude.
- Location (Edit Box) allows to edit the location by typing the new location name.
- Edit (Push Button) allows editing and storing in the database.

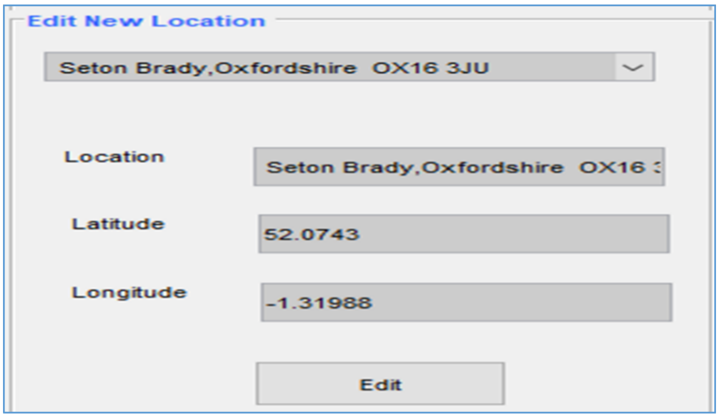

Figure 3.16 Editing location information

3.7.8 Adding, Editing and Deleting H&S Products and Consumables

Adding new equipment requires to call the add equipment window by pressing the add toolbox button in the main interface system and the name of new equipment is inputted in the name of equipment field with the initial weight or level and required quantity. The new equipment is added to the list of equipment in the interface system and in the database by pressing the press button, as illustrated in as showing in the figure below (3.17).

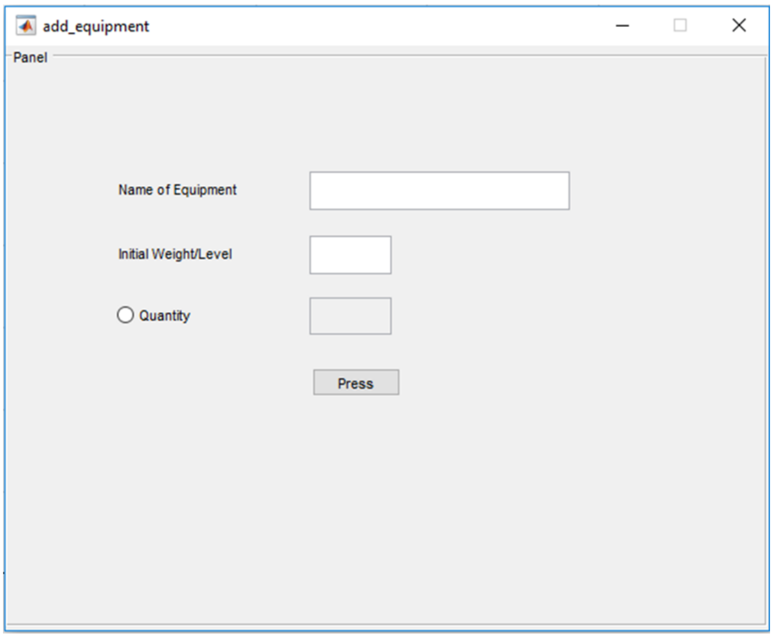

Figure 3.17 Adding equipment to the interface

As shows in as showing in the figure below (3.18), the system adds a new object to the database by selecting the location name from the list and is added in the database by pressing the insert button.

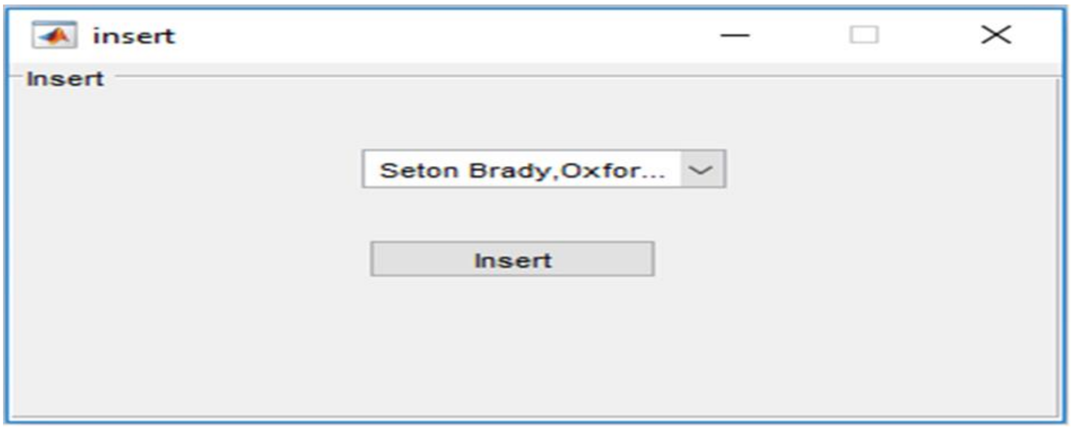

Figure 3.18 Inserting equipment to the interface application system

3.7.8.1.1 Delete Toolbox from Database

Deleting objects in the database. First aid box is deleted by selecting the location name from the list box, first aid ID number and shelf number and pressing the delete button as shown in the below figure (3.19).

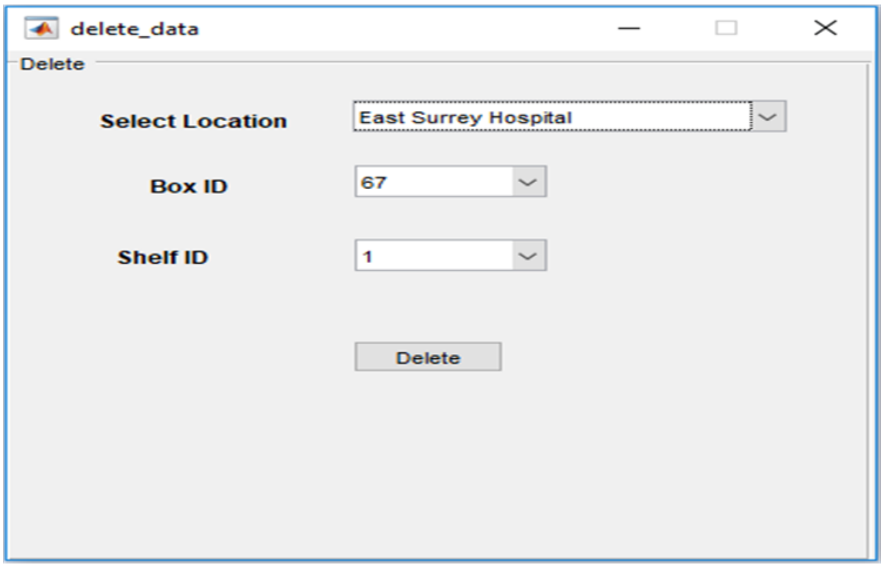

Figure 3.19 Deleting equipment from the database

3.8 Battery Management

Many methods, such as where reading after switching OFF the device (end of usage), are used to read and record data battery status using sensors. The sensors generate a signal and send it to the hub. The signal represents the battery energy (its current reading). The current reading declares the threshold. The sensor sends this reading status to the hub that contains a data record and a clock to print the date and time. The alarm is set to ON when the threshold is low. The hub sends a copy of this reading to the cloud that begins to compare the results between the current reading and threshold. The cloud sends an alarm or a target to the manager in three means after analysing the result. It either sends an SMS message, an email or records it on a website. The SMS has a short alarm to notify that details need to be inspected, whereas the email has more details about the situation. The website has more explanation of the details, such as the device number, place, energy status, company name and floor level. The state of energy level determines the situation. The system sends an SMS message to the manager who has the authority to access the management system by using a username and a password. The manager observes all the details regarding the situation by selecting the item. According to the importance of the details, the manager can determine how quickly the problem can be solved and which procedure can be used to remedy it, such as recharge or replenish. This process is recorded in a maintenance schedule. The manager sends the same SMS message to the available maintenance engineer who is responsible to fulfil the recharge or replenish procedures based on the maintenance schedule. The message can be automatically or manually sent either through an SMS message, an email or a website to the maintenance engineer. It is sent manually to ensure the arrival of the commands and alarms. After the procedure is completed, the sensor sends a new reading of the battery status to the cloud by the hub. The cloud sends new data to the manager informing him that the alarm status is off.

3.9 Battery Status Function Simulation

The battery has three stages (active, low and critically low), and the battery charge is calculated in terms of percentage. Initially, all the batteries are set to 100% as shown in the below figure (3.20).

State	Percentage
LOW	Battery Charge > Threshold and Battery Charge < Threshold + 20
CRITICALLY LOW	Battery Charge > 0 and Battery Charge < Threshold
ACTIVE	Battery Charge > (Threshold + 20)

Figure 3.20 Battery Status Simulation

3.10 Summary

Network modelling of H&S infrastructure in hospitals consist of many subnetworks, such as probability of injuries in UK per day, system simulation loop, system design and use case interaction. Several interfaces are defined to allow the communication between the hospital networks and to illustrate the system processes, such as adding, editing and deleting H&S products and consumables. The classes and objects of first aid box, database and data querying, and adding, editing and deleting H&S products and consumables are explained. Battery management and battery status function simulation are described.

The proposed network modelling of H&S infrastructure in hospitals comprises numerous subnetworks, such as probability of injuries in the UK per day, system simulation loop, system design and use of case interaction. Several interfaces are defined to allow the communication between hospital networks and illustrate the system processes, such as adding, editing and deleting H&S products and consumables. This study explains the classes and objects of first aid box, database and data querying, as well as the aforementioned system processes. Battery management and status function simulation are also described. The system used to identify the locations with critically low equipment is created, and the shortest routing path in the latest time is identified through AI algorithms.

by actively monitoring the status of critical devices in healthcare organisations and workplaces through ACO, TSP and GA in the proposed system, the salesman will be effectively assisted and supported to access the locations with critically low equipment efficiently. This process is also beneficial for saving time and cost. Similarly, using AI, particularly ANNs, to predict locations with critically low and near expiry equipment, is a key measure for improving preventive maintenance planning and asset optimisation.

4. Chapter Four: Scenario Definition, Simulation Results and Performance Analysis

4.1 Introduction

The IoT has revolutionised the healthcare sector by implementing sensors and actuators into IoT devices, such as wearables, to generate a huge amount of data. Monitoring the patient at home provides a report to the doctor about the patient movements and daily activities. Business analytics tools are embedded with IoT to assist humans to make appropriate decisions. The outcome affects the patient health quality and costs and reduces time [74].

This chapter presents the research motivation, followed by an explanation of first aid box legislation and the number of injuries in the UK per year. The weaknesses of management systems are described. The IoT in monitoring H&S product system along with the open challenges experienced by IoT are discussed. The main contributions of the research and study methodology are presented. The chapter summary is provided.

4.2 First Aid Legislation

With the increase in H&S consciousness in all aspects of life in the case of injury or accident at the workplace, most governments have established new legislations to protect human life resulting in the increasing likelihood of litigation by plaintiffs in the case of negligence by employers. In the UK, H&S (First Aid) regulations are established in 1981 that require all job sites and workplaces to meet the essential requirements for first aid performance, kits and management.

Depending on the circumstances in the workplace, employers must provide suitable and reasonable equipment, services and staff to ensure that their workers obtain an appropriate assistance when they suffer from a sudden illness or injury at their workplace to preserve their life, prevent their health from deteriorating or to support recovery. Scientifically, the human brain takes only 6 min to die due to lack of oxygen. Therefore, first aid is vital to minimise fatalities and provide urgent medical action to an injured person or suddenly becomes ill. Concerning the first aid equipment, employers are required to provide their workplaces with adequate and appropriate items that help to treat cuts, scrapes, injuries including sprains, burns, and supplies for various diseases.

An essential first aid box must contain basic items, such as bandages, plasters, antiseptic wipes and any supplies or equipment that are used to give medical treatment during an emergency.

