Application of Internet of Things in Spinning Industry

By

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DECLARATION

I certify that all the material in this thesis that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this thesis reflect my own personal views, and are not necessarily endorsed by the University.

Name Gida Ehab Ibrahim Aly

Signature

Date ..........................................................................................................................
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ABSTRACT

The world has entered a new technological era known as the “Internet of Things” (IoT) allowing everything-to-everything communication. IoT enables real time tracking and monitoring of different systems and environments based on real time data acquisition and sharing. By IoT, monitoring and controlling everyday devices can be done remotely from anywhere at any time though the Internet. This is done through IoT enabling technologies including sensing and identification technologies. Due to the novelty of the topic there are still many challenges that needs research. One of these challenges is the problem of IoT deployment in industrial legacy systems, which this work tackles.

The introduction of IoT into the manufacturing environment is leading to a fourth industrial revolution, known as Industry 4.0. The deployment of IoT technology into a manufacturing environment necessitates careful planning in order to make sure to meet the application requirement. This involves the selection of the appropriate sensors among numerous sensors available today in the market. The selection of the appropriate sensor requires to explicitly evaluate multiple conflicting criteria using a multi-criteria decision making (MCDM) approach.

This work presents the deployment of IoT in a textile manufacturing system where a decision has to be made regarding the selection of the appropriate sensors required for the IoT solution. A decision support system for the selection of the most appropriate sensors, especially RFID sensors, to meet the application requirement in a manufacturing shop floor is developed. The DSS is based on the two most widely adopted MCDMs methods; the Analytical Hierarchal Process (AHP) belonging to the compensatory models and the Elimination and Choice Translating to Reality (Electre) Method belonging to the non-compensatory models. Using both methods, the final results have produced optimal alternative meeting the decision maker’s preferences.
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LIST OF ACRONYMS/ABBREVIATIONS

AHP       Analytical Hierarchy Process
AIDC      Automatic identification and data collection
ANP       Analytic network process
CI        Consistency Index
CO        Carbon monoxide
CR        Consistency Ratio
dBi       Decibel relative to isotropic radiator
DC        Direct Current
DM        Decision Maker
DSS       Decision Support System
ELECTRE  ELimination Et Choix Traduisant la Réalité
EOLP      End of life products
EPoSS     European Technology Platform on Smart Systems Integration
EU        European Union
FAP       Fresh Agriculture Product
GDP       Gross Domestic Process
HF        High frequency
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>IBM</td>
<td>International Business Machines Corporation</td>
</tr>
<tr>
<td>IBSG</td>
<td>Internet Business Solutions Group</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated circuit</td>
</tr>
<tr>
<td>ID</td>
<td>Identity Document</td>
</tr>
<tr>
<td>IFC</td>
<td>International Finance Corporation</td>
</tr>
<tr>
<td>IIoT</td>
<td>Industrial Internet of Things</td>
</tr>
<tr>
<td>iOS</td>
<td>Internetwork operating system</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of things</td>
</tr>
<tr>
<td>IP</td>
<td>Ingress Protection</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organization</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid-crystal display</td>
</tr>
<tr>
<td>LF</td>
<td>Low frequency</td>
</tr>
<tr>
<td>LLRP</td>
<td>Low level Reader-Protocol</td>
</tr>
<tr>
<td>MCDM</td>
<td>Multi-Criteria Decision making</td>
</tr>
<tr>
<td>MENA</td>
<td>Middle East &amp; North Africa</td>
</tr>
<tr>
<td>MHz</td>
<td>Mega Hertz</td>
</tr>
<tr>
<td>Nm</td>
<td>Number unit</td>
</tr>
<tr>
<td>OCR</td>
<td>Optical character recognition</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>--------------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>OPM</td>
<td>Overall Preference Matrix</td>
</tr>
<tr>
<td>PoE</td>
<td>Power over Ethernet</td>
</tr>
<tr>
<td>RI</td>
<td>Random Like Matrix</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identification</td>
</tr>
<tr>
<td>SME</td>
<td>Small &amp; Medium Enterprise</td>
</tr>
<tr>
<td>TID</td>
<td>Tag Identifier</td>
</tr>
<tr>
<td>TOPSIS</td>
<td>Technique for Order of Preference by Similarity to Ideal Solution</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra high frequency</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>USB</td>
<td>Universal serial bus</td>
</tr>
<tr>
<td>V</td>
<td>volts</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Wireless fidelity</td>
</tr>
<tr>
<td>WIP</td>
<td>Work in Progress</td>
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CHAPTER ONE
INTRODUCTION
1 INTRODUCTION

In the last two years the topic internet of things has gained global relevance among industries and academia, this was witnessed in the increasing number of publications as well as international conferences and seminars addressing the topic. IoT has evolved as a result of technological advancement in the internet connectivity becoming more ubiquitous and cheaper every day. According to Moore’s law, sensors have decreased in cost, weight, and size over the past few years and became more available with much affordable price allowing devices which were not designed for internet connectivity to go online [1, 2]. The effect of this phenomenon was also felt by industry.

The introduction of IoT into the manufacturing environment is leading to a fourth industrial revolution, known as Industry 4.0 [3]. The deployment of IoT technology into a manufacturing environment necessitates careful planning in order to make sure to meet the application requirement. This involves the selection of the appropriate sensors among numerous sensors available today in the market. The selection of the appropriate sensor requires to explicitly evaluating multiple conflicting criteria. Here comes the role of Multi-Criteria Decision Making Methods (MCDMs) which considers the decision-maker's preferences to differentiate between alternatives and recommends an alternative which is optimal according to the decision maker’s preferences.

In this study, the deployment of IoT in a manufacturing shop floor is addressed through a case study in a small and medium enterprise (SME) to synchronize production, link machines, and monitor manufacturing processes remotely via smart phones where a decision has to be made regarding the selection of the appropriate sensors required for the IoT solution.

The IoT solution is needed to provide a way to get better visibility and insight into the company’s operations and assets. Therefore, it provides a method of transforming business operational processes by using as feedback the results gained from interrogating large data sets through advanced analytics, improved quality with the ability to track the manufacturing process in real time leading to early identification of issues.
A decision support system for the selection of the most appropriate sensors, especially RFID sensors, to meet the application requirement in a manufacturing shop floor is developed. The DSS is based on the two most widely adopted MCDMs methods in literature; the Analytical Hierarchal Process (AHP) belonging to the compensatory models and the Elimination and Choice Translating to Reality (Electre) Method belonging to the non-compensatory models. Using both methods, the final results have produced optimal alternative meeting the decision maker’s preferences.

1.1 AIM AND OBJECTIVES

The aim of this work is to deploy IoT into legacy industrial system to allow real time visibility and traceability of shop floor operations through building a ready to deploy solution.

1.1.1 Objectives of the Work

The objectives of this work are as follows:

1. Investigate the current trends in IoT research work.
2. Identify the various components of an IoT solution.
3. Focusing on RFID sensors, gathering information about the available types of RFID sensors.
4. Comparing different sensor alternatives and selecting the most suitable one with the aid of Multi-Criteria Decision Making (MCDM).
5. Development of a Decision Support System to automate the process.
6. Testing the developed system using real data.

1.2 THESIS OUTLINE

The thesis consists of six chapters, including the current chapter and five appendices. The thesis is organized as follows:
Chapter two covers a review of literature of the related work to this research encompassing Internet of things, Automatic Identification and Data Collection Systems, Small and Medium Enterprise (SMEs) as well as Multi-Criteria Decision Making.

Chapter three presents the Decision Support System (DSS) developed to aid in the selection of the best RFID reader alternative. The DSS is based on two major Multi-Criteria Decision Making algorithms; the compensatory AHP and the non-compensatory Electre MCDM algorithm. This is followed by comparisons of the two final rankings obtained using the two methods.

Chapter four presents the problem at hand, discussing the importance of the textile industry sector in Egypt followed by a detailed description of the use case under study describing the different processes present, as well as the problems addressed by IoT solution.

Chapter five presents implementation details of RFID in AlSaratex and the results of the proposed IoT Solution.

Finally, Chapter six covers the conclusions drawn from this work and recommendations for future work.

Furthermore, the thesis includes five appendices; these are:

- Appendix A: Publication Arising from this Work
- Appendix B: Summary of MCDM Literature
- Appendix C: RFID Alternatives
- Appendix D: Questionnaire
- Appendix E: Visual Basic Code
CHAPTER TWO

LITERATURE REVIEW
2 LITERATURE REVIEW

This chapter provides a review of previous research work in the field of Internet of Things (IoT) as well as Multi-Criteria Decision Making. The literature is mainly divided into two parts; the first part is addressing the Internet of things topic. And the second part is mainly focusing on Multi-Criteria Decision Making Methods.

In the first part, an overview and a background is first provided on this research field, followed by an explanation of the approach applied in this study to review and search for relevant publications. This is followed by a brief historical background provided on IoT and its evolution as well as its main issues.

Afterwards, a brief introduction on Automatic Identification Systems is presented, with a more comprehensive review on Radio Frequency Identification (RFID) systems describing in detail how this system works. This is followed by a review on the most recent popular areas of application of IoT shedding the light precisely on IoT in manufacturing and the role of SMEs in the world economy.

2.1 OVERVIEW AND BACKGROUND

In today’s fast-paced world, new technologies are transforming our business and personal lives. Among those, the internet, becoming an integral part of our everyday lives. As a result of the growing demand towards the internet, the world went beyond human-to-human communication [4, 5]. Consequently, the world has entered a new technological era known as the “Internet of Things” (IoT) allowing everything-to-everything communication [6].

To better understand the term IoT, let us consider what an IoT device is. An IoT device is mainly composed of a “thing”, “computational intelligence”, and a “network”. A “thing” is defined as anything besides a computer such as a car, a refrigerator, heart monitor etc. By embedding computational intelligence such as microprocessors to that “thing,” the resulting device is named
as an “intelligent device” but not an IoT device since it cannot send and receive data to a network. By adding any sort of a network to that thing, for example a Wi-Fi connection, an IoT device is developed.

Consequently, as more and more devices being interconnected to each other and to the network a new ecosystem referred to as the “Internet of Things” is developed [7]. Since IoT is still at its infancy, the literature still does not agree on a uniform universal definition for the IoT [8, 9]. Yet, many researchers have proposed various definitions where they all agree on the core concept which is that everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective [10].