Considering the kind of workplace hazards and risks, its size and other relevant factors, employers are required to assess the first aid needs continuously and regularly to determine

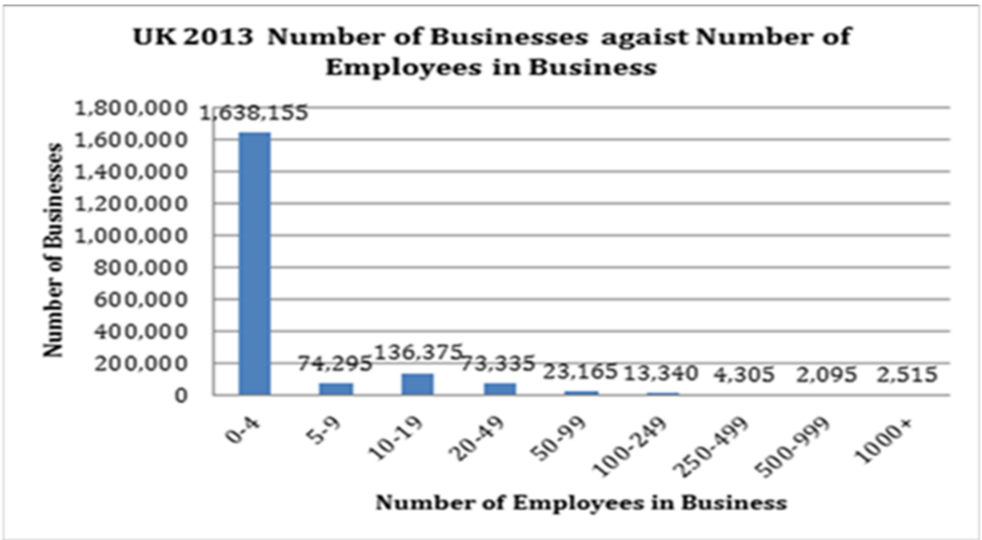

Figure 4.1 Number of businesses versus the number of employees in the UK in 2013 [75]

what kind of first aid equipment is needed or which one should be provided. Thus, the Work Health and Safety Act and Regulations requires that a first aider must be appointed to take the responsibility in providing an immediate lifesaving medical care before the arrival of regular medical help. A first aider must be trained to ensure that the right methods of administering medical assistance are provided and has the readiness and the ability to manage effective first aid in a life-threatening injury or sudden illness event in the workplace. However, the regulations do not put a legal obligation on employers to assign a trained first aider when the organisation is small (less than five employees) or is exposed to small risks as in clerical jobs, nor does it make first aid provision for nonemployees, such as the public. An appointed (trained) person is strongly recommended to take the role of looking for first aid kits and facilities and dialling the emergency services when required [76] as shown in the below figure figure (4.1).

4.2.1 First Aid Box Design

Each location, such as a company, a factory or a hospital, contains identifying address, hubs and H&S devices, such as first aid boxes, fire extinguishers and ear plug dispensers. Each device contains identifying address and sensors. The electronic sensor is powered by a rechargeable lithium-ion battery in which its charge state is regularly monitored, as illustrated in the figure (4.2). In this system, a special approach is used to monitor each equipment in the workplace depending on the measurement of weight, level and battery state. In a first aid box, two strategies are utilised, namely, 1) monitoring the first aid box without shelves and 2) monitoring the first aid box with shelves.

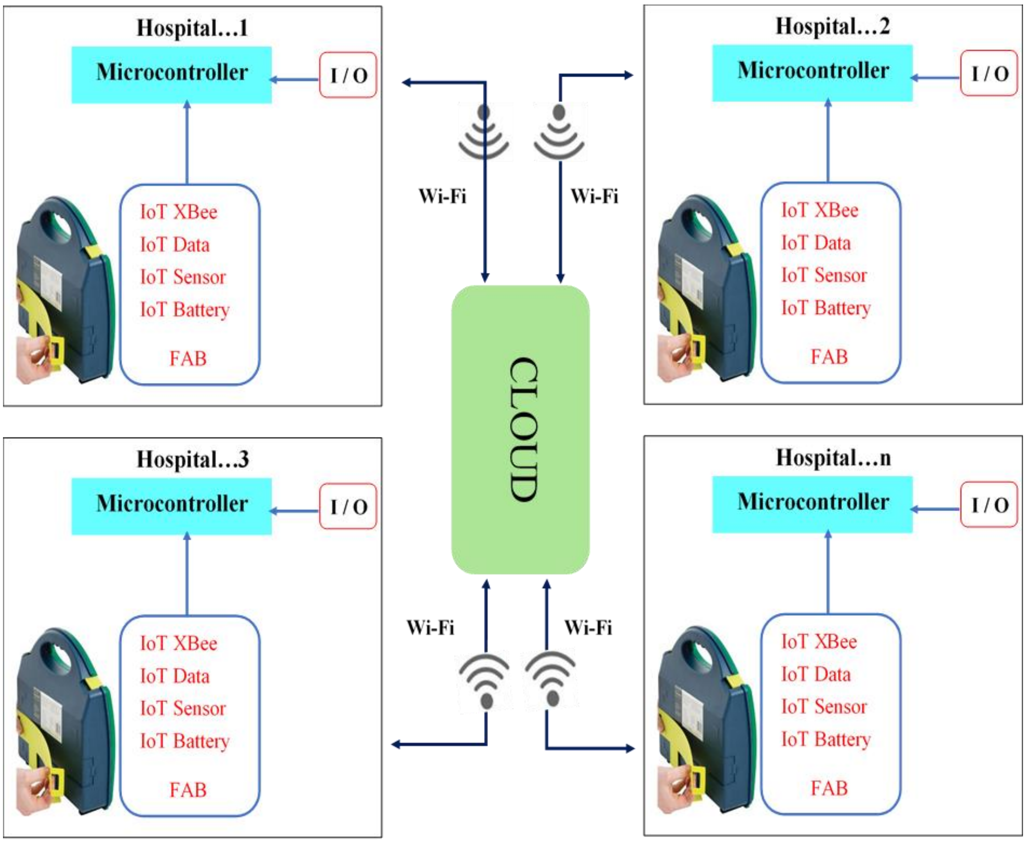

Figure 4.2 Network of first aid box in each hospital

4.3 First Aid Box Strategies and Design

The design of first aid box obtain two kinds, first is first aid box without shelves and other kind is first aid box with shelf as below.

4.3.1 Supporting First Aid Box without Shelves

The first strategy relies on measuring the weight change to monitor the boxes in different locations. Each box has a special ID address and specific weight. A flexible sensor is fixed inside the first aid box to read and send data when the first aid box is opened or closed. Measuring the total weight of consumables in a first aid box helps the building service manager to observe whether the box is opened (consumables are unused) without manual checking. The box door sensor records that a box is opened but the total weight of the first aid box shows no weight change. The total weight of the first aid box is taken by measuring the total weight of all the items inside the first aid box. The sensor reads when any weight change occurs and sends a signal to the hub as shown in the below figure (4.3).

Figure 4.3 First aid kit without shelves

4.3.2 Supporting First Aid Box with Shelves

The second strategy is used for the first aid box with shelves. In this strategy, the weight cannot be directly measured because the box is fixed on the wall using screws. However, the total weight of the box can be obtained based on the total weight of the consumables on each shelf. The weight of the box can be determined by measuring the weight of all items, such as conforming bandage (75 mm × 4 m) 120 gm has 10 gm, scissors 200 gm, gloves (pair) 150 gm, safety pins 100 gm, sterile wipes 100 gm and foil blanket 130 gm, a specific weight. In this way, the sensor will send a signal of the remaining weight to the hub to determine which item is missed by comparing the change in weight and considering the network architecture of first aid boxes in each hospital.

The hub holds a record of collected usage data, battery charge state and a clock. The data of H&S devices sent by the sensor to the hub are accompanied by an identification number of devices (i.e. device1, device2 and device3). The clock is used to obtain the time when the data are sent (i.e. hours, days, weeks or months). The hub keeps a record of the time period and the frequency of device usage. It keeps a record of the maintenance threshold, that is, defines how frequently the device is used before replenishment. The battery status data should be monitored to ensure that it has sufficient charge to operate the hub.

Then, all the usage data collected by the hub and battery charge state are regularly sent and stored in the database in the cloud to determine which device needs to be replenished. The cloud is monitored by the building service manager to identify which H&S product needs to be replenished. The two strategies provide huge benefits to save money compared with other strategies. Hubs are used because hospitals are supplied by Wi-Fi. Cellular communication is expensive and requires a high cost. The equipment required for monitoring are located inside the hospital, indicating that cellular communication is not required as showing in the figure (4.4).

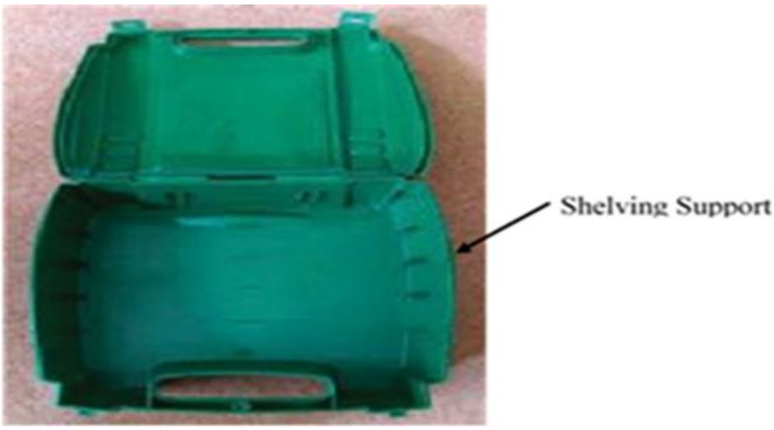

Figure 4.4 First aid box with shelves

4.3.3 AI Techniques

Shortest Path Routing

The database consists of latitude and longitude information of each location. The time and distance to reach each location are extracted from Google maps. The distance to each location from the starting point is arranged in ascending order. The location with shortest distance is selected to be the next visiting location from the starting point. The time is calculated based on the distance and average speed of salesman.

Supporting Hospitals with Regionalisation of Hospitals

The total time taken to visit all the critically low equipment is calculated as follows:

$$\mathbf{T_{total}} = \sum_{\mathbf{i=1}}^{\mathbf{N}} \mathbf{t_i} \tag{4.1}$$

$$N = \frac{T_{total}}{h} \qquad (4.2)$$

where T_{total} is the total time taken, N is the number of critically low equipment, ti is the time spent to reach next critically low location from the starting point up to five days a week, and seven hours (h) a day is considered as the working hours accomplished by a salesman, however, if the time is exceeded more than seven hours it will be considered a new day. Then the new cluster is created and serviced per day, and the number of clusters is proportional to the number of days of work. If is taken to visit all the critically low equipment is two days, then the number of clusters will also be two clusters. The number of clusters is equal to the number of days. The total clusters can be calculated as shown in the equations above. The algorithms which is used to create the above-mentioned clusters is K-means.

4.3.4 Simulation

During simulation, the database is read to obtain the previous states of all shelves and battery after the timer starts, energy consumption is calculated, and the state of each node is classified into active, low and critical states. The simulation time and threshold are set in the GUI. The opening and closing times of the nodes are calculated at the beginning of the simulation using the class event node. An event node is a class that is used on the event list in the simulator that keeps track of all events and is represented as a DLL of nodes. Multiple DLL node objects can be linked together to create linked lists.

Each node contains a piece of data related to an event and provides access to the next and previous nodes. The time is calculated to close the shelf when the node is opened, and the next node is inserted. The battery state is read, and which shelf is opened is determined. The node remains active when the battery charge is higher than the limit. The toolbox weight is defined, and the change in weight of the shelf determines that the toolbox is removed. The total weight changes determine which medical component is removed because there is the shelf weight and the weight of medical components inside the toolbox. The reduction in weight is sensed by the sensor and is updated in the database as showing in the figure (4.5).

Figure 4.5 First aid boxes open/close number of times

4.4 Simulation Scenario Definition

The total number of hospitals consists of 100 hospitals within the South East UK geographical area, which is listed in a table consisting of their name, latitude and longitude. The location and name are used to plot them on a map. Ten first aid boxes are used in each hospital, and each box contains four shelves. Each shelf is identified by their ID (1, 2, 3 and 4) (Table 4.1).

Materials from the first aid boxes are randomly used based on a negative exponential distribution, which is defined by its mean parameter, and their corresponding weight is detected by the weight sensor whenever it is removed. The information of a removed material in the toolbox is automatically updated in the database. A usage flag equals true indicates that the toolbox is opened, whereas a usage flag equals false indicates that the toolbox is opened but its materials are unused.

Hence, the total weight of the shelf is automatically updated depending upon the insertion and removal of materials from the shelves in the toolbox. The door sensor electronics on each first aid box is battery powered, and energy is consumed during the transmission and reception of information. The remaining energy level in the battery is recorded. The packet size transferred to the base station is set to 175 bytes. Energy is consumed, and the remaining battery energy is calculated. The energy of the batteries in the nodes is identified as ACTIVE, LOW or CRITICALLY LOW. The battery status greater than the threshold (threshold is set to 20% of total energy) and less than (threshold + 20) the node is considered to be LOW, and the battery status less than the threshold and the node is considered to be CRITICALLY LOW, otherwise the node is ACTIVE.

All information is regularly stored in the database, and only the critically low equipment is extracted from the database, which requires replenishment by the salesman. The critically low equipment is marked by a red marker, and the salesman algorithm is used to visit all the critically low nodes and replace their medical components and batteries to make them active again.

Table 4.1 H&S safety equipment parameters

Parameters	**Values**
Number of locations	Input from file
Number of nodes in each location	10
Sensing duration	5 s
Coordinates	Latitude and longitude (Read from the file)
Equipment	First aid boxes, fire extinguishers, ear plug dispensers, life jackets
First aid box	Bandage, scissor, thermometer, glue, tape
Fire extinguisher	Fire fighter
Ear plug dispenser	Earplugs
Life jacket	Jackets
Shelf weight	1000 gm
Scissor weight	20 gm
Glue tape weight	10 gm
Thermometer weight	5 gm
Energy Consumption/bit	185.9 NJ/bit
Initial battery charge	2 J
Extinguisher weight	5 kg
Ear plug dispenser level	100
Life jacket weight	1.5 kg
Total no. of life jackets	20
Threshold	20% of total energy
Simulation duration	200

4.4.1 ACO Process

As shown in the figure (4.6), ACO starts by generating m random ants, and an ant k (k = 1, 2, 3…. n) represents a solution with the selected value for each variable. Then, an ant is evaluated by using an objective function. The pheromone concentration associated with each possible route is changed in a manner to reinforce good solutions.

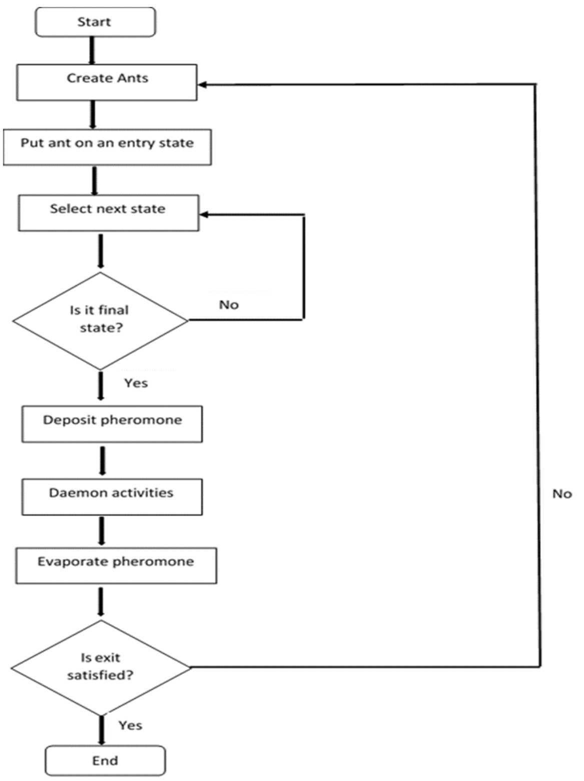

Figure 4.6 ACO flowchart

4.4.2 Algorithm Simulation

Several algorithms are implemented to enable the salesman to find the shortest routing path and latest period of time for supporting hospitals in appropriately maintaining or replenishing critically low equipment.

4.5 Supporting Hospitals without AI Learning and Prediction Using TSP

There are many methods to supporting hospitals, i.e. supporting hospitals without shelves, supporting hospitals with shelves, supporting hospitals without AI, supporting hospitals with AI, supporting hospitals without regionalisation of hospitals and supporting hospitals with regionalisation.

TSP is a combinational optimisation problem. It is a classic mathematical difficult optimisation algorithm that can quickly converge to a solution by using computational networks to solve difficult optimisation problems. TSP mainly focuses to reach the optimised solutions [77]. TSP is a famous algorithm and is widely used in various fields, such as engineering, science and other computational processes. It can be easily represented by a graph to define the places of a group of nodes [78]. TSP aims to find the 'best' route starting from one city, travelling to all other listed cities one by one and returning to the home city where the salesman begins in a short (or minimum) total path length. Here, the best solution indicates travelling in the least time, distance and cost. TSP are categorised into two groups, namely, symmetric and asymmetric TSPs. Symmetric TSP refers to the travelling distance that the salesman spends between two locations, such as A to Z, is the same as the spent distance from Z to A. TSP is asymmetric when the spent distance is different. Generally, asymmetric TSPs are more common than symmetric TSPs. Hence, asymmetric TSPs can be symmetric TSPs by applying certain algorithm to find solutions [79]. Although TSP is difficult to be solved because its class belongs to NP-complete problems, many questions can be modelled and solved as a kind of TSP problem. TSP is widely used because of its wide applicability, theoretical appeal and high representativeness.

As shown in the figure below (4.7), four different cases are used in the TSP algorithm implementation, and each case has different number of nodes; (a) 10, (b) 21, (c) 44 and (d) 49. Three performance parameters, namely, distance in Km, iteration number, and execution time in seconds, are used in measuring the algorithm simulation. Each case is run 50 times to obtain the outcome. The best total distance accomplished in case (b), which has a distance of 1.45 km. Regarding iteration, the minimum number is obtained in case (a), which has seven iterations.

The minimum execution time is obtained in case (a), which has 0.58815 s

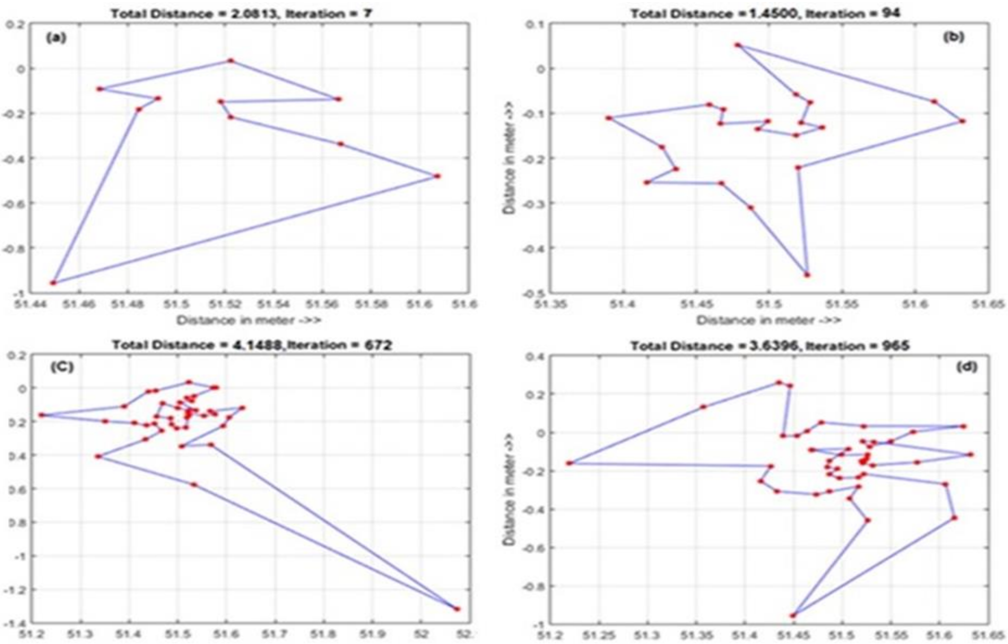

Figure 4.7 TSP algorithm results

4.6 Supporting Hospitals with AI Learning and Prediction Using ACO

Considering the unlimited connections and interconnections between heterogeneous devices through the Internet that lead to the concept of IoT, many intelligent web applications should be used to manage IoT systems. These applications collect and send the sensed data to the main manager for additional processes. A trusted routing procedure is required during data transmission. ACO is a tracking algorithm used to improve the best route selection for the transmitted data within the IoT system [80].

The metaheuristic search method is used for global optimisation to find the optimal path in a graph. ACO is an imitation of the performance of real ant colonies. Generally, ants usually use the shortest way from the food source to their colonies. Ants can trace a trail to help other ants to go through the same route by using a biological constituent called pheromone [81]. The algorithm benefits from the use of ant colony ideas in the IoT system to obtain the best route. This optimisation technique has been successfully applied to many engineering problems, such as structural optimisation [82].

As a classical combinatorial optimisation problem, TSP is successfully solved by utilising ACO. Figure (4.8) clarifies the ACO. Similar to the TSP algorithm, the same cases are applied to the TSP algorithm, where four cases have different number of nodes: (a) 10, (b) 21, (c) 44 and (d) 49. Three performance parameters (distance in km, iteration number, and execution time in seconds) are used to measure the simulation. After running each case for 50 times, different outcome results are obtained. The best total distance is obtained in case (b) with the value of 1.45 km. The minimum iteration number is obtained in case (a), which has one iteration. For the execution time, the least time is achieved in case (a), which is 1.419915 s.

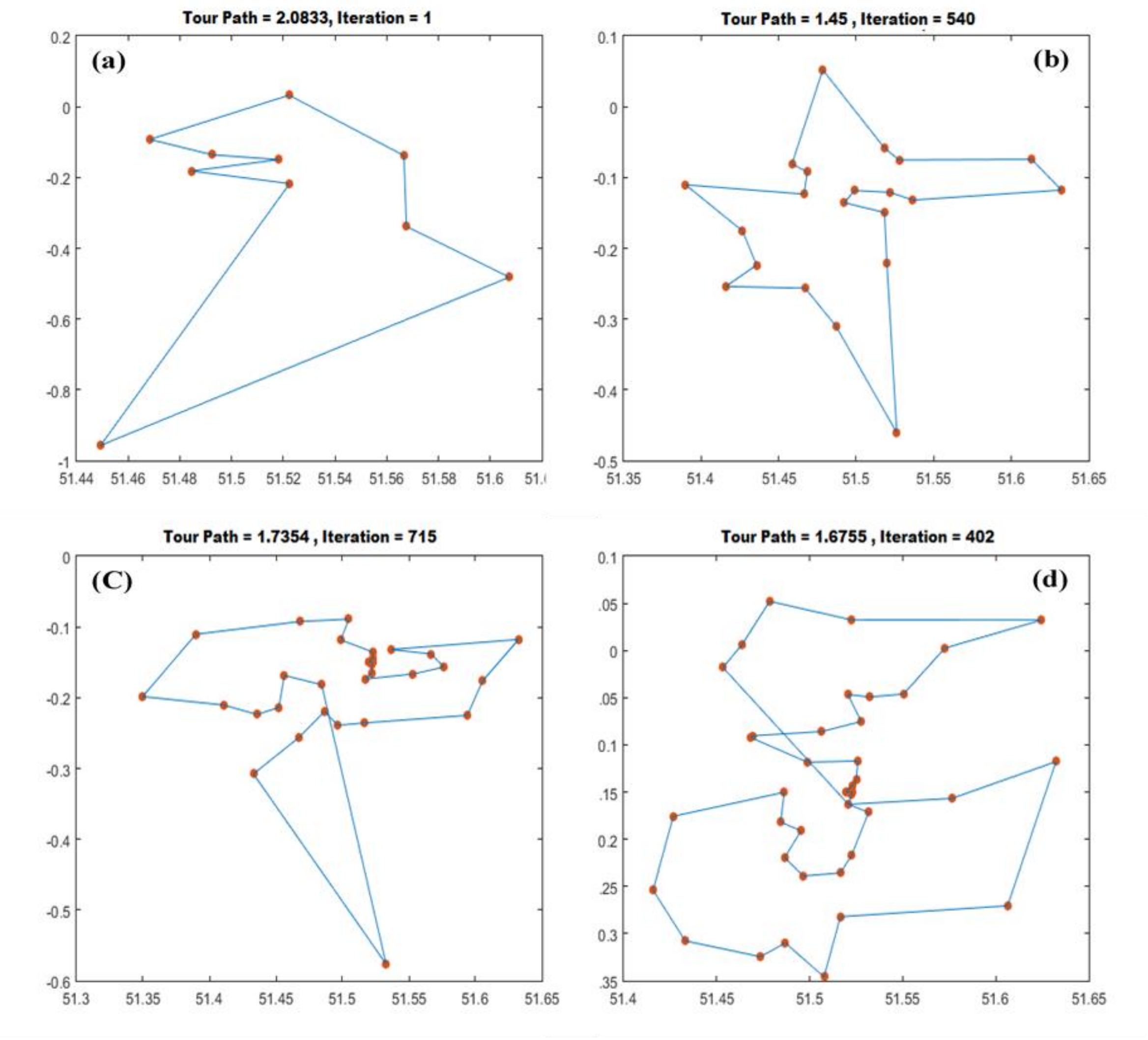

Figure 4.8 ACO results

4.6.1 Measurement and Monitoring of Earplugs Dispenser Levels through Image Processing

The use of an image sensor in a micro digital camera in addition to a laser light that is affixed at a certain level at the other side of an ear plug dispenser is considered to be effective in measuring the number of ears plugs in light and dark environments. This procedure operates by sensing the laser light with the image sensors of the micro digital camera when the device storage reaches the sensor level. The camera records an image of the storage when the laser light is transmitted through the empty level to the camera. This image is recorded and analysed, and the state of ear plug dispenser is recorded in the cloud database by the hub, which registers all the equipment data with a new time and date of recording. Analysis software periodically checks the state of ear plug dispensers, such as 25%, 50% and 100%, and sends a notification either by an SMS massage, an email or a website to inform the building service manager about the remaining number of earplugs in the dispenser, enabling him to decide of what action is required to guarantee the availability of earplug dispensers as showing in the below figure (4.9).