IoT enables real time tracking and monitoring of different systems and environments based on real time data acquisition and sharing. By IoT, monitoring and controlling everyday devices can be done remotely from anywhere at any time though the Internet. This is done through IoT enabling technologies including sensing and identification technologies namely sensors, RFIDs, real time location technology and IC cards, communication technologies such as wireless network technologies particularly IEEE 802.11 (Wi-Fi), 6LoWPAN, Zigbee and Bluetooth. However, using that data can be a challenge and here comes the role of analytics. Analytics are used to identify patterns in the data, converting these data into useful information, which help in decision-making.

Another definition for IoT is “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual ‘things’ have identities, physical attributes and virtual personalities” [11–13]. According to the European Technology Platform on Smart Systems Integration (EPoSS) [14] “The semantic origin of the expression is composed by two words and concepts: “Internet” and “Thing”, where Internet can be defined as “The world-wide network of interconnected computer networks, based on a standard communication protocol, the Internet suite (TCP/IP)”, while Thing is “an object not precisely identifiable”. Therefore, semantically, Internet of Things means “a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols.”
2.1.1 Basic definitions

Antenna Gain: A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern. The measurement is typically measured in dBi (Decibels relative to an isotropic radiator)

Internet Protocol: Each computer (known as a host) on the Internet has at least one IP address that uniquely identifies it from all other computers on the Internet.

Signal Attenuation: is the loss of transmission signal strength measured in decibels (dB). Attenuation is a natural consequence of signal transmission over long distances.

2.1.2 Approach to Literature Review

The search for relevant publications was performed using several Web-based scientific search engines, databases and electronic libraries. The search was limited to articles published in refereed journals and reputed conferences. The review was carried out in three stages:

- Search in scientific databases with relevant keywords
- Identification of relevant papers by abstract reading
- Full text reading and grouping into research topics

In addition, a manual search was done to supplement the automated search. The manual procedure involved searching the reference sections of the papers identified by the automated search by following up any relevant references within those papers. Abstracts for selected papers were screened to avoid irrelevant papers.

2.1.3 Growing interest in Internet of Things

There is considerable growth in the number of articles published addressing the topic internet of things over the last two years. The analysis in Figure 2-1 signifies the criticality of this research area in the literature, reporting a wide, recent and growing interest within the research community regarding the adoption of internet of things in various domains.
Research for publications was done using the following keywords and phrases: Internet of things, IoT, RFIDs, real time monitoring, traceability, Industry 4.0. Those keywords and phrases were searched in “Subject/Title/Abstract” field options. Because of the novelty of the concept of Internet of Things, no time limit was used in first search. Moreover, abstracts reading was done in order to reduce the number of gathered papers. Papers mainly focusing on IoT security, hardware design, IoT Network design architecture were eliminated.

Over 80 research papers were reviewed and classified according to their publication year, as well as area of application. More than 60% of papers were published between the period 2016-2018, almost 30% between the period 2013-2015 and about 10% before that. Accordingly, one can conclude that internet of things has attracted increasing attention over the last 2 years; this is reflected in a significant growth in the number of published applications.

Figure 2-2 shows the accumulation of publications gathered for the review, if one eliminates the period before 2015, the result is almost a straight line. As can be seen, there is a rising trend in the number of articles published in this field.

2.1.4 Issues in IoT

There is massive growth in the number of publications in the area of IoT as has been mentioned in the previous subsection.
The major findings that can be reported as a result of the literature review conducted are as follows:

- IoT security represents the main hurdle for the implementation of IoT in real life. Large scale application and services based on IoT are still vulnerable to security attacks. One of the reasons for this problem is the lack of common standard for IoT security.

- Trust and information privacy is another key challenge facing the IoT. Users must build trust in IoT based systems as well as confidence that the information and services provided can be relied upon especially in the healthcare field. This can only be realised in the presence of a reliable system; it means that the system should be successful in delivering IoT service at different circumstances.

- More research is needed in the field of Big Data Analytics. Since benefiting from IoT implementation mainly depends on extracting insights from data for analysis. Hence more work is being done in the field of cognitive technologies, artificial intelligence as well as real time data processing and analysis.

- The requirement of new business models to facilitate the application of IoT in various domains is essential in the current phase to accelerate the real implementation of IoT.

- Another major issue in IoT implementation is interoperability. The ability to connect hundreds of heterogeneous devices from different vendors and different platforms poses a
challenge. Accordingly, interoperability is an important point that is being considered to ensure that different devices can share information and can interact with each other.

**IoT in Legacy System**

Existing industries especially, the small and medium enterprises (SMEs) seek the deployment of Industrial Internet-of-Things (IIoT) over legacy systems. Unlike larger firms, one of the traditional problems that faces SMEs is the limited resources represented in the lack of financing and difficulties in exploiting new technologies which allow them to upgrade their machines and their technology base [15]. Funding gaps are a serious obstacle for the growth of SMEs; wide variance in the profitability, survival and growth of SMEs compared to larger firms brings special financing problems [16].

According to literature, a significant challenge is that many legacy and existing devices, which make up 85% of all devices in a system, are isolated and unconnected [17, 18]. The true value in the Internet of Things is realized when most devices, both old and new, are connected to the internet and their data is collectively analysed, revealing actionable insights that can transform business. It is not always possible or economically feasible to upgrade a large number of devices to enable them to communicate with the internet. Moreover, many legacy devices, especially those used in commercial and industrial applications, tend to have long life-spans. Hence it is unlikely to replace those machines before the end of their useful life [19].

### 2.2 EVOLUTION OF IOT

In the mid-1960s the world witnessed the beginning of the research on the internet, however, it was not until the 1990s where the internet gained popularity [20]. Meanwhile, as a result of the vast growth in the demand towards the internet, there was a massive increase in the IP addresses being used up, which was the starting point for the development of IPv6 that was published latterly in 1998 to cover that shortage.

The year 1999 is one of the important dates in the history of IoT, this year witnessed the term IoT being coined for the first time in history by Kevin Ashton, executive director of the Auto-ID
Centre, MIT [4]. He defined IoT as a network that connects anything at anytime and anyplace in order to identify, locate, manage and monitor smart objects [13]. In 2000, LG Electronics company announced its plan to reveal a smart refrigerator that would determine itself whether or not the food items stored in it need to be replenished [21].

Following that, in 2006 IoT gained recognition by EU and the first European IoT conference was held. Soon after, the world witnessed the inauguration of the Internet Revolution known as “Internet of Things” (IoT) between the years 2008 and 2009. As reported by Cisco IBSG in its annual report in 2011, the IoT was born as a result of the increase in the number of devices connected to the internet reaching 12.5 billion which exceeded the number of world’s population in 2010, and according to its statistics, Cisco forecasted this number to reach 50 billion by 2050 [22]. In 2011, Cisco, IBM, and Ericsson produced large educational and marketing initiatives on the topic.

A year after, in December 2012, the auto manufacturer Volvo Car Group and Ericsson announced their new partnership to take new “Connected Vehicle Services” to market. The car would be able to share internet access to other devices, inside and outside the vehicle in addition to allowing passengers to access applications for information, navigation, entertainment and more from a screen in the car through the Connected Vehicle Cloud built on Ericsson’s Service Enablement Platform [5].

The quantum leap was the foundation of “Industrial Internet Consortium” (IIC) in 2014 under the collaboration of the giants; Intel, SAP, GE, and Schneider Electric. Its goal is to promote the accelerated growth of the “Industrial Internet of Things” across industries and public infrastructure [23].

In 2015, the retail giant Amazon launched its own IoT device known as “Amazon Echo.” This hand free voice controlled device offers many services by connecting it to a wireless internet connection. Through Echo, one can check weather and news; play music from streaming music services; maintain voice-controlled alarms, timers, shopping and to-do lists and can access Wikipedia articles. Furthermore, through Alexa, the Echo's voice assistant, one can order food or get a taxi as well as many other services.
Today we are witnessing governments, industries and academia spending millions on funding programmes and research initiatives in implementing IoT on different scales. Germany proposed the Industry 4.0 strategy, which presents that the IoT and related services enable the creation of networks that incorporate the entire manufacturing processes that can convert factories into smart environments. Other countries notably the United States, Japan, South Korea, and some European and Asian countries have formulated their own IoT strategies and market positions [24, 25]. Figure 2-3 shows IoT timeline highlighting the milestones owing for the evolution and the development of the Internet of Things.

Figure 2-3 Internet of Things timeline evolution

### 2.3 IOT APPLICATIONS

The applications of IoT span numerous areas such as manufacturing environment, supply chain and logistics, smart infrastructure, and many other applications, as shown in to Figure 2-4. Based on gathered publications, reviewed papers are classified according to their application domain, refer to Figure 2-5. It can be concluded that manufacturing environment is the most popular application in IoT accounting for 25% of gathered publications, followed by IoT in Smart City infrastructure contributing by 19%. IoT in healthcare comes in the third place making up 16%. This is followed by review papers contributing to 13% of literature. As for the supply chain and logistics, it accounts for 11%. Finally, other papers that do not belong to one of those classes are grouped together in the “others” class representing around 16% of gathered publications.
2.3.1 IoT in Manufacturing and Supply Chain Logistics

IoT allows “everything to everything” communication by networking resources, information, objects, and people for the first time. The effect of this phenomenon was also felt by industry. In the realm of manufacturing, this technological evolution can be described as the fourth stage of industrialisation, or Industry 4.0. The first three industrial revolutions came about as a result of mechanisation, electricity, and IT, respectively. Now, the introduction of the Internet of Things into the manufacturing environment is leading to a fourth industrial revolution, Industry 4.0 [23].

In the specific context of manufacturing, IoT has been also referred to as the “Industrial Internet” to highlight the applications in the world of heavy industrial assets [5]. Because of globalization, competition among industries became even tougher than before specifically in the manufacturing environment. Hence, agility, responsiveness, and flexibility became the key for any company wishing to survive and maintain its good relations with its customers [24].
To put it differently, manufacturing enterprises must be able to respond to customer changes, as well as unpredictable events in no time in order to be able to sustain oneself in this competitive environment. Therefore, the manufacturing industry has moved to adapting innovative technologies to enhance productivity, quality as well as be able to compete against its rivals, among those technologies the “Internet of things.”

F. Civerchia [26] used IoT for ubiquitous monitoring of industrial machinery to aid in predictive maintenance. The feasibility of the proposed system was tested through a two-month test bed in a real electricity power plant with the aid of 33 IoT sensing devices performing advanced temperature and vibration monitoring tasks.