Figure 4.9 Empty and full ear plug dispensers

Depending on the colour of earplugs to be used, the suitable component can be determined to obtain optimal results.

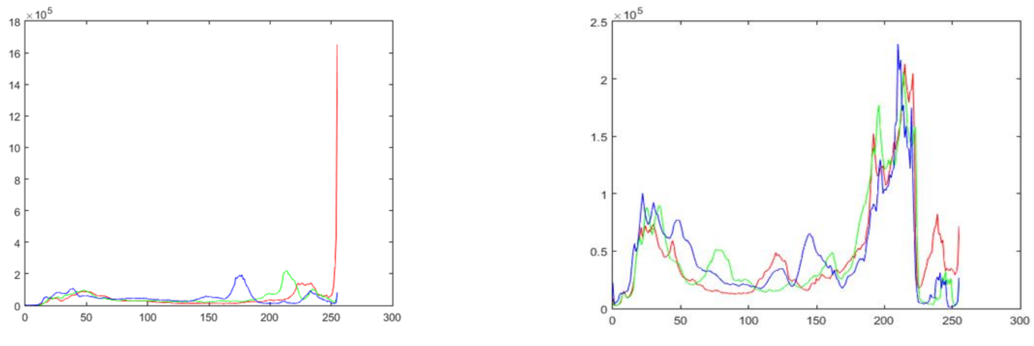

Figure 4.10 Full and empty histogram image respectively

The red component is used for explanation purposes. R (x, y) is a 2D plane that represents the intensity values of the red component of the image. The next step is to subtract the values of the empty image from the full image, which is illustrated and discussed as follows:

Figure 4.11 Full minus full dispenser and Empty minus full dispenser

Figure 4.12 Thresholding the full red component over the mean of empty dispenser

Two approaches are used to identify whether the jar is empty or not in the experiments.

The first one is illustrated on the above images, where the values of the red component of empty dispenser is subtracted from that of full dispenser. The results are shown in figure (4.12) and represented as:

$$Rs\ (X, Y) = Rf\ (X, Y) - Re\ (X, Y) \quad (4\text{-}3)$$

Where Rf (x, y) and Re (x, y) represent full and empty dispenser images of red components, respectively. Rf (x, y) and Re (x, y) represent full and empty dispenser images of red components, respectively.

The second option is to threshold the values of the full dispenser image over the mean of the empty dispenser. This process is a background-based computation, whereby the empty dispenser is used as the background. Difference in the intensity values was observed when the image is captured, and the dispenser is not empty. This process can be used to determine the content level in the jar and can be represented as:

$$R_{thresh}\ (x, y) = Rf\ (x, y) < M(Re). \quad (4\text{-}4)$$

Where R_{thresh} (x, y) is a new image caused by thresholding the values of full dispenser Rf (x, y) to the mean values of empty dispenser M(Re).

Note: The values subtracted can be swapped depending on the image, colour and RGB component selected. The threshold can be a fixed value that provides the result, indicating the difference between the background and the new image compared. Subsequent steps can also be taken to determine the precise level of dispenser contents.

4.7 Support Hospitals without Regionalisation of Hospitals

Supporting hospitals without regionalisation of hospitals requires many steps to run the salesman in performing maintenance or replenishment. The locations with critically low equipment are determined to find the total number of points required. The total distance and time required are calculated to determine the required distance. The time is calculated based on area type and working hours, such as town area or motor way area and rush hours (congestion), or non-rush. The time spent to make a maintenance or replenishment for each type of equipment is considered.

First aid box maintenance or replenishment requiring more time than fire extinguisher or ear plugs indicates that fire extinguisher or ear plug dispensers take approximately 10 min, whereas the first aid box requires approximately 15 min. Running salesman from the first node and visit all locations one by one until all the required nodes are completed. Two scenarios are used to run the salesman to visit all locations with critically low equipment. The first scenario is where the salesman starts from a specific point, and the second scenario is where the salesman is randomly run. The total time spent of the first scenario is longer than the second scenario because the salesman is supposed to start and return to the same starting as showing in the figure (4.13).

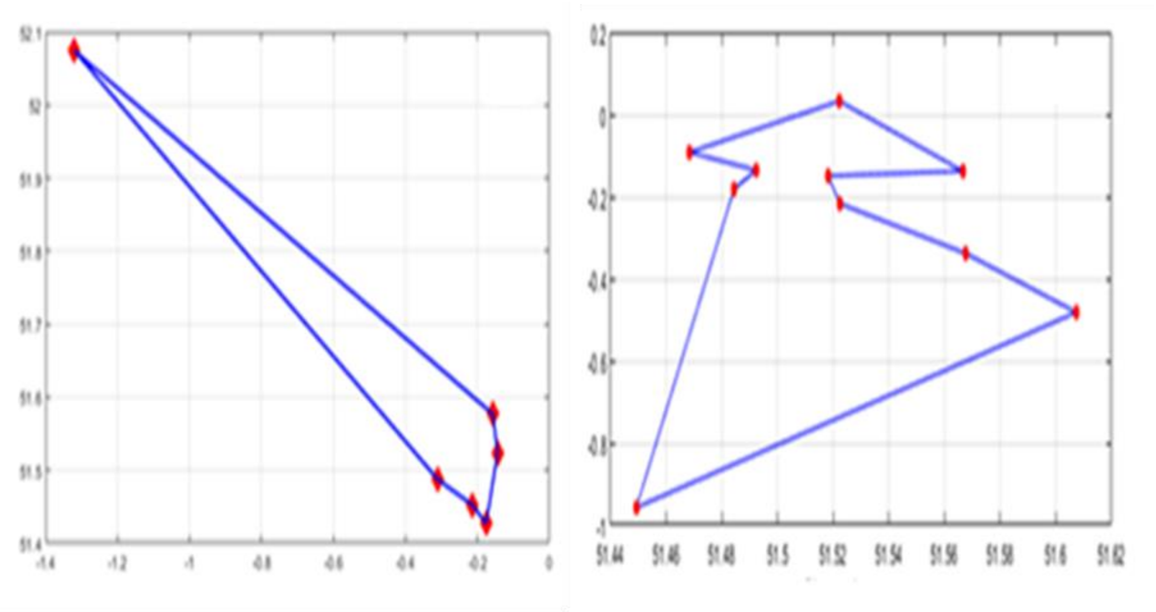

Figure 4.13 Salesman specific starting point and Salesman random starting point

4.7.1 Supporting Large Number of Hospitals with Limited Sales Force

Time factor is important during maintenance. Sending a limited number of salesmen requires preparing an advance plan, and maintenance is difficult and ineffective because it requires time and money. The salesman should establish a proper plan to run from a specific node to visit all locations with critically low H&S equipment and return to the same starting point to prevent visiting the location twice as showing in the figure 4.14).

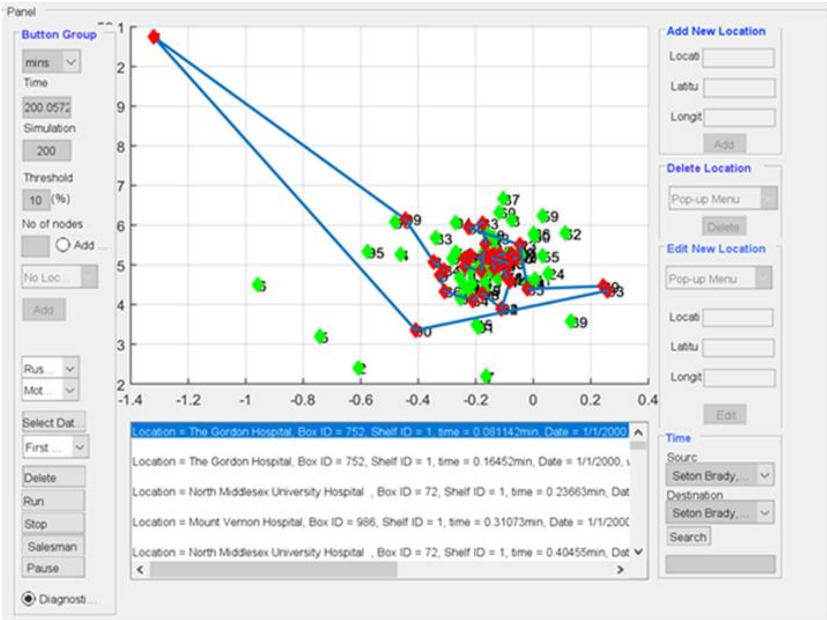

Figure 4.14 Supporting large number of hospitals with limited salesman

4.7.2 Supporting Large Number of Hospitals with Large Sales Force

Critically low devices are divided into two clusters by using k-means algorithm, and each cluster is run separately by one salesman or more. The time spent for each cluster is recorded for each salesman. The total spent time is recorded based on the maximum time spent by the salesman rather than the number of salesmen whether by 1, 2 or 3. For example, when three salesmen start a parallel running and the first salesman takes 2 h, the second salesman takes 3 h, and the third salesman takes 4 h, the total time is measured based on the maximum time spent by any one of them. The total time taken to run the cluster is 4 h. Total Time = max ($TS1$, $TS2$, $TS3$), where $TS1$ is the time taken by salesman 1, $TS2$ is the total time taken by salesman 2, and $TS3$ is the total time taken by salesman number 3 as showing in the figure (4.15).

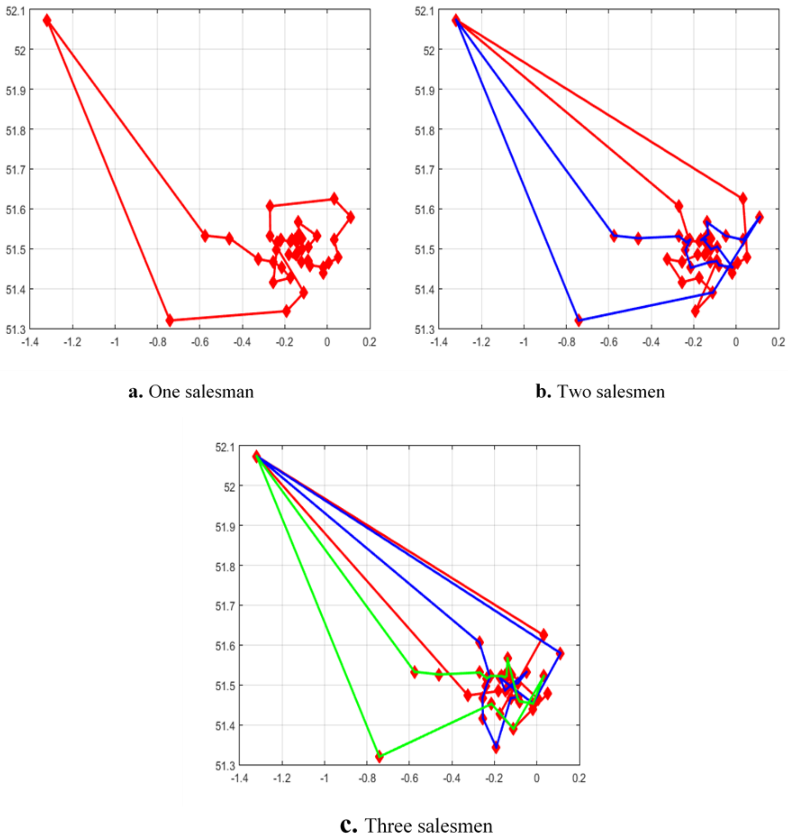

Figure 4.15 Multi salesmen routing path

4.8 Simulation Results and Analysis

Figures (4.16, 4.17 and 4.18) show the simulation results of TSP, ACO and GA with different number of nodes after running the simulation by 50 times. Here, the number of nodes varies from 10, 21, 44 and 49. Three performance metrics, namely, DISTANCE in km, ITERATION number, and EXECUTION time, are used to measure the simulation. GA outperforms TSP and ACO in terms of the minimum path under low number of nodes, which is around 1.2 and 1.47 Km. For the high number of nodes, such as 44 and 49, ACO obtains the lowest distance, which is 1.95 and 1.87 km. For the minimum number of iterations, TSP obtains the lowest value, which is approximately 86 times for 10 nodes, 861 times for 44 nodes, and 906 times for 49 nodes. TSP obtains the best result when it is simulated with 10 nodes, which is approximately 86 times. The number of iterations of TSP increases from 275 iterations to 906 iterations with the increase in the number of nodes.

In terms of execution time, GA and TSP have the same trend. As shown in the figure (4.18), no different times are observed in GA when the number of nodes is 10, 21, 44 and 49. For all these cases, GA only requires (1) s to finish the simulation. This approach is stable with the increasing number of nodes. TSP obtains the lowest execution time, which is approximately 0.67 s, when a network is deployed with 10, and the time increases to 2.58 s. The execution time of ACO increases. This approach obtains the worst value when the number of nodes increases from 1.91 s for 10 nodes to 141.32 s for 49 nodes. As previously mentioned, GA can be used to help the salesman in identifying the shortest path and least time when the equipment in different locations are critically low and require maintenance or replenishment.

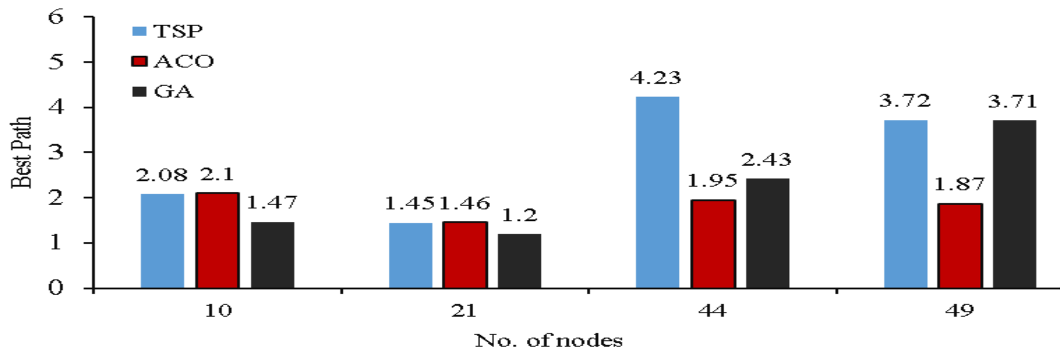

Figure 4.16 The best path selected by different search algorithms

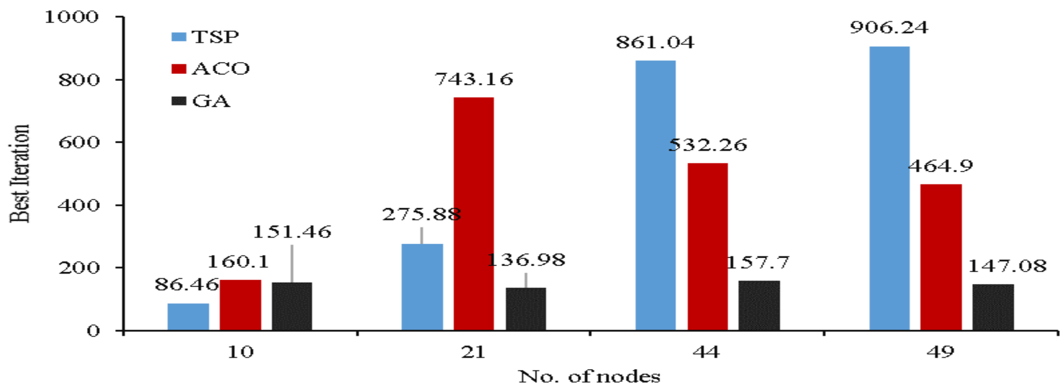

Figure 4.17 The best iteration number of different search algorithms

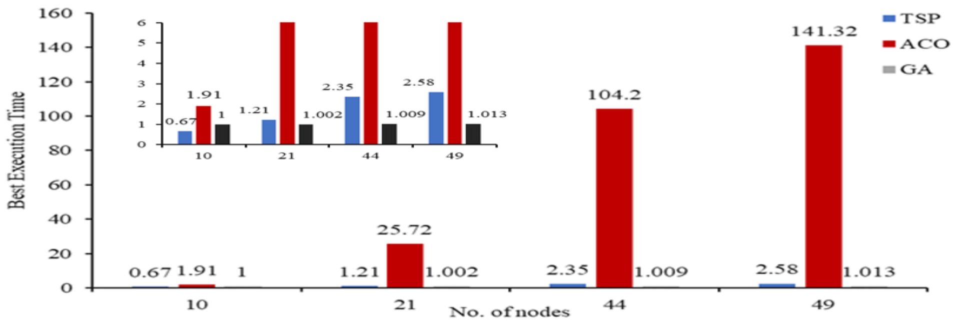

Figure 4.18 The best execution time of different search algorithms

4.9 Summary

This chapter describes the scenario definitions, simulation results and performance analysis. The H&S system has been revolutionised to ensure the workplace safety of many organisations. The proposed IoT-based implementation system develops the healthcare first aid box, earplug dispensers and fire extinguishers by measuring their weight changes, level and battery status to ensure their suitability for continuous daily use based on the regulatory requirements. Smart sensors are used to collect data from devices to monitor the status of different facilities simultaneously, which can be stored and analysed in the cloud. TSP, ACO and GA are implemented to find the shortest path with the least time in visiting the hospital locations for medical equipment maintenance. Measurement is conducted to determine which medical equipment is likely to be in critically low status that requires appropriate replenishment. This prototype is validated because it enables many companies and hospitals to monitor and control their (H&S) devices using the least amount of time, money and workforce.

The system tested four cases in which three parameters are used: path routing (distance), iteration and execution time. Unfortunately, cases 10 and 21 nodes exhibited similar results but with slight improvement. Case 44 nodes clearly decreased the path routing time compared with that of the actual target (TSP). Compared with the TSP with ACO, case 44 nodes revealed the value of 2.28, which accounts for 53.5%. TSP with the GA resulted in 1.8, which accounts for approximately 42.55%. Similarly, case 49 nodes considerably decreased the path routing time compared with that of the actual target (TSP). Compared with the TSP with ACO, case 44 nodes demonstrated the result of 1.85, which accounts for approximately 49.73%. The results show that the system provided and saved approximately 50% of the time spent for the salesman to replenish the equipment.

5. Chapter Five Prediction of Consumable Equipment Expiry Time

5.1 Introduction

Accurate analysis of massive medical data for early disease detection has promoted patient care and community services. Hence, these massive amounts of data received from several healthcare industries are difficult to handle. Accurate analysis is reduced when the quality of medical data is incomplete. Thus, the advancement of telemedicine should be enhanced by mining and extracting the hidden patterns amongst patients' medical database for the diagnosis and treatment of diseases. Medical data mining is a major application area where accuracy is important and AI applications play a vital role. It provides various profits in this field, such as lowering the cost of available therapies for patients, identifying the identity of each patient, exploring the causes of several illnesses and determining the possible methods of treatment [83]. ANNs provide huge benefits in predicting which locations have critically low H&S products.

5.2 GA Supporting Salesman with Learning and Prediction

In the past decades, Darwinian evolutionary principles have become the main notion in many fields of research. Influenced by evolution theory, GA uses biological techniques, such as selection, mutation, inheritance and recombination, to find reasonable solutions for various complex problems. GA has been widely used as a search and optimisation method in numerous areas, such as science, commercial trade, optimised telecommunication routing, engineering designs and other domains. Its success primarily arises from its comprehensive applicability, ease of use and global perspective. In AI and computing, GA is used to find the optimised solutions for search problems based on the concept of biological selection and evolutionary nature. Therefore, GA is an excellent heuristic search method used for searching through large and complex data sets [84].

In the implementation stage, GA is applied to find the optimal results for the shortest path with the minimum time for the salesman problem to replenish the critically low devices to keep them compliant. In this implementation, different results are obtained for the four cases with different numbers of nodes (a) 10, (b) 21, (c) 44 and (d) 49 figure (5.1). The same performance parameters (e.g. distance in Km, iteration number and execution time in seconds) are used in measuring the simulation.

Similar to the previous algorithms (e.g. ACO and TSP), each case runs for 50 times to obtain the outcomes. Case (b) achieves the best total distance, which has 1.1858 km. The minimum iteration number is achieved in case (a) with the value of 3 iterations. The minimum execution time has been obtained in case (a), which has the value of 1.0029 s.

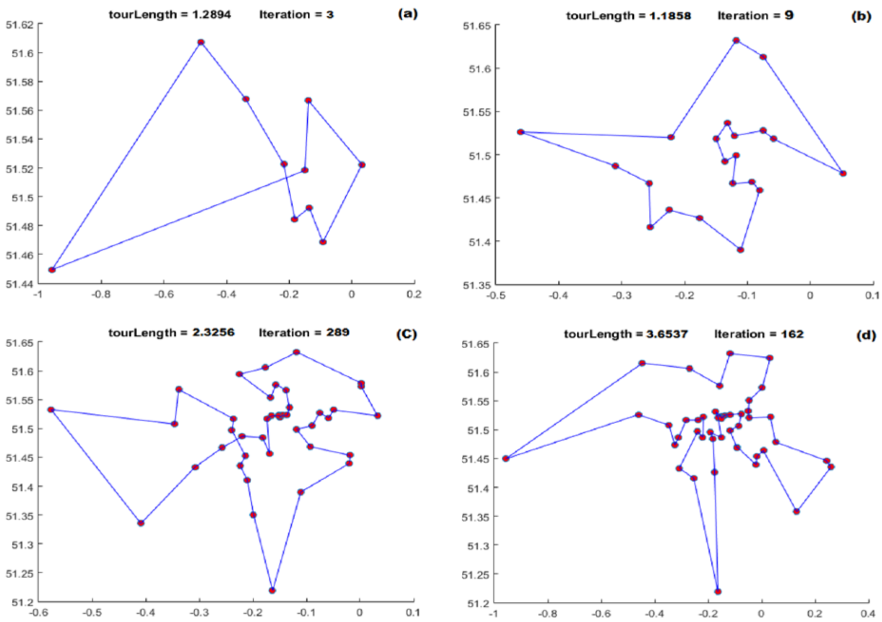

Figure 5.1 GA results

5.3 GA Process

GA has several genetic operators that can be used to increase the performance of any application. Different selection strategies are used in GA to solve many application problems, such as TSP, for obtaining an efficient optimal solution. The different selection strategies used in the GA process significantly affect the performance of the algorithm.

GA comprises numerous processes as showing in the figure (5.2), where the first process is the selection of individuals for the production of the next generation. In this stage, the algorithm begins by creating a random initial population that provides and evaluates the priority of possible individuals to be developed. Then, the algorithm creates a sequence of new populations by using an elitist strategy to preserve the best individual solution for the next generation.

In this stage, the algorithm performs the following steps:

First, each member of the existing population is scored by calculating its fitness value. These values are called the raw fitness scores.

Second, raw fitness scores are scaled to convert them into practical values. These scaled values are called expectation values.

Third, members, called parents, are selected and built on the basis of their expectation. Some of the individuals in the existing population that have low fitness are considered elite. These elite individuals are passed to the next population.

The elitist strategy can determine which individuals are selected for reproduction and the number of Offspring that are produced by the selected individual. The main principle of elitist strategy is “the better an individual is; the higher its chance of being a parent will be”.

The second process is the manipulation of selected individuals to form the next generation by using ‘crossover’ and ‘mutation’ techniques. Mutation refers to the production of offspring from the parents by making random changes to a single parent. Crossover refers to the combination of vector admissions of a pair of parents. Then, the algorithm replaces the current population with the offspring to form the next generation. The algorithm stops when the number of generations reaches the value of generations, indicating that the main criterion is met.

Weak individuals should not be discarded because they might be selected as a useful genetic material. Generally, crossover and mutation techniques discover the search space, whereas elitist strategy reduces the search area within the population by discarding poor solutions.

Hence, exploration and exploitation should be balanced during the selection to find a global optimum. Exploration refers to giving the poor solutions a chance to go the next generation, whereas exploitation refers to giving good solutions the priority to go to the next generation rather than the poor solutions [70].