Xua et al. [27] developed an IoT technology based dynamic production scheduling framework for supporting dynamic Just In Time (JIT) manufacturing environment. The proposed framework can respond to the dynamic changes with customer orders, production progress, and availability of required resources. This allows manufacturers to adjust planned schedules during production to maximize the production outputs with limited resources.

Sensors have decreased in cost, weight, and size over the past few years that allow it to be embedded into devices without even changing the devices’ original interface. The challenge nowadays is to create a suitable IoT solution with the suitable sensors, networking and processing capabilities for existing facilities and to properly analyse collected data to improve decision-making tools.

RFIDs have been part of several IoT solutions proposed for manufacturing. Zhong et al. [28] and Z. Guo et al. [29] proposed an RFID-enabled shop floor that translates Big Data into valuable information by integrating IoT and cloud manufacturing concepts to create an intelligent production environment. A pilot implementation of the architecture is reported in a distributed clothing-manufacturing environment that demonstrate a 25% increase in production efficiency, and a 12% reduction in production wastes, and an 8% reduction in labour and system costs.

Finally, Ondemir et al. [15] proposed the use of IoT to help in improving the planning of remanufacturing operations by overcoming the problem of uncertain quality and quantity of
collected End Of Life Products (EOLP). This is done by embedding sensors and RFID tags to products that will save information about the product through its whole life cycle. Data will be retrieved wirelessly as soon as the EOLPS enter the communication range of the intended servers at the recovery facility.

Internet of things has been widely applied in the area of supply chain and logistics with the attempt to allow supply chain visibility and transparency providing greater insight into exactly what is happening at each stage and at any times in the supply chain.

H.Luo et al. [30] proposes an intelligent tracking system for the cold chain by integrating IoT and tracking technologies. The proposed system allows the latest status of perishable goods to be available in remote monitoring centres. If the temperature or humidity of goods is abnormal, the system will generate alerts. Accordingly, users of this system can easily monitor goods transported in cold chains. The goal of the proposed tracking system is to achieve effective and fast live monitoring of goods in the cold chain at the lowest cost and with the largest network capacity.

B.Yan el al.[31] applied IoT in fresh agriculture product supply chain (FAP). The study uses RFIDs for the production, transportation, quality and safety management, and traceability of FAPs; and explains the process of obtaining freshness information and controlling freshness based on the operation mode of a three-level supply chain. The proposed solution was tested through a case analysis which resulted in an improvement in the resource utilization as a result of better coordination between the entire supply chains, a reduction in the loss in the circulation process, as well as improvement in the circulation efficiency of FAPs as a result of the application of IoT.

Further applications related to the implementation of IoT in supply chain and logistics can be gained by reviewing the works of M.Ilgin [32], X.Wei et al.[33], M.Ramachandra [34]. Motivated by the considerable amount of work in this field, a recent review of related researches appeared in [35].
2.3.2 Other Applications for IoT

The application of IoT in infrastructure aims to exploit public resources, enhance the quality of services offered to the citizens while minimizing operational costs [36]. A smart city comprise smart home, intelligent energy management and smart grid, smart automotive, intelligent waste management in addition to traffic management [37].

For instance, waste management would be more efficient with the use of “Intelligent Waste Monitoring” system. With the use of Global Positioning System (GPS) and level sensors attached to bins and connected to a network, which enable it to communicate wirelessly. Consequently, collection operation becomes more efficient by route optimization where efficient routes for only the containers requiring servicing are generated [38, 39].

A proof of concept for smart city implementation is illustrated in “Padova Smart City” project in Italy. The project aims to make better use of public resources, increase the quality of offered services in addition to reducing operational costs of government. This is done by monitoring and analysing data collected data by deploying sensors to monitor public street lightening and to collect environmental parameters such as air temperature, Carbon Monoxide (CO) level, and humidity as well as vibration and noise levels. [36][40].

Another key model of smart cities is seen in Dubai city. Dubai is introducing a new digital backbone known as “SMART DUBAI PLATFORM.” The platform aims to enhance city leadership decision making, operational efficiencies and daily quality of life [41]. The Smart Dubai Platform will store the complete catalogue of open and shared city data, enabling efficient and secure data sharing and secure data-cloud services for the city.

Another important area for IoT applications is healthcare. According to the “Global Health and Aging” report, which is released by the United Nations, in 2010 approximately 524 million people were aged 65 or older, representing 8 % of the world’s population. However, this number is expected to increase by 2050 reaching about 1.5 billion that represents 16 % of the world’s population [31].
There is a difficulty in providing high quality healthcare services with reasonable costs because of the increasing number of elderly and disabled people that suffer from diseases that necessitates continuous health status monitoring. Hence, the need for the deployment of new technologies such as IoT in healthcare services to provide e-healthcare which offers instantaneous, cheaper and more effective service provision [42]. As a result, the healthcare system is gradually moving from traditional clinic-centred health systems into more personalised and mobile-centred healthcare systems [43]. According to Forbes more than 177 billion dollars will be spent on IoT in healthcare by 2020 [44].

Healthcare systems will use a set of interconnected devices to create an IoT network devoted to healthcare assessment, including monitoring patients and automatically detecting situations where medical interventions are required [45]. The idea is based on deploying wireless sensors such as Physiological sensors and Image sensors as well as Ambient sensors and wearable devices such as Fitbit Flex that are capable of capturing vital signals and readings from the patient’s body such as heart rate and blood pressure as well as readings from the surrounding environment [46]. Captured data will be sent to servers where it is updated in real time and analysed by healthcare professionals to track the patient condition on real time basis.

With the introduction of IoT in healthcare electronic historical records will be available for each person combining medical records and past prescription even if it was from several doctors in different clinics. Unlike traditional system complete past medical records of a patient are usually unavailable that occurs as a result of the poor sharing of information among different doctors.

Overall, IoT in healthcare provides an opportunity to improve the quality of medical care to patients while reducing the cost of service. However, more research need to be done in the field of IoT in healthcare to earn the trust of users and patients to accept and rely on an IoT disease management service.

Based on the gathered literature few research has been conducted in other application areas such as tourism [47–49], agriculture [50–52] as well as sustainability [32].
2.4 SENSORS IN IOT

In an IoT system, sensors play a major role. Sensors are in charge of object identification, sensing desired parameters on objects (things), communicating information inside the IoT and primary processing and computation in the information. Identification technologies aim to make a clear identity for any object inside the network. General design specifications for each technology are optimized for a certain application.

Automatic identification and data collection systems, also known as Auto-IDs, are a group of technologies its goal is to identify objects, collect related data, and send those data directly into computer systems automatically.

Examples of AIDC include barcodes, biometrics, smart cards, as well as Radio Frequency Identification System (RFID) [53].

2.4.1 Automatic Identification Systems (Auto-IDs)

Barcode

The barcode is a binary code comprising a field of bars and gaps arranged in a parallel configuration. Those black and white bars are arranged according to a predetermined pattern and represent data elements that refer to an associated symbol. Optical device, usually called scanners, ‘‘read’’ the bar code pattern and translates it into usable data.

Biometrics

Biometrics is defined as the body measurement procedures involving living beings. Biometrics refers to authentication techniques that rely on measurable physical characteristics for identification and access control. Biometrics includes voice recognition, fingerprinting procedures, hand geometry recognition as well as iris and retina identification procedure.
**Smart Cards**

A smart card is a plastic card that contains an embedded computer chip, either a memory or microprocessor type, which stores and transacts data. Smart cards offer safe data storage protected against manipulation and undesired read access. Smart cards are placed in a reader, which makes a galvanic connection to the contact surfaces of the smart card using contact springs. Today smart card is used in many applications such as transportation, banking, SIM cards and telecommunication as well as healthcare.

**Radio frequency Identification Systems**

Radio-Frequency Identification (RFID) technology is a wireless sensor technology which is based on the detection of electromagnetic signals [54]. RFID can be defined as electronic barcode. An RFID system is composed of three elements a reader, antenna (connected or integrated to a reader), and a tag. Figure 2-6 present components of an RFID system.

![RFID system](https://www.epc-rfid.info/rfid)

The reader, known as interrogator, sends signal via the antenna to interrogate and collect data from the tag. The tag, also known as transponder, is located on the object to be identified and is responsible for providing information about the object to which it is attached.

The system works as follows, the reader sends signal via the antenna, which is responsible for establishing the communication between the reader and the tag. As long as the tag is in the electromagnetic zone generated by the reader, the reader detects the tag. Consequently, the reader can track and collect information from the tag and thereby track the object to which the tag is
attached [55]. The reader decodes the data encoded in the tag’s integrated circuit [56]. Collected data are send to backend systems to extract useful information to help in improving process and decision making.

**Reasons for Selecting RFIDs for Data Collection**

RFIDs were considered the most suitable in our case. To explain, RFIDs use contactless technology unlike smart cards, which require mechanical contact that is impractical in our case [57]. Compared to barcodes, RFIDs do not require line-of-sight requirement for object identification, tags transfer data automatically as soon as tags pass through an electromagnetic field generated by a reader. Moreover, RFIDs offers high speed where readers can read multiple tags simultaneously in a response time less than 100 milliseconds. Furthermore, RFIDs allow data to be stored and updated automatically in addition to being reliable even in harsh environments such as dust or damp conditions [23]. However, RFIDs still have some drawbacks. Cost is considered expensive when compared with barcodes. In addition, when a large volume of tags must be read together in the same RF field, collision problem usually takes place [55], which necessitates the use of effective anti-collision protocols [58].

**2.4.2 RFID systems**

Setting up an RFID system requires a lot of effort and precision to ensure that the components in the system are compatible and will operate correctly and efficiently. Hence, each component in an RFID system must be selected carefully to meet the application requirements.

RFID systems are classified according to their operating frequencies; low frequency (LF), high frequency (HF) and ultra-high frequency (UHF) [55, 56].

Low Frequencies (125- 134 kHz) offer very short reading range limited to 10 cm [54]. LF RFID systems have long wavelength hence they possess high ability to penetrate metallic surface [28] as well as liquid surfaces such as water. Furthermore, low frequency RFID systems have the lowest cost compared to HF and UHF systems. Nevertheless, LF systems have some drawbacks such as
low data transfer rate in addition to the inability of LF readers to identify multiple tags simultaneously [59].

High Frequencies (13.56 MHz) offer higher reading range up to 1 meter. HF RFID system can work fairly well around metallic and liquid substances. Moreover, they offer higher data transfer rate and the ability to read few tags simultaneously [59].