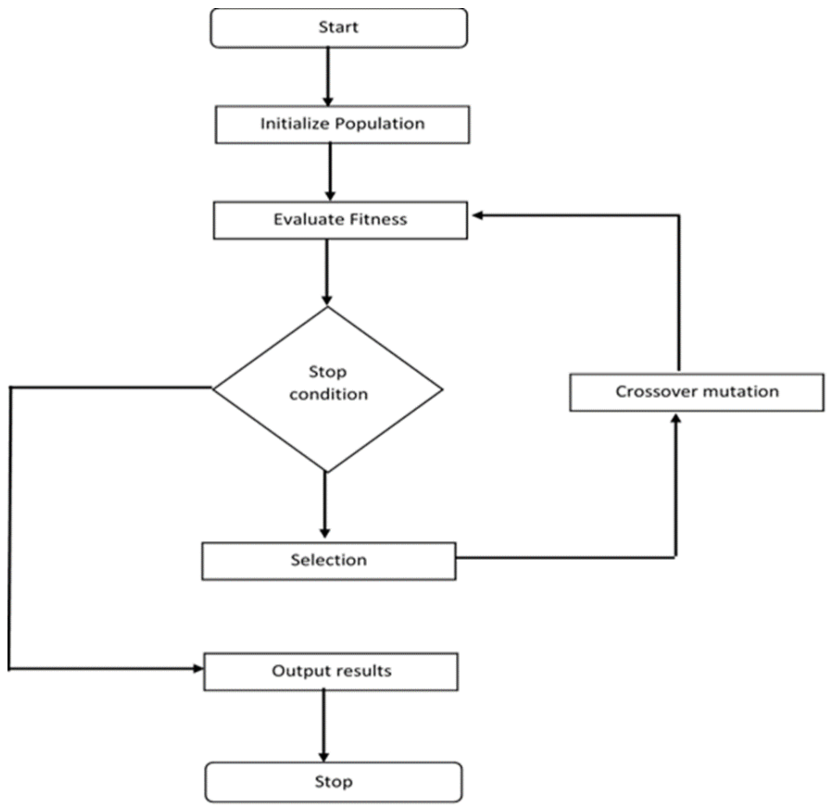

Figure 5.2 GA flowchart

5.4 ANNs Structure

Parallel operation requires the functioning in a large number of neurones. This active set of neurones, termed a layer, is a standard building block of ANN structure or topology. The specific structural arrangement of neurones that make up the ANN is closely related to the learning algorithms used in network training. Three distinct primary categories of network structure can be identified as follows:

5.4.1 Single-layer Feedforward Networks

Figure (5.3) shows the schematic of single-layer feedforward network. This kind of network involves a single layer of connected weights that can be categorised frequently as an input component. This component collects signals from the external environment and communicates them to other network components for processing. This initial layer neither is involved in the performance of computations nor in the function of the output unit that delivers the network response. Consequently, this layer is not calculated on the basis of layer numbers.

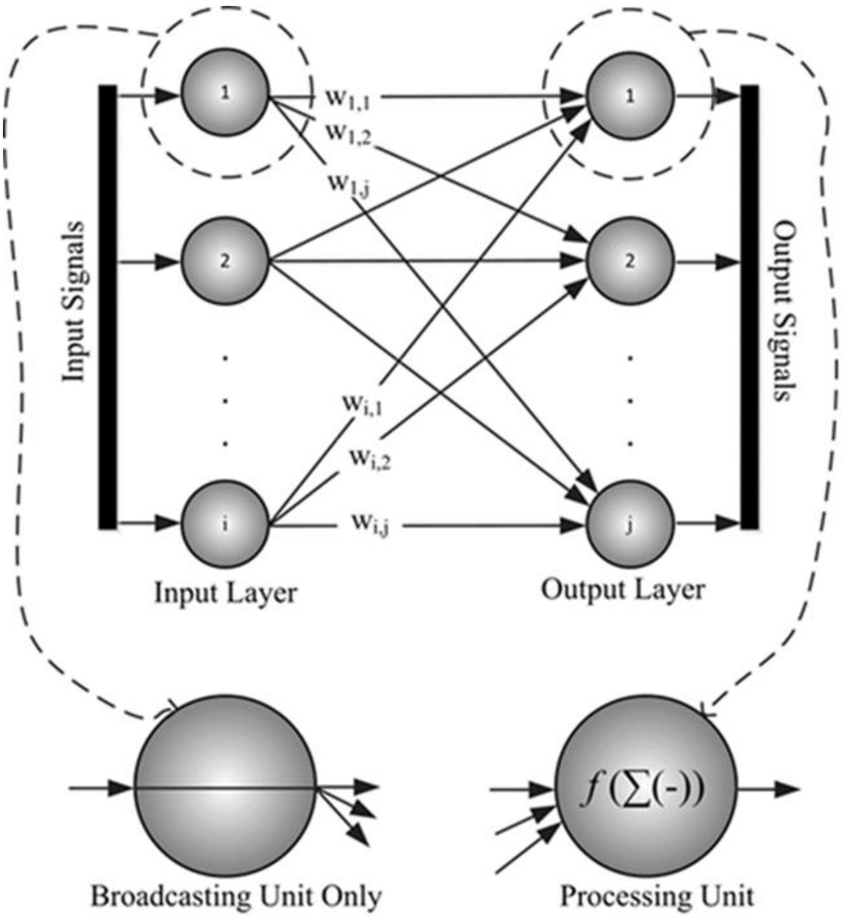

Figure 5.3 Diagram of a simple feedforward ANN [85]

5.4.2 Multilayer Forward Network

Figure (5.4) clarifies the systematic process of a multilayer forward network. This network is characterised by the presence of extra hidden layers that comprise hidden neurone computation nodes (also termed as hidden units). These units are used to present a suitable mediation between the external input and network output. The presence of one or more hidden layers enables the network to provide high instruction statistics [86]. The significance of this kind of NN is implied in its abundant exploitation in clarifying a comprehensive number of challenging problems in numerous scientific and technological areas [85].

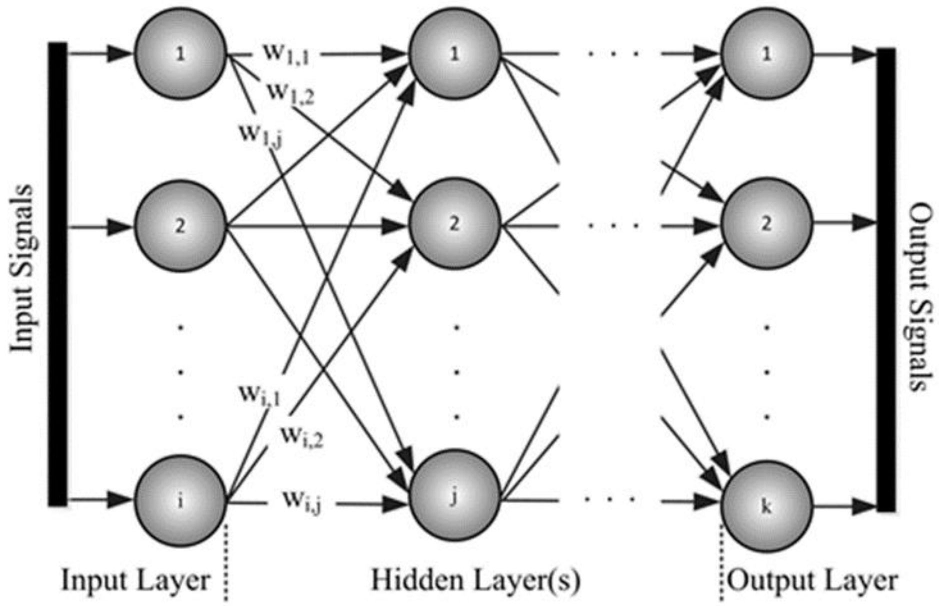

Figure 5.4 Schematic of a multilayer feedforward ANN [85]

5.4.3 RNNs

Compared with simple ANNs, RNNs have dynamic memory, that is, they can remember the things learnt from previous inputs whilst generating outputs during their training. An RNN is designed with internal connections that can feedback to another layer or to itself. This design makes the production of one or more output vectors at any specific time possible for the network by taking one or more input vectors. In contrast with a regular ANN, in which its outputs are influenced by input weights, RNNs can produce outputs depending on the hidden or previous state context based on prior inputs and outputs. Consequently, RNNs enable networks to perform temporal association and prediction in identifying time-dependent patterns whilst performing sequence recognition and reproduction in learning sequences. RNN architectures consist of a standard multilayer perceptron (MLP) that can combine one or more feedback loops that can utilise the powerful nonlinear mapping capabilities of MLP [87].

5.5 Simulation Analysis

AI techniques have been developed and implemented to overcome the limitations associated with prediction, which is a vital mission in various fields of science, such as manufacturing, healthcare, engineering and other domains that use data to predict future problems. In this context, ANNs have exposed promising consequences for this mission compared with traditional statistical techniques. ANN is a learning system based on a computational technique that can simulate the neurological processing ability of the human brain and can be applied to quantify a nonlinear relationship between causal factors and medical responses by means of iterative training of data obtained from a designed experiment. ANNs are economical, simple, efficient and can learn from examples [88]. ANN is modelled by using Levenberg– Marquardt training algorithms, with the absolute percentage prediction errors obtained by using the steps are outlined in this chapter.

ANN simulation: Three different ANN network topologies (Levenberg–Marquardt, Bayesian Regularisation and Scaled Conjugate Gradient) are used to obtain the performance and regression of the input and output.

Data selection: The input data is selected, which are 500×3 matrix that represent the statistical data of 500 samples from three elements. The target data are a 500×1 matrix that represents the statistical data of 500 samples of one element.

Data validation and testing (select percentages): Five hundred samples are randomly divided. Firstly, the training percentage is 70%, indicating that 350 samples are presented to the network during training, and the network is adjusted on the basis of its error. Secondly, the validation percentage is 15%, indicating that 75 samples are used to measure network generalisation, and training stops when generalisation stops progressing. Thirdly, the testing percentage is 15%, indicating that 75 samples that have no effect on training, and an independent measure of network performance is provided during and after training.

Data processing and analysis: In this step, the number of neurons in the fitting network hidden layer was set to 10 nodes. In this way, the ANN input is 3, the hidden layer is 10 nodes, the output layer is 1 and the output is 1.

ANN training using the data collected from three different topologies (e.g. Levenberg–Marquardt, Bayesian regularisation and scaled conjugate gradient): In this step, one algorithm must be selected to begin with the training. The progress results using Levenberg–Marquardt are presented, where the epoch ranges from 0–1000 iterations, and setting time, performance, gradient and validation checks range from 0 to 6. The network with minimum errors is more preferred between the predicted and actual outputs.

Testing of the trained ANN to evaluate model generality: The trained network is evaluated on the basis of hidden data, and the output is compared with the actual one.

Postprocessing of the output data: The normal value of the output is calculated by post processing of the predicted value after an acceptable result is obtained during network testing.

5.6 Simulation Result

ANNs positively affect the enhancement of economy, comfort, efficiency and the ability to learn at the appointed time. ANNs can be used to predict optimal performance by using the rule table and ANN parameters as inputs and outputs, respectively. In Table (5.1), three ANN algorithms (e.g. Levenberg–Marquardt, Bayesian regularisation and scaled conjugate gradient) are used to verify the input for finding the optimal results in predicting and determining which location has critically low equipment. After several data training, the Levenberg–Marquardt algorithm exhibited the best outcome amongst other algorithms. Therefore, ANNs are modelled by using the Levenberg–Marquardt training algorithms.

In this model, neurons were set in the fitting network's hidden layer, which is 10 nodes. Moreover, three ANN inputs are used in the 10 hidden layers, and the output layer has 1 output. Mean squared error is the average squared difference between the outputs and targets. Low values are preferred. Regression (R) values measure the correlation between the outputs and the targets, and zero indicates no error. A R value of 1 indicates a close relationship, whereas 0 indicates a random relationship. Levenberg–Marquardt outperforms Bayesian regularisation and conjugate gradient algorithms in terms of minimum performance (MES) number for training, which is approximately 0.2285. Regarding the minimum number of regressions, the Levenberg–Marquardt obtains the best neural training result and gained the lowest value, which is approximately 0.96623.

Table 5.1 ANN results

ALGORITHM TYPE	MSE	REGRESSION	EPOCHS
Levenberg-Marquardt	0.2285	0.96623	5
Bayesian regularisation	0.2525	0.95899	39
Scaled conjugate gradient	0.3064	0.96026	27

After testing the performance of various architectures using the selected approach in figure (5.5), the ANN system trained by Levenberg–Marquardt algorithm shows significant performance, as indicated by the mean squared error of less than 10^{-1}. The figure (5.5) illustrates that the training session of ANN iterations (epochs) is determined when the training error decreases to the target.

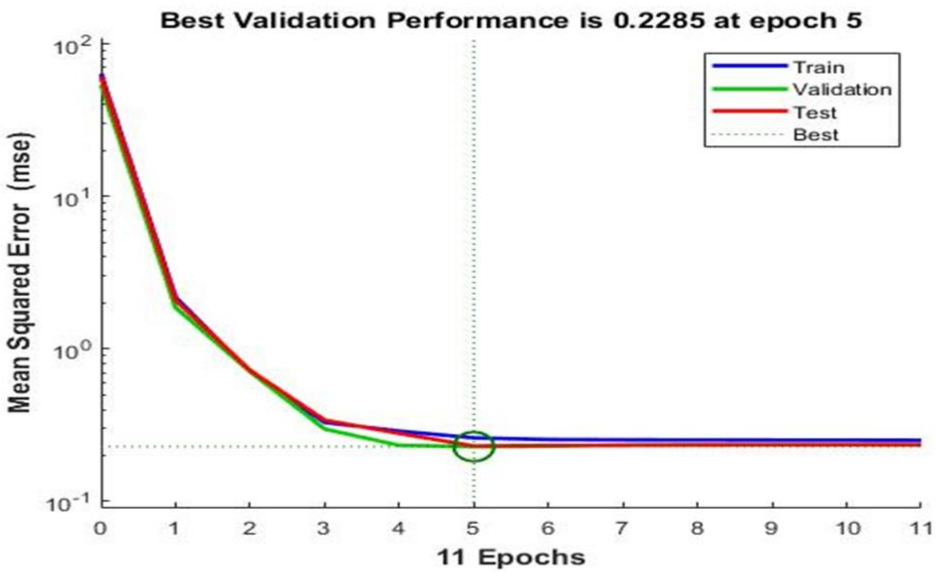

Figure 5.5 Training session using Levenberg–Marquardt method

The regression analysis between the predicted and targeted outputs can provide considerable information. Figure (5.6) shows that a right line indicates the perfect linear regression that concerns the target to the network response rate in an ANN. A better fit, that is, the predicted outputs clearly matched the actual values, would give a right line with a gradient of one and a stop of zero. Figure (5.6) indicates that the values obtained are nearly optimal, in which the iteration to the training sets is perfect.

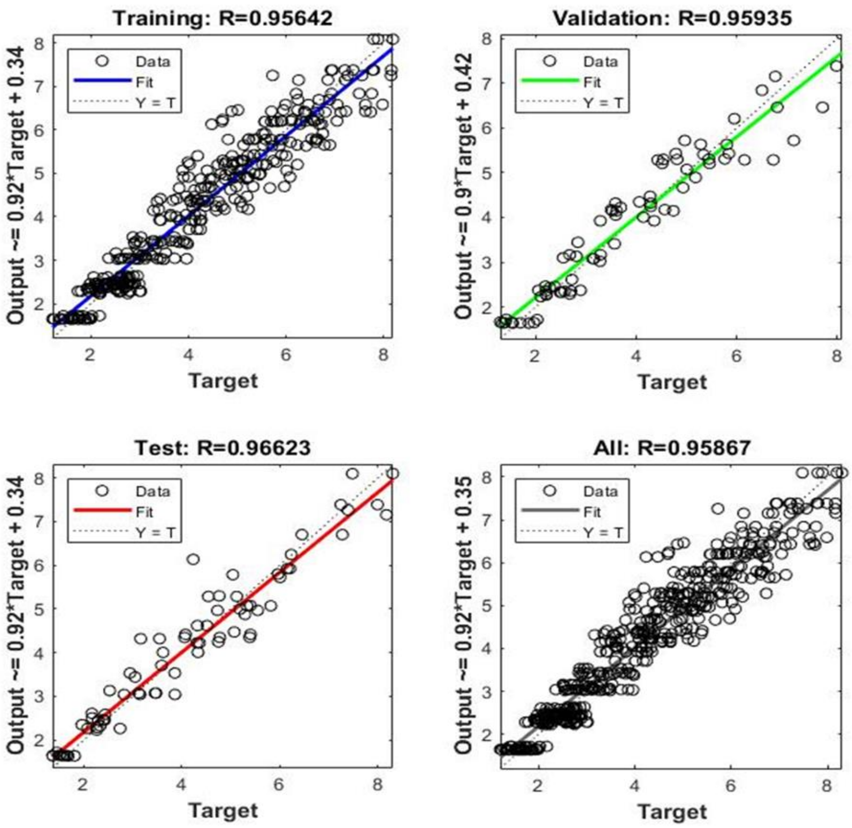

Figure 5.6 Linear regression of targets relative to outputs

Using Levenberg–Marquardt method

Scaled conjugate gradient has 0.30463 performance at 27 epochs. The mean squared error ranges from 10^{-1} to 10^{2} with 33 iterations.

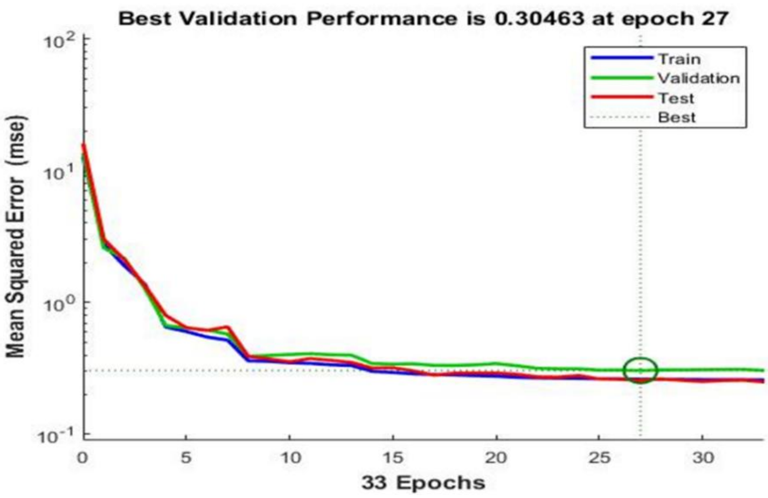

Figure 5.7 Training session for scaled conjugate gradient performance

The regression of the targets relative to the outputs for the ANN performance in the training set for all regression is 0.96.

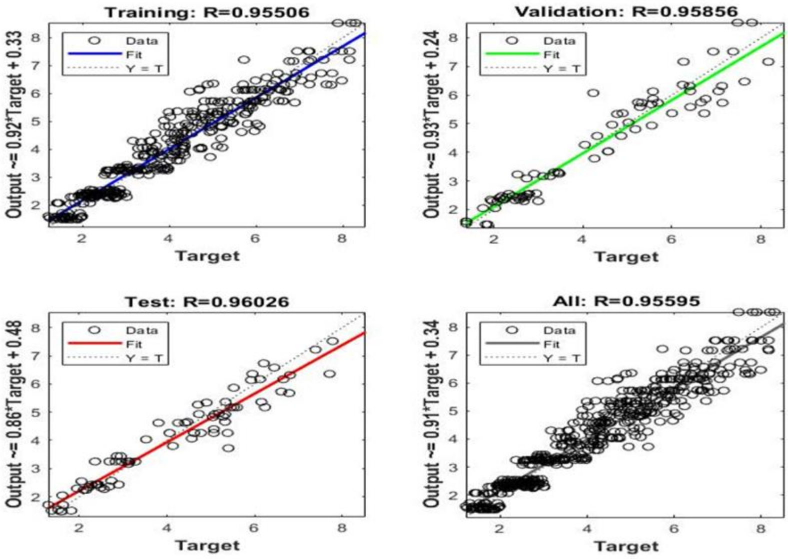

Figure 5.8 Linear regression of targets relative to the outputs for ANN scaled performance on the training set.

Bayesian regularisation has 0.25 performance at 39 epochs. The mean squared error ranges from 10^{-1} to 10^{2} under 77 iterations.

Figure 5.9 Training session for Bayesian regularisation performance

The regression of the targets relative to outputs for the ANN performance in the training set for all regression is 0.95.

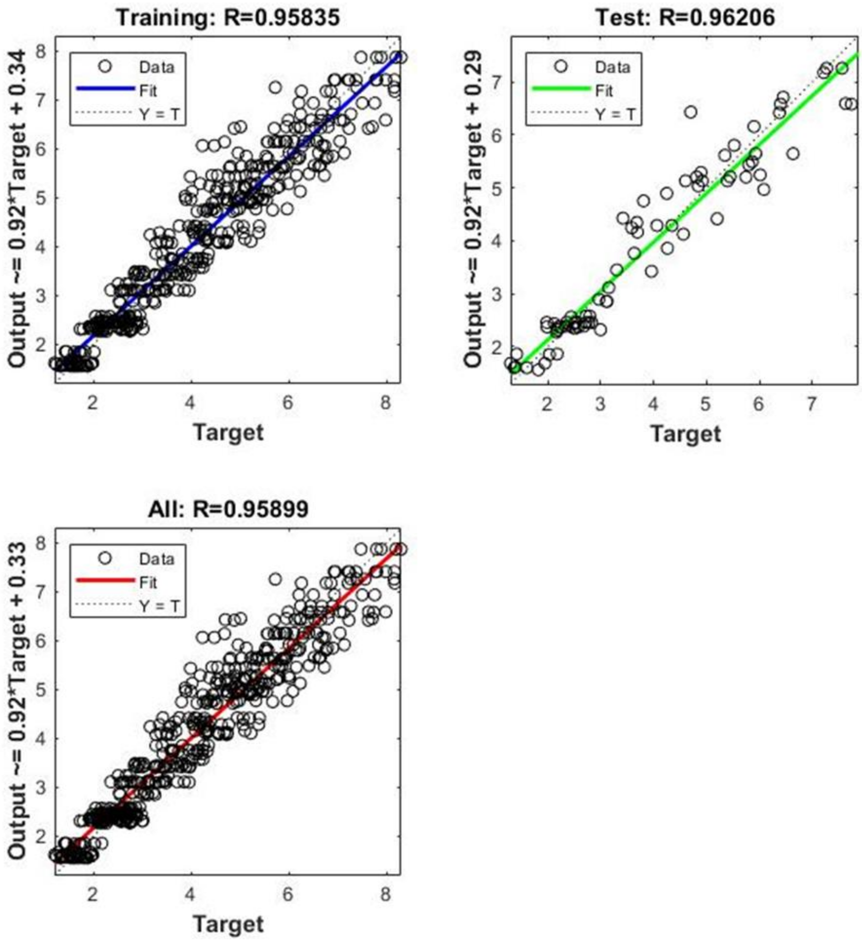

Figure 5.10 Linear regression of the targets relative to outputs for ANN performance on the training set

5.7 Network Architecture Topology

Concerning the selection approach, Figure (5.11) shows the results of the network architecture. This consists of three input neurons and ten nodes in the hidden layer with a logarithmic sigmoid nonlinear activation function and one output neurons in the output layer. The training of the network shows the best performance of the ANN structure gives comparably best performance of MSE, with respectively 0.2285×10^{-1}, as shown in the figure (5.9). A two-layer feedforward network with 10 sigmoid hidden neurons and 1 linear output neuron (Fitnet) can fit multidimensional mapping problems arbitrarily because of its consistent data and sufficient neuron contents in its hidden layer.

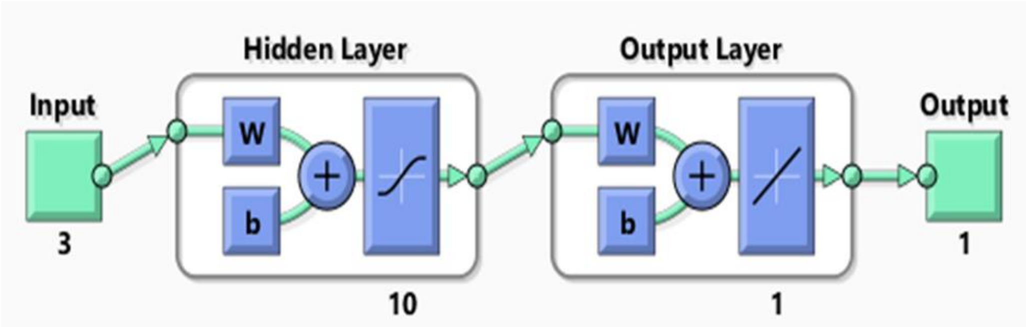

Figure 5.11 ANN with three inputs and one output

5.8 Prediction Places with Critically Low Equipment

After the simulation, 100 hospitals are deployed depending on the number of populations that use the hospital. Figure (5.12) shows that hospital ID 31 has the lowest number of utilisations, whereas hospital ID 39 has the largest number of utilisations. Figure (5.13) illustrates the prediction of which locations have critically low expiring equipment.