Ultra High Frequencies (860-960MHz) permit long reading range up to 10 meters in the case of passive tags [59] and 100+ meters in the case of active tags being deployed [54]. UHF offers very high data transfer as well as the ability to read hundreds of tags at once. Compared to LF, UHF have shorter wavelength hence they have higher probability to be attenuated therefore they cannot pass through metal as a result of reflection nor liquid substances as a result of refraction [60].

**RFID Reader Selection Criteria**

Readers are the brain of RFID systems. A reader is equipped with antennas for sending and receiving signals, a transceiver and a processor to decode data [61, 62]. Important criteria to consider when selecting an RFID reader:

- Handheld/Fixed Reader
- Operating Frequency
- Data Interface
- Antenna port
- Operating Temperature
- Power Source
- Ingress Protection (IP) rating

A handheld reader is a reader which is portable and can be carried anywhere, it is usually battery operated. However, there are some cases which necessitate reading tags across a single zone hence a fixed reader can be employed in this case. There are some locations where it is impractical or impossible to use fixed readers, in this case handheld readers are employed.

The *operating frequency* is determined according to the read range required between the tag and the reader in the application.
Data interface means the mode for transferring data to the end user whether it could be transferred by Wi-Fi connection, Ethernet, Bluetooth or by USB.

Antenna ports; each reader is designed with specific number of antenna ports that can be connected to. As number of antenna ports increase this means more antennas could be connected to the same reader hence more reading zones could be read by the same reader.

Operating temperature; every device has an optimal reading temperature. Outside this specified range, the device may work slowly or stop working.

Power Source Mode; each reader has its own power source mode. Examples of power source mode include: battery, AC power supply, Power over Ethernet (PoE) or USB connection.

IP Rating consists of two digits. The first digit from 0-6 indicates the level of protection against solids like dust. The second digit will be 0-9 indicates the level of protection against liquids like water.

RFID Antenna Selection

The beginning and end of a communication circuit is the antenna. RFID Antennas plays a major role in the radio communication between the tag and the reader. The antenna, connected and powered by the reader, generates electromagnetic field to transmit and receive signal from the tags. The selection of the appropriate antenna is a fundamental step to ensure the link between the reader and the tag.

Several factors must be considered to select the appropriate antenna that meet the application requirement such as:

- Indoor / Outdoor
- Operating Frequency
- Polarization
- Gain
- Maximum read distance
- Beamwidth
- IP Rating
- Operating Temperature
Some antennas are specifically designed for working in either indoor or outdoor application. Others can work in both environments.

*Operating Frequency* means whether it is LF, HF or UHF.

*Antenna polarization* refers to whether the antenna has linear or circular polarization. Linear polarized antenna broadcast electromagnetic waves on a single plane. On the other hand, circular polarized antenna broadcast their waves on two planes.*Antenna Gain;* A higher gain indicated a more powerful antenna hence a higher reading range. On the other hand, a low gain antenna has lower power and hence lower reading range.

The *maximum distance* by which a tag can be read by the antenna’s generated signal depends mainly upon the gain and operating frequency.

*Beamwidth;* as the name implies, beamwidth means the width of a beam. A higher beamwidth implies a wider read width.

The *IP Rating* describes the level of protection from solids like dust and liquids.

*Operating Temperature;* every device has an optimal operating temperature. Outside this specified range, the device may work slowly and stop working.

**RFID Tag Selection Criteria**

Tags or transponders are responsible for providing data of the object to be tracked. Tags are comprised of embedded antenna and an integrated circuit (IC). The antenna is responsible for defining the read range of the tag. The integrated circuit, also known as the chip, is responsible for collecting data about the item being tracked, process data, send and receive data as well as provide anti-collision protocol.

Several factors must be considered to select the appropriate tag that meet the application requirement such as:

- Passive/Active Tag
- Operating Frequency
Tags are classified as passive, semi passive and active. A passive tag does not have its own power source, instead, it scavenges its power from the signal generated by the reader [61]. To explain, when a tag comes within the reader’s range, its embedded antenna resonates with the received electromagnetic signal. The flow of the electromagnetic signal in the antenna generates electric power needed to activate the circuitry inside. Accordingly, the tag communicates back to the reader by sending a signal that carries stored information about the identified object. This is known as “backscatter communication” [63]. Figure 2-7 Backscatter communication in passive tags.

Compared to active tags, passive tags are much cheaper, smaller; lighter and most importantly they have indefinite operational life [64].

On the other hand, active tags have their own power source (battery) hence they have stronger signal and therefore have extremely long read ranges [65] as well as large memory banks. Unlike passive tags, active tags do not wait for the reader’s signal; the tag constantly broadcast a signal. Therefore, active tags are large, expensive and have limited lifetime and therefore require replacing [57][66].
Semi-passive tags, also known as semi active /battery assisted passive tags, are tags that operate with the same backscatter communication principle used in passive tags in addition to the presence of a battery [57]. Because the tags are self-powered, they can transmit their data over greater distances and they reply more quickly to the reader as well as the possibility of including sensors [67].

The operating frequency, is determined according to the read range required between the tag and the reader in the application.

Tag Forms; there are several tags forms. Tags are in the form of labels that are paper thin and flexible or in the form of hard tags that are thicker and made of rigid materials such as ABS, ceramic...etc.

The size of the tag must fit the size of the object to which it is tagged. The size also plays a major role in the read range. The large the tag the larger the read range.

Tag Orientation includes whether the tag is vertical, horizontal, or otherwise in relation of the RFID system’s antenna. Therefore, a test must be made before deciding on the final orientation of the tag.

Tag Angle; the tag angle is front of the tag must directly face the antenna to obtain best results.
Tag Placement; with the aid of several tests and trials the “sweet spot” must be identified which generates the best reads.

The tag attachment method is one of the critical criteria in tag selection. If an attachment method fails, the tag will fall off and the object will be no longer trackable.

Application Surface Material; Tag’s antenna is very sensitive to the type of material to which it is tagged. Attaching the tag to an incompatible type of surface could result in lower read range or no reading at all.

Important Factors in RFID Selection

When designing our RFID network system many factors were considered to ensure the system will operate as planned.

To begin with, all components in an RFID system should have same Tag type and same operating frequency and air interface protocol so that they work together in a compatible manner. For example, a passive HF reader will only be able to read passive HF tag; it will not be able to read LF or UHF tags.

Another key point when selecting operating frequency is the geographical location. A standard operating frequency is defined for each country, violating this standard is considered illegal. Hence, it is important to select components with the acceptable frequency for each country or else choose a component with generic frequency known as “global frequency” that can work in any country.

Radio Wave Propagation Model

Radio propagation is the way radio waves travel or propagate when they are transmitted from one point to another and affected by the medium in which they travel. There are many factors that affect the way in which radio signals or radio waves propagate. These are determined by the medium through which the radio waves travel and the various objects that may appear in the path.
Radio waves are affected by the phenomenon of reflection, refraction, diffraction, absorption, polarization in addition to scattering. Accordingly waves coming from various routes reach the antenna. This process is called multipath propagation that can cause radio wave fading. The radio wave propagation loss and the fading caused by multipath propagation depend on the propagation environment. Therefore it is important to examine the real world effects to accurately predict the radio propagation loss in order to design a reliable wireless communication network [68]. Accordingly, a basic formula modelling indoor wave propagation is given in [69].

The power signal received at RF tags is calculated by the following equation (in terms of dB):

\[ P_{r,tag} = P_{PA} - L[db] \]

\[ L[db] = 10 \log \left( \frac{1}{G_{TX}G_{Tag}} \right) \left( \frac{\lambda}{4\pi} \right)^2 d^n + \alpha[db] \]  

Equation 1

Equation 2

Where \( P_{PA} \) is the power output by the RFID reader, \( L \) is the propagation loss considering multi-path fading, \( n \) is the path loss exponent between 1.5 and 3 depending on the environmental conditions [69] and \( \alpha \) is about 10 dB [69] in worst case. \( G_{TX} \) and \( G_{Tag} \) is reader antenna gain and tag antenna gain respectively.

2.5 MULTI-CRITERIA DECISION MAKING METHODS

Multi-Criteria Decision Making (MCDM), also known as Multi-Attribute Decision Making (MADM), is one of the areas in the Operational Research (OR) which has witnessed rapid growth over the past 20 years. This is noticed in the increasing number of publications in this field including various applications such as supply chain selection [70–72], water resources management [73–75], personnel recruiting [76, 77] and various other applications as well as reviews.

The presence of real life problems requiring the consideration of multiple criteria has been the catalyst for the development of many MCDM as well as its applications in many different domains. Multi-Criteria Decision Making methods are applied to aid the decision maker in selecting the best alternative (option) among finite number of alternatives characterized by a set of multiple criteria.
MCDM methods are used to ameliorate the quality of the decisions by making the decision making process more rational [78].

MCDM can be classified into: compensatory and non-compensatory models. In compensatory models, a shortfall in one of the criterion can be compensated by a good rating in other criterion. Example of compensatory model is the AHP, MAUT, MAVT [79].

On the other hand, non-compensatory models are different. In non-compensatory models, if a certain alternative did not satisfy a specific criterion by a certain threshold, the alternative will be omitted nevertheless it had good rating in other criterion [80]. Hence, non-compensatory models are used to aid the decision maker in the selection of the best alternative that meets all criteria with a certain degree and to reject any alternative considered weak in at least one of those criteria. Examples of non-compensatory models are the ELimination Et Choix Traduisant la REalité (Electre) family methods and Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE).

A systematic literature research was realized to find articles published in the period of 2010 until present using same approach explained in section 2.1.2. Research for publications was done using the following keywords: Multi-Criteria Decision Making, MCDM, Decision-Making, Multi-Criteria, and Multi-Attribute.

Our literature focused on several MCDM methods which according to M. Marttunen et al. [81] are the most extensively used recently in literature, refer to Table 2-1.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Method</th>
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<tbody>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
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<tr>
<td>ANP</td>
<td>Analytic Network Process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELECTRE</td>
<td>Elimination and Choice Expressing Reality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAVT/MAVA</td>
<td>Multi-Attribute Value Theory</td>
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<tr>
<td>MAUT/MAUA</td>
<td>Multi-Attribute Utility Theory/Analysis</td>
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<tr>
<td>PROMETHEE</td>
<td>Preference Ranking Organisation Method for Enrichment Evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOPSIS</td>
<td>Technique for Order Preference by Similarity to Ideal Solution</td>
<td></td>
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</table>
Moreover, separate research was conducted for each MCDM method using the name of each method separately such as AHP, Electre, and TOPSIS and so on. The search was also refined by only displaying published articles since 2010. According to the number of results that appeared after searching by each method separately, it was obvious that ANP, AHP (Compensatory) and Electre (Non-Compensatory) were the most popular used MCDM methods in the last decade.

Particularly, our research aimed to find articles which provided clear and explicit understanding of different ways to use each MCDM in various applications. Moreover, our research considered the following criteria:

- All research papers fall within the last decade time frame, with a higher priority assigned to those published in the last 3 years.

- Coverage of different application areas and geographical locations.

- All articles published only in English language.

- Review papers providing clear and rich vision and on one or all MCDM methods in the last decade and analysing the advantages and disadvantages of each method.

- Considering Research papers with an explicit problem statement that is similar with the presented problem in this study.

- Elimination of articles focusing on modification and extensions of methods without a numerical application to test the validity of proposed method.

The following section will give very brief description on each of those methods, except for the Electre and AHP. A more detailed explanation of these two methods is provided since they are the two methods applied in this study.
2.5.1 Analysis of MCDM Literature

A summary and analysis of the literature gathered in the area of MCDM is graphically represented below with the aid of different types of charts. The following subsections present classifications of references according to publication type, MCDM method applied.

Classification by publication type

The reviewed publications are classified according to the type of research paper whether it is journal paper or a conference paper. Based on Figure 2-10, 87% of gathered publications were published in academic journals while the remaining 13% in reputable conferences.

Classification by MCDM method

The reviewed papers are further classified according to the MCDM method. According to Figure 2-11, it can be observed that AHP and Electre are the most popular MCDM methods applied in literature both accounting for 24% of gathered publications. This is followed by TOPSIS making up 20% of gathered literature. This is followed by other MCDM methods each accounting for almost same percentage as others.

2.5.2 Analytical hierarchy process (AHP)

The Analytical Hierarchal Process, known as AHP method, was developed by Thomas L. Saaty in the 1970s. The AHP deals with decision making problem by dividing it into hierarchies as goal, criteria, sub criteria and decision alternatives. The major characteristic of the AHP is the pairwise
comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. Pairwise comparisons are made using linguistic scale, which is introduced by Saaty, from 1 to 9. The AHP algorithm investigates the consistency level of the decision criteria weights on each level of hierarchy. The consistency of preferential information given by the Decision Maker (DM) is measured by calculating the Consistency Index (CI). If the value of CI is close to 0 the preferential information given by the DM is considered to be almost fully consistent. The acceptable level of CI is below 0.1 [82]. Final results are given in the form of ranking of alternatives from best to worst.

![Figure 2-11 Classification according to MCDM method used](image)

### 2.5.3 Elimination and Choice Expressing Reality (ELECTRE)

The Electre method was first introduced by Bernard Roy and his colleagues in 1960s [83]. Electre methods are based on outranking relations between alternatives. After the introduction of the first version, known as Electre I, further versions were introduced including: Electre II, Electre III, Electre IV, Electre IS as well as Electre TRI. Today, the most widely used versions are known as Electre II and Electre III.

### 2.6 LITERATURE REVIEW FINDINGS

Recent years have witnessed increasing interest in the topic Internet of Things. Among numerous applications, IoT in manufacturing was the most popular. In a manufacturing facility immense
opportunities are presented by the capability to analyse and utilize huge amounts of IoT data. By examining large data sets it can reveal trends, unseen patterns, hidden correlations, and new information.

Consequently, there was a significant focus on the application of IoT in manufacturing environment where companies and individuals can benefit from analysing large amounts of data and managing huge amounts of information that can affect businesses.

The major findings that can be reported as a result of the literature review conducted are as follows:

- Manufacturing environment and Smart City infrastructure are the most popular application areas of IoT.
- Legacy Systems represents a major challenge for the deployment of IoT.
- The literature about IoT solutions for SMEs is very limited.
- RFIDs is still the most extensively used Auto-IDs in IoT applications. Large number of conflicting criteria must be considered upon the selection of the best RFID components to meet certain application requirements.
- Industries have strong interest in deploying IoT devices to develop industrial applications such as automated monitoring, control management, and maintenance. Due to the rapid advances in technology and industrial infrastructure, IoT is expected to be widely applied to industries.

This research tackled the problem of integrating IoT technology into legacy system. The main contribution of this work is the deployment of IoT, in an Egyptian Manufacturing SMEs across the factory floor to synchronize production, link machines, and monitor manufacturing processes remotely via smart phones.

The selection of our case study was based on several criteria:

- The selection of an important industry in the Egyptian Economy.
- The selection of a facility classified as SME.
- The selection of a facility with legacy system composed of machines of different vintages and conditions.
- The deployment of IoT can add value to the facility.

To aid in the selection of best IoT sensor there was a need for a method to evaluate finite number of decision alternatives under a finite number of conflicting criteria and here comes the role of Multi-Criteria Decision Making method. The two extensively used MCDM in literature were applied in this study. To facilitate the computation, a decision support system was developed in Microsoft Excel using Visual Basic as programming language to automate the process.
CHAPTER THREE
RFID READER SELECTION USING THE DEVELOPED DECISION SUPPORT SYSTEM
3 RFID READER SELECTION USING THE DEVELOPED DECISION SUPPORT SYSTEM

This chapter focuses on detailed description of the Decision Support System development, using Excel Visual Basic which is used to select appropriate sensors, specifically RFIDs, for the case study. The DSS has been developed with generality to help in the sensor selection process for any similar manufacturing facilities. It includes two major MCDM algorithms; the compensatory AHP and the non-compensatory Electre MCDM algorithm. The DSS receives input from the user through an interactive graphical user interface, processes this input and then ranks alternatives from best to worst based on the MCDM chosen by the user.

3.1 COLLECTION OF RFID READER ALTERNATIVES

The DSS requires a database of sensors in order to provide the user with an extensive grasp of various types of sensors. Therefore, 40 alternatives of RFID readers were gathered from well-known online stores that sell reputable brands of RFID readers such as Keon, Thingmagic, Zebra and many other brands. Most of the stores provided a datasheet for each reader which includes the characteristics of each reader, in case of missing data; emails were sent to the store to provide us with the missing information needed for our study. In case no further information available, the reader was eliminated. Hence, only readers with available necessary information were kept. Refer to Appendix C for full view of alternatives selected.

RFID Reader Selection Criteria as defined in section 2.4.2.

- Handheld/Fixed Reader
- Operating Frequency
- Data Interface
- Antenna port
- Operating Temperature
- Power Source
- IP rating
3.2 DECISION SUPPORT SYSTEM ARCHITECTURE

Briefly, the mechanism of the DSS can be summarized as follows; RFID reader alternatives are inserted in the DSS “Alternatives” sheet. In order to be able to perform the AHP and Electre which require pairwise comparison the number of alternatives had to be reduced to the minimum possible.

This was done through filtering process. Through a friendly user interface the DSS asks the user few questions related to the application, refer to Figure 3-1 and Figure 3-2. The user has to respond to all questions by selecting one of the replies to be able to proceed. Those questions are:

- Where will the reader be placed? Does the reader need to be mobile?
- How much read range will you require to your application?
- Will the reader be connected to a network?
- How many tags need to be read at one time?
- Any excessive environmental conditions to consider?
- The minimum and maximum temperature needed in the working environment?

![RFID Reader Selection](image)

Based on the user replies the DSS screens all alternatives which is too far from the requirement of the user, leaving only few alternatives which requires a MCDM to recommend the best alternatives among the filtered alternatives.
Based on the user input, the alternatives are screened which means the DSS removes any alternative not meeting the user requirements. Screening is done to minimize the number of alternatives in order to be able to apply one of the MCDM methods applied in this study. After screening, the user chooses the MCDM method to rank the remaining alternatives from best to worst relative to the score of each alternative according to the criteria. Figure 3-3 displays the DSS architecture.
3.3 RFID READER SELECTION USING AHP

3.3.1 General Concept of AHP method

One of the MCDM methods employed in the DSS is the AHP. The AHP is proposed as a method for ranking decision alternatives and selecting the best RFID solution that would meet the decision maker requirements.

Using AHP the following steps are applied:

1. Develop a model for the decision: Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

2. Derive priorities (weights) for the criteria: The importance of criteria is compared pairwise with respect to the desired goal to derive their weights. We then check the consistency of judgments; that is, a review of the judgments is done in order to ensure a reasonable level of consistency.

3. Derive local priorities (preferences) for the alternatives with respect to each criterion separately (following a similar process as in the previous step, i.e., compare the alternatives pairwise with respect to each criterion). Check and adjust the consistency as required.

4. Derive Overall Priorities. All alternative priorities obtained are combined as a weighted sum—to take into account the weight of each criterion—to establish the overall priorities of the alternatives. The alternative with the highest overall priority constitutes the best choice.

5. Making a Final Decision: Based on the synthesis results and sensitivity analysis, a decision can be made.
3.3.2 Calculation Procedure of AHP

**Develop Decision Hierarchy**

The decision hierarchy includes breaking down of the decision into a hierarchy of goals, criteria, and alternatives.

![AHP decision hierarchy](image)

**Derive priorities (weights) for the criteria**

Table 3-1 Fundamental scale of absolute numbers

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Importance</td>
</tr>
<tr>
<td>2</td>
<td>Weak or Slight</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Importance</td>
</tr>
<tr>
<td>4</td>
<td>Moderate Plus</td>
</tr>
<tr>
<td>5</td>
<td>Strong Importance</td>
</tr>
<tr>
<td>6</td>
<td>Strong Plus</td>
</tr>
<tr>
<td>7</td>
<td>Very Strong or demonstrated Importance</td>
</tr>
<tr>
<td>8</td>
<td>Very very strong</td>
</tr>
<tr>
<td>9</td>
<td>Extreme Importance</td>
</tr>
</tbody>
</table>

Reciprocals of above

If activity $i$ has one of the above non-zero numbers assigned to it when compared with activity $j$, then $j$ has the reciprocal value when compared with $i$. 
The estimation of priority weights of a set of criteria or alternatives from a square matrix of pair-wise comparison $A = [a_{ij}]$ which is positive and if the paired comparison judgment is perfectly consistent it is reciprocal, i.e. $a_{ij} = 1 / a_{ji}$ for all $ij = 1, 2, 3, n$.