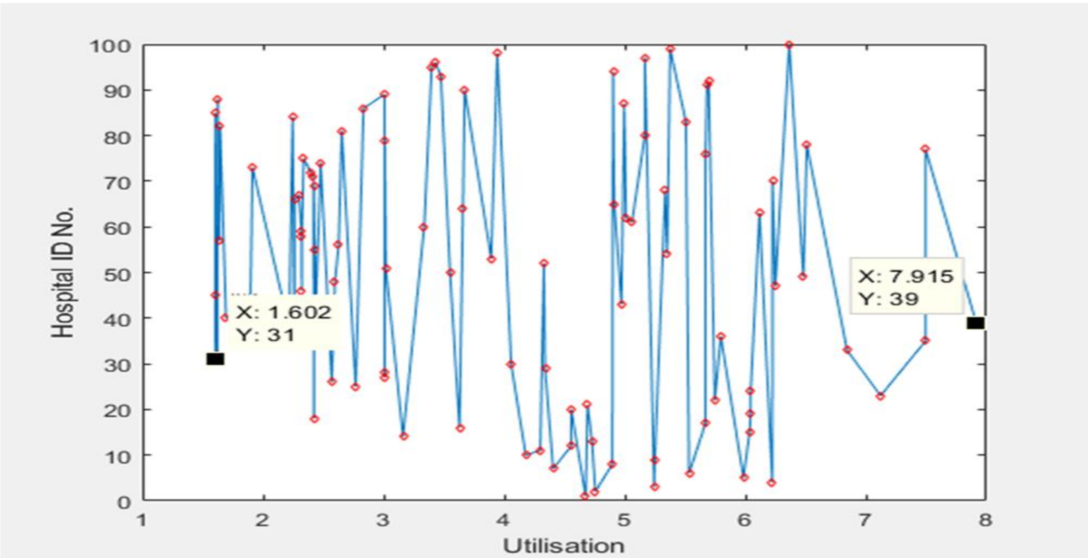

Figure 5.12 Prediction of hospital utilisation

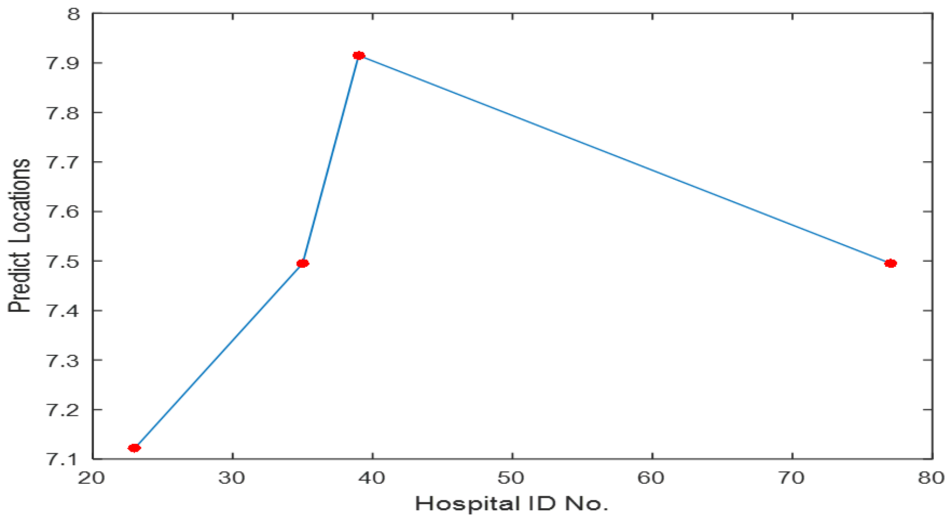

Figure 5.13 Predictive locations with critically low equipment

5.9 Summary

This chapter precisely introduces the vital properties of ANN modelling techniques and the basic concepts of this methodology, which is scientifically based on the attempt to model the way that a biological brain processes data. Three algorithms for ANN training (e.g. Levenberg–Marquardt, Bayesian regularisation and scaled conjugate gradient) that belong to three broad classes are evaluated to find the correlation between effective input factors and performance output. ANN can be used as a predictor of future problems, such as the prediction of the critically low equipment in different locations. In this study, the data are randomly divided into 70% training set, 15% validation set and 15% testing set. The optimal structure of the network is selected on the basis of the best performance (minimum error between the predicted and actual matrices). After different trainings, the results show that the use of Levenberg–Marquardt as a training algorithm provides an acceptable performance for all the trained topologies. The system selected four locations out of 100 to replenish the critically low status equipment. That is, the largest benefit enables the salesman to visit only four locations, which indicates that not all locations must be visited.

6. Chapter Six: Conclusion and Future work

6.1 Conclusion

IoT applications have accelerated the pace of advancement in healthcare technology by implementing numerous kinds of assisted systems that provide healthcare monitoring and prompt access to medical treatment and emergency health systems. Therefore, IoT-based healthcare systems have an important contribution in developing medical data systems to enhance the quality of healthcare service and guarantee the safety of patients. This thesis proposes an IoT-based healthcare architecture for tracking, tracing and monitoring H&S products at workplaces using a GUI programme. The proposed design is called 'Smart H&S Equipment Monitoring System for Distributed Hospitals', which is a novel maintenance system used for the early detection of critically low H&S devices in various facilities by using smart sensors for data collection and status monitoring.

The thesis presents representative examples from a comprehensive survey of various studies that demonstrate numerous manipulations of the integration of IoT, cloud computing and mobile core network with the help of the promising 5G technology. This integration is anticipated to provide promising solutions for generating a smart world. In the literature review, several experts have highlighted the capability of the IoT in connecting a plethora of digital devices with several sensors, actuations and computing capabilities with the Internet, which will offer new diverse services in the context of a smart city. Therefore, IoT is used by diverse specialists in numerous scenarios of multifaceted services, such as medical care, transportation, industrial mechanisation and environmental monitoring.

Hence, most authorities believe that IoT can play a significant role in rendering various applications in daily and social lives and improve their quality. Although numerous works have investigated the significance of the advancement of medical devices to enhance the required level of performance and guarantee their accuracy and reliability, only a few works have highlighted the importance of revolutionising the old-fashioned maintenance approaches that remain applicable in healthcare systems and services. For example, many previous studies have focused on IoT related to healthcare systems, but studies related to the management of health and safety products are unavailable, apart from one research. This research mentions that companies experience pressure from clients, insurance companies and regulatory bodies in terms of transparency. Moreover, technologies are increasingly being introduced into industrial workplaces to promote health and safety, prevent liability risks and improve auditing and verification. Consequently, most healthcare administrations have faced the challenge of detecting critically low equipment, which would have been improved if efficient real-time monitoring equipment is available. The proposed architecture, which is based on IoT real-time monitoring framework, confirms the comprehensive prominence into H&S devices and provides the capability of predicting possible failures.

Hence, constructing the proposed system, including ANN algorithms, to predict the critically low locations and the ACO, TSP and GA to identify the shortest route in the least time demonstrates performance enhancement, thereby solving several current challenges. That is to say, by actively monitoring the status of critical devices in healthcare organisations and workplaces through ACO, TSP and GA in the proposed system, the salesman will be effectively assisted and supported to access the locations with critically low equipment efficiently. This process is also beneficial for saving time and cost. Similarly, using AI, particularly ANNs, to predict locations with critically low and near expiry equipment, is a key measure for improving preventive maintenance planning and asset optimisation.

This thesis also presents a comprehensive study for personalised healthcare, which influences the advantages of remote monitoring, cloud computing, big data and machine learning. This comprehensive study provides an organised approach to support the rapidly expanding data of people with severe diseases. This approach is performed by simplifying the task of physicians without overwhelming them with false alerts when using IoT-based cloud computing in predicting diseases. Moreover, this study highlights and explores the historical relationship between AI and the healthcare sector and illustrates the benefits of AI in the healthcare domain, such as cost reduction, prediction and diagnosis of disease and doctor assistance, in numerous complex areas in healthcare.

The use of AI in the healthcare sector significantly influences the monitoring, management and decision making of patients and clinical staff members. Furthermore, several factors affect the decision making on the use of AI in system learning and predictive ANN. AI algorithms can collect big data in short order and time, whilst machine learning algorithms can be used to generate the databases used in expert systems and the predictive analysis of data. Hence, the benefit of the AI-based healthcare applications, such as ANNs, general algorithms and ACO, include the generation of effective solutions in the proposed system. Similarly, these algorithms can support the 'salesman' in identifying the critically low health and safety equipment in the shortest route and least time.

The proposed network modelling of H&S infrastructure in hospitals comprises numerous subnetworks, such as probability of injuries in the UK per day, system simulation loop, system design and use of case interaction. Several interfaces are defined to allow the communication between hospital networks and illustrate the system processes, such as adding, editing and deleting H&S products and consumables. This study explains the classes and objects of first aid box, database and data querying, as well as the aforementioned system processes. Battery management and status function simulation are also described. The system used to identify the locations with critically low equipment is created, and the shortest routing path in the latest time is identified through AI algorithms.

The IoT-based implementation system develops the healthcare first aid box, earplug dispensers and fire extinguishers by measuring their weight changes, level and battery status, to ensure that the H&S system is revolutionised to secure the workplace of numerous organisations. Moreover, their suitability for continuous daily use is ensured based on regulatory requirements. The scenario definitions, simulation results and performance analyses are described in Chapter five. Measurement is conducted to determine medical equipment that is likely to be in critically low status, thus requiring appropriate replenishment. Smart sensors are used to collect data from devices to monitor the status of different facilities simultaneously, which can be stored and analysed in the cloud.

TSP, ACO and GA are implemented to find the shortest path with the least time in visiting hospital locations for medical equipment maintenance. This prototype is validated because it enables numerous companies and hospitals to monitor and control their H&S devices using the least amount of time, money and workforce. The efficiency of the systems' performance is improved by using GA, ACO and TSP to support numerous hospitals with a limited number of salesmen to find the shortest routing path in real time.

The system tested four cases in which three parameters are used: path routing (distance), iteration and execution time. Unfortunately, cases 10 and 21 nodes exhibited similar results but with slight improvement. Case 44 nodes clearly decreased the path routing time compared with that of the actual target (TSP). Compared with the TSP with ACO, case 44 nodes revealed the value of 2.28, which accounts for 53.5%. TSP with the GA resulted in 1.8, which accounts for approximately 42.55%. Similarly, case 49 nodes considerably decreased the path routing time compared with that of the actual target (TSP). Compared with the TSP with ACO, case 44 nodes demonstrated the result of 1.85, which accounts for approximately 49.73%. The results show that the system provided and saved approximately 50% of the time spent for the salesman to replenish the equipment.

The vital properties of ANN modelling techniques and the basic concepts of this methodology, which is scientifically based on the attempt to demonstrate a biological brain processes data, are introduced in Chapter 6. The proposed system provides the best effective results in predicting the locations that have critically low equipment by evaluating three algorithms for ANN training (e.g. Levenberg–Marquardt, Bayesian regularisation and scaled conjugate gradient) from three broad classes; to find the correlation between effective input factors and performance output. ANN can be used as a predictor of future problems, such as the prediction of critically low equipment in different locations.

The data in this study are randomly divided into 70% training set, 15% validation set and 15% testing set. The optimal structure of the network is selected on the basis of the best performance (minimum error between the predicted and actual matrices). After different training methods, results show that the use of Levenberg–Marquardt as a training algorithm provides acceptable performance for all the trained topologies. The system selected four locations out of 100 to replenish the critically low status equipment. That is, the largest benefit enables the salesman to visit only four locations, which indicates that not all locations must be visited.

The main objective of our system is to enhance the H&S of occupational personnel by monitoring and predicting the changing status of any H&S equipment in hospitals or workplaces to alert the building service managers to take preventive measures in real time. Therefore, the real-time controlling and monitoring system is designed to access the status of consumable hospital devices, such as first aid boxes, earplug dispensers, life jackets and fire extinguishers. Consequently, unnecessary waste of time and efforts can be avoided by hospitals and companies by reducing workforce requirements compared with previous manual maintenance approaches that consume considerable time, efforts and cost. The results of the proposed system are reliable and can be used to manage many consumable H&S products in different district hospitals and companies whilst meeting the regulatory requirements, which aid in reducing time, costs, efforts and workforce resources.

6.2 Future Work

This study present various recommendations for future study directions by using an intelligent agent in SDN network based on the proposed ANN prediction concept and optimisation technique. The recommended future investigations are summarised as follows:

An experiment is performed to evaluate the system in real environment facilities, such as hospitals and companies.

Other AI methods, such as PSO and other algorithms, were used to verify their optimal outcomes and suitability for other purposes.

The data pool is extended and inserted into a standard/regulation to serve as reference or guide.

The first direction is to use the application optimisation programme: This process prioritises and changes the behaviour of the network based on application behaviour by analysing the application type.

Intelligent cloud controller: Cloud organisation should consider the efficient utilisation of the main controller functions in an intelligent controller to increase network reliability. In this case, any ANN controller could connect to the intelligent controller to investigate the network environment on an ongoing basis, thereby enabling the latter to report back to the prior in real time.

Predict network size programme: The behaviour of the network environment with an intelligent programme is investigated and analysed and predict the number of controllers needed by the network and the best place for the new controller was determined by the previous results.

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