As the difference in dimension among various criteria is the main factor affecting the result of the overall evaluation, the data need to be dimensionless. Therefore, normalization process is done. The normalization of each column of the comparison matrix this is done by adding the values in each column and then dividing each cell by the total of the column.

The final normalized weight, also known as priority vector, $w_i$ is given by

$$w_i = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad \forall i = 1, 2, \ldots, n$$

**Equation 3**

**Consistency Check**

The measure of inconsistency of deviation from consistency, consistency Index (CI) is defined as

$$CI = \frac{\lambda_{MAX} - n}{n - 1}$$

**Equation 4**

The $\lambda_{max}$, known as Eigen Value, is obtained from the summation of products between each element of Eigen vector and the sum of the columns of the reciprocal matrix.

A Consistency Ratio is calculated using

$$CR = \frac{CI}{RI}$$

**Equation 5**

A random matrix is one where the judgments have been entered randomly and therefore it is expected to be highly inconsistent. Table 3-2 provides the standard calculated RI value for matrices of different sizes. A CR of 0.1 or less is acceptable to continue the AHP analysis.

**Table 3-2 Consistency indices for a randomly generated matrix**

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.9</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td>1.52</td>
<td>1.54</td>
<td>1.56</td>
<td>1.58</td>
<td>1.59</td>
</tr>
</tbody>
</table>
The geometric mean is then calculated based on the number of valid questionnaire using the following formula:

\[
Geometric\ Mean = \sqrt[n]{w_1 \times w_2 \times w_k}
\]

Equation 6

Where

**Derive**

In

For comparing alternatives with respect to qualitative criteria, we do a pairwise comparison (using the numeric scale from Table 3-1) of all the alternatives, with respect to each criterion. After constructing the reciprocal matrix, \( w_i = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad \forall i = 1,2,3...n \)

**Equation 3** is applied to calculate the priority vector.

On the other hand, quantitative criteria can be classified as the greater the better (GTB) and some are the opposite; the smaller the better (STB).

If STB then:

\[
Reader\ Criterion = \frac{MAX-Criterion\ Value}{MAX-MIN} \times 8 + 1
\]

Equation 7

If GTB then:

\[
Reader\ Criterion = \frac{Criterion\ Value-MIN}{MAX-MIN} \times 8 + 1
\]

Equation 8

After that Equation 3 is applied to calculate the **priority vector**. Up to this point we have obtained local priorities which indicate the preferred alternative with respect to each criterion.

**Derive Overall priorities**

In this final step, we need to calculate the overall priority (also called final priority) for each alternative; that is, priorities that take into account not only our preference of alternatives for each criterion but also the fact that each criterion has a different weight. The weights are created by summing the priority of each element according to a given criterion by the weights of that criterion.
3.4 RFID READER SELECTION USING ELECTRE

3.4.1 General Concept of Electre Family Algorithm

To understand the concept behind the Electre family method, few notations related to the basic concept is introduced.

Construction of Performance Matrix

For a set of \( m \) potential actions, this set is defined as

\[
X = \{x_1, x_2, x_3, \ldots, m\}
\]

A decision maker (DM) is faced with the problem of ranking these alternatives, which are evaluated with respect to following criteria

\[
\{C_j : j = 1, 2, \ldots, n\}
\]

\( \{w_j\} \) reflects the DM’s relative preferences between criteria.

Depending on the criteria \( j \), if \( x_i \) is better than \( x_k \), it would be recorded as

\[
y(x_i) > y(x_k)
\]

The goal is then to select the best alternative given the performance values of each alternative with respect to each criterion (given as a \( m \times n \) decision matrix) and the corresponding weights of the criteria. For modelling the preference information between each pair of alternatives, such as \( x_i \) and \( x_k \) (\( i, k = 1, m \)), ELECTRE uses the concept of outranking relations. A true outranking relation of \( x_i \rightarrow x_k \) (also denoted as \( x_i \ S \ x_k \)) implies that \( x_i \) is preferred to \( x_k \) if \( x_i \) is at least as good as \( x_k \) on a majority of criteria and if it is not significantly bad on any other criteria (i.e., the difference between the two are within a predefined threshold).

The identification of an outranking relation between \( x_i \) and \( x_k \) requires two sets of comparisons: one among the criteria in which \( y_j(x_i) \) is superior to \( y_j(x_k) \), one among the criteria in which \( y_j(x_i) \) is not superior to \( y_j(x_k) \). In other words, the ELECTRE methods need to separately examine both
the criteria that vote for $x_i \rightarrow x_k$ and those that veto such relation. These two sets of comparisons are performed based on the concordance and discordance tests.

The \textit{concordance test} allows the decision maker (DM) to verify if $x_i$ is at least as good as $x_k$. The other extremity of the concordance test is the \textit{discordance test}. It checks if there exists a very high opposition to the outranking relation $x_i S x_k$. This test is intended for the criteria in which $x_i$ performs worse than $M_k$, and it can be binary or fuzzy. If the test fails, it can be said that there is a high opposition vetoing the concordance test. For instance, if an alternative has the best values regarding some criteria but at the same time it has significantly low values regarding some other criteria, it is likely that it passes the concordance test but not the discordance test. Only when both the concordance and discordance tests are passed, it can then be said that the outranking relation of $x_i S x_k$ is true. If neither $x_i S x_k$ nor $x_i R x_k$, then $x_i I x_k$, meaning that is incomparable $x_i$ to $x_k$. When $x_i$ is indifferent to $x_k$, it is said $x_i I x_k$, implying that one is not preferred over another for the DM. All outranking based methods rely on the concepts of concordance and discordance.

\textbf{3.4.2 Calculation Procedure of Electre II Method}

\textit{Construction of Performance Matrix}

In this step a matrix is constructed where the score of each alternative according to each criterion is determined through a scoring method. This is followed by data processing and treatment to make sure that all data is dimensionless. Various methods such as Normalization processing, Extremum treatment…..etc. could be used. In our study Normalization processing was used.

\textit{Determine the criteria Weights}

In order to provide fair comparison between the final ranking obtained by AHP and by Electre, the same weights obtained by the questionnaire is used.

\textit{Construct the Outranking Relation}

Depending on the criteria $j$, if $x_i$ is better than $x_k$, it would be recorded as $y(x_i) > y(x_k)$. The set of all criteria $j$ which meet the condition $y(x_i) > y(x_k)$ would be recorded as
\[ J^+(x_i, x_j) = \{ j | 1 \leq j \leq n, y(x_i) > y(x_j) \} \]  
Equation 9

Similarly, the formula of \( J^\equiv = (x_i, x_k) \) and \( J^- = (x_i, x_k) \) is as follows:

\[ J^\equiv(x_i, x_j) = \{ j | 1 \leq j \leq n, y(x_i) = y(x_j) \} \]  
Equation 10

\[ J^-(x_i, x_j) = \{ j | 1 \leq j \leq n, y(x_i) < y(x_j) \} \]  
Equation 11

**Concordance Test and Discordance Test**

**Concordance Test**

In order to perform the Concordance test, two indexes must be calculated:

\( I_{ik} \) is defined as a ratio of sum of the weights of the criteria where \( x_i \) is not inferior to \( x_k \) to the sum of all criteria weights. The formula is as follows:

\[ I_{ik} = \frac{\sum_{j \in J^+} w_j + \sum_{j \in J^\equiv} w_j}{\sum_{j=1}^{n} w_j} \]  
Equation 12

\( I_{ik}' \) is defined as a ratio of the sum of these properties’ in which \( x_i \) is better than \( x_k \) weights to the sum of all the properties (in which \( x_i \) is inferior to \( x_k \) ) weights. The formula is as follows:

\[ I_{ik}' = \frac{\sum_{j \in J^+} (x_i, x_k) w_j}{\sum_{j \in J^-(x_i, x_k)} w_j} \]  
Equation 13

Set \( 0.5 \leq \alpha \leq 1 \), if \( I_{ik}' \geq 1 \) and \( I_{ik} \geq \alpha \), then is passes the concordance test.

To be able to perform the test, the value of the three threshold (high, medium, low) respectively called \( \alpha^*, \alpha^0, \alpha^- \) must be determined where \( 0 < \alpha^- < \alpha^0 < \alpha^* < 1 \).

**Discordance Test**

The threshold of each property should be set by the decision makers. For any \( j \), if \( y_j(x_k) - y_j(x_l) \geq d_j \), then no matter how large the values of the other properties are, it could not accept the compensation for other properties, namely \( x_i S x_k \) is no longer recognized.

To be able to perform the Non-Concordance test the two values of discordance thresholds \( d \) must be defined where \( d_j^0 < d_j^* \).
In Electre II the concordance condition is modified in order to include two embedded relations. A Strong Outranking relation and Weak Outranking relation.

The Strong Outranking Relation (\(O_s\)) is defined if and only if one or both of the following sets is defined:

\[
X_i o_s X_k \leftrightarrow \begin{cases} 
I'_{ik} \geq 1 \\
I_{ik} \geq \alpha^* \\
y_{ki} - y_{ij} \leq d_j^*
\end{cases} \tag{Equation 14}
\]

\[
X_i o_s X_k \leftrightarrow \begin{cases} 
I'_{ik} \geq 1 \\
I_{ik} \geq \alpha^0 \\
y_{ki} - y_{ij} \leq d_j^0
\end{cases} \tag{Equation 15}
\]

Weak Outranking Relation (\(O_w\)), respectively, the following conditions must be satisfied:

\[
X_i o_w X_k \leftrightarrow \begin{cases} 
I'_{ik} \geq 1 \\
I_{ik} \geq \alpha^- \\
y_{ki} - y_{ij} \leq d_j^*
\end{cases} \tag{Equation 16}
\]

**Construct the point-to graphs**

Construct strong points to graph based on the Strong Outranking relation \(O_s\), and construct weak points-to graph based on the Weak Outranking relation \(O_w\).

Strong Outranking Graph \(G_{F,s}(Y, U_F)\), in which the set of nodes \(Y\) corresponds to the set of alternatives \(X\), and the set of arcs \(U_F\). More precisely, an arc \((x_i, x_k)\) is in \(U_F\) if and only if \(x_i\) is strongly preferred to \(x_k\).

Weak Outranking Graph \(G_{F,w}(Y, U_f)\)

**Ranking Procedure**

The ranking procedure consists of a forward ranking, a reverse ranking and an average or average ranking.
Forward Ranking $v'$

Let $Y(1) = Y$ (the set of all alternatives) and $Y(k)$ be a sub graph of $Y$. The set of preferred alternatives, $A(k)$, is chosen from $Y(k)$ and the ranking $v'$ is made according to the following four steps.

1. Working from $G_F$ (the graph of strong outranking) select all nodes in $Y(k)$ not having a precedent or an incoming arrow (i.e., the management alternatives which are not strongly outranked by other elements). Denote this set of non-dominated alternatives by $C(k)$.

2. Next, use $G_f$ (the graph of weak outranking) to remove as many ties as possible between systems in $C(k)$. For this purpose, look for the set of arcs in $U_f$ with both extremities in $C(k)$; call this set of $\overline{U_f}$. Construct the graph $(C(k), \overline{U_f})$.

3. Select all nodes of $(C(k), \overline{U_f})$ not having a precedent: denote this set, which corresponds to the set of non-dominated solutions at iteration $k$, by $A(k)$. The set $A(k)$ consists of all nodes having no precedent in either graph $G_F$ or $G_f$.

4. Define the ranking $v'$ by use of the following iterative:
   
   i. Start with $k = 1$ and $Y(1) = Y$
   
   ii. Identify the sets $Y(k)$, and $A(k)$ as indicated in 1,2,3 above and 4(iv) below
   
   iii. Rank $x$ as: $v'(x) = k$ for every $x \in A(k)$
   
   iv. Identify $Y(k + 1) = Y(k) - A(k)$ and delete all arcs emanating from $A(k)$: this removes systems that have been ranked from the forward ranking process.
   
   v. If $Y(k + 1)$ is an empty set, then all the representative. If $Y(k + 1)$ is not empty, then set $k = k + 1$ and go to step (ii).

Reverse ranking $v''$

i. Reverse the directions of the arcs $U_F$ of $G_F$ and $U_f$ of $G_f$ so as to obtain a mirror image of the direct outranking relationship.
ii. Obtain a ranking $v^0(x)$ on these new graphs as $v'$ was obtained above.

iii. Re-establish the correct ranking order by setting:

$$v'' = 1 + \max_{x \in X} v^0(x) - v^0(x)$$

Equation 17

**Median order $\bar{v}$**

The final ranking $\bar{v}$ between $v'$ and $v''$ is obtained from the formula as follows:

$$\bar{v}(x_i) = \frac{v'(x_i) + v''(x_i)}{2}$$

Equation 17
CHAPTER FOUR

PROBLEM IDENTIFICATION AND MODEL DEVELOPMENT
4 PROBLEM IDENTIFICATION AND MODEL DEVELOPMENT

This chapter provides detailed description of the use case addressed in this study. The case study is used specifically for this research as an example of an industrial facility requiring real time visibility and traceability at a manufacturing shop floor. All the problems discussed in this chapter were used to drive the proposal of an IoT solution that will be discussed in the next chapter.

4.1 TEXTILE INDUSTRY IN EGYPT

The textile industry, which includes the spinning and weaving processes, is one of the oldest industries worldwide as it has deep roots in history. Egypt is considered a pioneer in the textile industry as its history dates back thousands of years since pharaohs. Through the different decades and with the support of different successive governments, the textile industry has developed to become a major pillar for the Egyptian development.

The textile sector plays a significant and effective role in solving the unemployment problem in Egypt as it provides numerous job opportunities for the Egyptian labour force. The government has long utilized this sector to absorb Egypt’s growing labour force and help tackle unemployment problems and generate incomes for about half a million Egyptian families [85].

Moreover, labour costs are considered a competitive advantage in Egypt, as they are thought to be amongst the lowest labour costs in the world [86, 87]. The textile sector plays an extremely central role in the Egyptian economy. It is the first in terms of jobs accounting for 30% of local employment [88]. Textile sector falls under the category of “Industries” in Egypt which amount to 35.8% of GDP in 2016 [89]. Based on statistics reported by Ministry of Trade and Industry, textile exports accounted for 2,758 million dollars in 2015 representing 13% of total Egyptian exports, refer to Figure 4-1.
4.2 THE INTERNET OF THINGS CASE STUDY

The proposed case study is based on a typical acrylic yarn manufacturing (named AlSaratex) which is located in Kafr El Dawwar city in northern Egypt. Currently, AlSaratex employs around 250 workers encompassing white and blue collars. The company is specialized in manufacturing around 250 types of products “Relaxed/Normal” yarn with yarn count ranging from 30/1 to 50/1 Nm (Nm stands for Number metric which measures linear mass density aka the weight of a given length of fiber) and “High-bulk” yarn with yarn count 14/1 and 28/2 Nm. The company mainly benefits from exports to foreign countries namely South Africa, Kenya, Poland, Hungary, Greece, Syria, and Lebanon. The Acrylic fiber is a synthetic fiber that is the direct alternative of its natural counterpart; wool. It closely resembles wool in its characteristics yet with much cheaper price.

4.2.1 Corporate Structure

As in the case of most SMEs worldwide, AlSaratex is a family run business. By referring to Figure 4-2 it can be observed that each of the family members is responsible for managing a certain position in the corporation.
4.2.2 Description of the process

The manufacturing process in AlSaratex begins by receiving raw materials (tow fibers) from suppliers. The fiber is made out of acrylic that is measured in terms of linear mass density (Nm), which means the weight (grams) of a given length of a fiber. Fabrics with a high “Nm” count tend to be thick, sturdy, and durable. Fabrics with a low “Nm” count tend to be sheer, soft, and silky. The company requests fibres with different colours and specifications according to the orders it receives.

The company has two products, as mentioned before; the “Relaxed/Normal” yarn and the “High-bulk” yarn. It takes three manufacturing stages to transform the acrylic fiber into a “Relaxed/Normal” yarn namely; preparation, spinning and winding. As for the case of “High-bulk” yarn, the fibers pass the same three stages in addition to two extra stages after winding, which are twisting and shrinkage. Refer to Figure 4-3 for the manufacturing process flowchart and facility layout respectively at AlSaratex.

![Figure 4-3 Manufacturing process flowchart at AlSaratex](image)

**Error! Reference source not found.** demonstrates AlSaratex facility layout drawn on Microsoft Visio diagramming application to illustrate the machine positions for each stage.
Stage 1: *Preparation Stage of Fiber*

The first and the most important stage in the process of converting acrylic tow to yarn is the preparation stage. This stage comprises Stretch Breaker, Re-Breaker, Draw framing, and Finisher.

1. **Stretch Breaker Process:** The input for this process is fiber tows packed in bales. This process is responsible for arranging, aligning, and stretching the wide and sturdy fiber tows, by subjecting it to very high tension to break the filaments composing the fiber into long staple sliver.

2. **Re-Breaker Process:** This step is valuable in a variety of ways. Firstly, the function of the re-breaker is to re-stretch and re-break the sliver coming from the preceding step. The aim of this step is to ensure that all individual filaments have been broken down to the desired staple length (11mm length) before entering the Draw framing process and breaking those outliers that have slipped by the Stretch Breaker.
3. **Draw framing Process:** The process, in which the slivers are blended, doubled, levelled, and drafted. The functions of Draw frame are to straighten the crimped and hooked fibres, to achieve a fairly parallelization of the fibres, to eliminate short fiber and fine dust, improve evenness by doubling of slivers, to produce a more uniform silver and to reduce the weight/unit length of the sliver.

4. **Finishing Process:** The output sliver of the final draw frame feeds this process. Then the sliver is subjected to drafting to reduce the linear mass density in addition to adding a twist to the sliver converting it to roving that forms the bobbin. This twist helps in reducing the volume of the sliver and hence ease transportation of the bobbin to the next stage. The bobbin is a cone on which the roving is wound.

**Stage 2: Spinning Stage of Roving**

Spinning is the most important stage in a textile industry. It is the part of the manufacturing process where low cost roving ($0.17/meter) are converted into high cost yarn ($3.88/meter). The input for this process are the bobbins arriving from the finisher at the Preparation Stage. Many methods are used for spinning however, “Ring Spinning” is the method used in our case, which is considered the most common spinning method in the world. There are different functions through the Ring Spinning process in which roving is converted into yarn through passing different zones like drafting, twisting, and winding zone. Drafting is the first zone of ring spinning process and is a very important part of the machine. By drafting the roving, it further reduces the linear mass density until the required fineness is achieved. The second phase is twisting where the drafted strand is twisted to form yarn with required count and strength. The third and the final zone is winding. The twisted yarn is wound on the spinning bobbin for ease of transportation and downstream processing.

**Stage 3: Winding Stage of Yarn**

Winding is the process which is responsible for extraction of all disturbing yarn faults. It is also responsible for the formation of big yarn packages which can be smoothly unwound later. The objective of the winding process is to reduce yarn faults to the maximum and transfer the yarn from spinning bobbin to a convenient yarn package, which is the cone. Winding is the final stage in
AlSaratex in case of “Relaxed/Normal” yarn production unlike the “High-Bulk” yarn which needs further processing. Finished cones are then packaged and shipped to customers.

Stage 4: Twisting Stage

The purpose of producing doubled yarns is to improve yarn uniformity, abrasion resistance, tenacity and flexural endurance. This is also an essential process for the production of balanced yarn. In this step two yarns are twisted together to form a single stronger yarn. The amount of twist is an important factor to customers. Fine yarns require more twist than coarser yarns.

Stage 5: Shrinkage Stage

This is the final stage for producing “High-bulk” acrylic yarn. Yarns are exposed to steam to obtain characteristic of high bulk. Finished cones are left to dry for 24 hours prior to packaging then it is shipped to customers.

4.2.3 Reasons of High Variation in Completion Time and Quality of a Lot

After several interviews with the managers and personnel, the main problem the company is encountering is the high variation in the completion time and quality of a lot which is measured in terms of three tons. This could be the result of many factors that take place individually or combined together including: quality of raw materials received from suppliers; specification of raw materials ordered by the company; machine downtime; machine settings such as speed; machines with different efficiencies at the same manufacturing step in addition to workers absenteeism, or carelessness and many other factors. This section discusses the problems related to each category in the cause and effect diagram thoroughly:

Raw Materials

There are many causes connected to the problem of poor raw materials. Static electricity generation is very common [90] which appears because of insufficient antistatic chemical treatment by suppliers. Static electricity causes the surface of the fibers to pick up dust; it may also cause problems during manufacturing operations. Another influencing factor that affects the quality of
raw materials is the fiber specifications such as fiber fineness, fiber length, proportion of short fiber content as well as softness level.

**Machines**

In the yarn manufacturing, each machine in each step in the production line must be adjusted accurately to produce the yarn with the required specifications. Correct machine adjustment plays the major role in ensuring the production of uniform yarn with high strength and minimum defects such as neps formation.

One of the problems in the **preparation stage** is the presence of different machines at the same step with different productivities. This is because those machines are of different brands (makers), and were purchased at different times.

One of the common problems in the **stretch breaking** process is the cracking of rollers because of overheating. Overheating takes place when the pipes, where the chilled water circulate, is blocked obstructing the flow of the water which is responsible for cooling off the rollers. In that case, the rollers are overheated resulting in premature wear that causes high losses in terms of downtime since replacing the worn rollers may consume more than thirty minutes as well additional expenses taking into consideration the very high cost of a single roller. Other factors such as heating plate’s temperature setting, working speed, as well as working pressure must be adjusted accurately to ensure high quality of yarn.

Frequent unexpected stoppage is among the problems encountered in AlSaratex during the **re-breaker** process. This problem is the result of the high proportion of fibers that was slipped by the Stretch breaker process. Hence, those fibers have higher linear mass density than what the re-breaker can ingest. When this happens, the stretch breaker stops, causing downtime.

**In draw framing** the objective is to ensure parallelization of slivers, produce uniformity by mixing and blending different slivers, as well as to reduce linear mass density of slivers. Critical success factors for the process include proper machine setting such as type and setting of auto leveller in draw frame, delivery speed, conditions of rollers, break draft setting, as well as total draft setting.
Improper machine setting will affect yarn evenness and increase imperfections and will produce sliver with high variation.

**Combing process** ensures the removal of short fibers and neps, removal of impurities and dust in addition to straightening the fibers. Hence, it has a large impact on the quality of the produced yarn. One of the critical success factors for the combing process includes top comb condition. If worn comb is used, there will be high chance for the loss of quality. Another important factor is the machine settings comprising top comb penetration depth and the selection of the correct number of teeth in the comb for each step.

**Finishing process** is the last step in the preparation stage, it is extremely important to be done correctly for two reasons; the sliver coming from draw frame is thick and untwisted which creates hairiness and fly. The ring frame also cannot process it in that form, hence drafting is necessary to reduce its linear mass density and produce fine twisted roving. Another reason, draw frame can represent the worst mode of transport and presentation of feed material to the ring spinning frame machine. Common defects in this stage includes irregular roving, roving breakage as a result of lack of enough resistance as well as the presence of thick and thin places. The appearance of such defects is caused by improper machine setting including wrong apron type, damaged apron, improper flyer speed, worn flyer, unsuitable bobbin height as well as incorrect maintenance of the machine.

One of the most critical problems in the **spinning stage** is the yarn breakage. Yarn breakage has always been a complex phenomenon in ring spinning hence considerable research works have been carried out with the attempt to reduce its occurrence [91, 92]. In order to guarantee high profit and quality in ring spinning, yarn breakage must be kept to minimum. Yarn breakage occurs when the exposed tension exceeds the strength of the weakest point in the yarn. Hence, fiber breakage takes place, stopping the conversion of sliver to yarn, which will then be removed by the suction tube. Unless a worker fixes the problem instantly, the remaining sliver on the bobbin will be converted to waste.

Many factors could be responsible for such phenomenon such as high fiber fly in the working environment, incorrect machine maintenance, poor quality of raw materials as well as improper
machine setting which includes damaged ring, too high spindle speed, improper traveller type (part of the machine) and speed, uneven tension, worn apron and damaged ring.

In the **winding process**, many factors play a major role to ensure accurate removal of faults from the yarn as well as to produce a good yarn package (cone). Among them the condition and geometry of the cone where the yarn will be wound, the winding speed, yarn clearer setting as well as the quality of feed material which is coming from the spinning. Incorrect machine setting may result in less removal of neps, dirt, and loose fibres, variation of tension besides faulty shape of package.

In the **twisting process**, two threads are twisted together to form a single yarn, which is then wound on an output cone. One of the repeated problems in this stage is the end breakage of one of the two threads before being twisted. When such an occasion takes place, the sensor that is responsible for the detection of the end breakage must stop the spindle immediately to prevent the production of inconsistent cone with one end yarn instead of two that will not meet customer requirements. When the worker usually discovers the occurrence of such an event, it becomes too late to solve such an issue. Consequently, the entire cone is defective and must be disposed of.

**Shrinkage process** is the key for producing “High Bulk” yarn with the required characteristics satisfying customer requirements. Common problem that usually appears in this process is the lack of coordination, in terms of speed, between the input yarn from the spindle and the output yarn being wound on the cone. When this happens, the spindle forces itself to halt trying to coordinate with the output cone. However, this causes the overworking of the motor causing it to overheat and stop completely. Another recurrent problem is the variation in the oven temperature where the yarn is exposed to steam. When the temperature falls outside the appropriate range, that is defined to be between 92°C to 100°C, then in this case yarn is either not being exposed to enough steam to shrink to its maximum potential, or it is being exposed to too much steam which deforms the properties of the output yarn.

**Man Power**

In a labour intensive manufacturing facility, workers play a major role on the quality and the progress of final products. For example, workers are responsible for adjusting the machine settings
e.g. speed for each machine in the production line to produce the desired final product with particular specifications meeting customer requirements. Furthermore, workers are responsible for clearing the working environment from fiber fly and cleaning roofs from any accumulated fiber flies after each lot production. Fiber fly, which is one of the most popular problems in textile literature [93, 94], may contribute in reducing the quality of the produced yarn in several ways. In the first place, fiber fly is one of the main reasons for the formation of non-uniform yarn e.g. neps, thin and thick places. Besides, fiber fly clearing is an integral step in the case of producing successive lots with dark and light colours. For example, presence of black fiber flies from preceding lots may discolor white yarn in case workers did not clear flies properly causing the spoilage of the whole lot.

Furthermore, maintenance workers are also responsible for ensuring that the machine and its spare parts are in good condition before running the machine to avoid poor quality of yarn. They are also responsible for reducing downtime as well as fixing the machines properly and punctually. Long downtimes slow down the production, creates bottlenecks, and increase manufacturing costs.

Another important step that relies entirely on workers is the real time monitoring of the spinning process in order to detect any yarn breakage. As stated earlier, spinning process is considered the most important step where cheap fiber is converted in to expensive yarn, hence the aim of this step is to convert all fibers entering the ring frame machine into yarn and reduce the waste to the utmost. The role of workers is to detect yarn breakage at any spindle instantly, stop the faulty spindle, and adjust the fiber threads manually once again allowing the conversion of fiber to yarn to continue. This step fully depends on the worker’s ability and experience in detecting the faulty spindles among the fine spindles, taking into consideration the presence of more than 20 ring frame machines in AlSaratex with more than 50 spindles at each machine, therefore, there must be enough workers with plenty of experience to be able to troubleshoot the flawed spindle.

For the purpose of clarity, a cause and effect diagram, Figure 4-5, is developed to categorize and summarise all the causes contributing to high variation in the finishing time and quality among similar lots.
Figure 4-5 Fishbone diagram classifying problems in AlSaratex
4.2.4 Problems Addressed by IoT Solution

After presenting the different problems the company is facing in the previous section, IoT enabling technologies such as Radio Frequency Identification Systems (RFIDs) and cameras and internet connection; can enable shop floor visibility and reduce uncertainties related to variation in quality and progress of lots. Among many problems found in AlSaratex, refer to Figure 4-5, the proposed IoT solution can only tackle the problems that can be solved by real time data capturing and monitoring. The following section discuss only the problems solved by the proposed IoT solution.

The high variation in completion time makes it very difficult to answer customer questions about order status as well as to forecast whether there is enough time or not to meet the time limit needed for the container for export shipment. Therefore, the company aims to effectively track and monitor the progress of each lot in real-time to help in improving the manufacturing process in several ways.

- With real time captured data, the company can define a standard cycle time for each step in the manufacturing process that will help in comparing similar lots to detect any deviations outside normal standard time.

- Using IoT the company can trace root causes for those deviations whether it is a result of machine downtime, machine settings in each step e.g. speed, worker absence or carelessness, or poor quality of raw materials received from suppliers. It will also allow accurate time estimation for the delay caused by a certain type of failure.

- Also, with the help of IoT the company will be able to precisely monitor the flow of a lot in addition to determining “the remaining finish time” which will help to improve the scheduling of orders shipped to marine port for exports.

Due to the fact that that SMEs have limited financial resources which makes it not economically feasible to upgrade large number of machines to enable it to communicate to the internet the challenge this work addresses is to help companies willing to deploy IoT solutions to improve their system’s performance while preserving its legacy system, represented in machines of various vintages and conditions.
In a labour intensive manufacturing facility, as the one addressed here, it is necessary to track and monitor the behaviour of workers throughout different manufacturing stages, to identify and control it instantly and to avoid any delays or defects in yarn production. This can only be done by image sensors for visual surveillance and recording of series of happenings. Hence, it is proposed to install IP-cameras for real time monitoring of the spinning stage. Data from these cameras is collected by Wi-Fi access-points and sent to a central processing station in the monitoring office. This station has an artificial intelligent solution that detects the faulty spindles from captured images and signals alarms accordingly.

It is advised also to provide LCD panels that provide the location of the faulty spindle when the alarm is signalled to allow the specialized workers to head directly and promptly to the faulty spindle. IEEE 802.11, known as Wi-Fi, is selected as the communication network since it is the most familiar wireless technology in this country and because Wi-Fi routers are already installed in the facility.

Monitoring the progress of a lot can be achieved by binding RFID tags to transportation cans and spindles that will be read by RFIDs readers installed on the entrance and exit of each machine. RFID readers will detect the arrival and the departure of the lot in order to capture the lot status in real time.

Moreover, by recording the starting time and the finishing time at each machine, the company will be able to define a standard cycle time for each process as well as record the time delay caused by any type of failure. It will also help in providing an accurate estimation on the remaining finish time that will improve the scheduling of customer shipments which is mainly shipped to marine port for exports.
CHAPTER FIVE

INDUSTRIAL INTERNET OF THINGS IN ACTION
5 INDUSTRIAL INTERNET OF THINGS IN ACTION

This chapter focuses on the implementation of IoT in AlSaratex. The most appropriate IoT solution; specifically, RFID readers, are firstly selected using the developed MCDM models. Afterwards, with the aid of diagrams, a detailed description of the deployment of the proposed solution consisting of RFIDs and cameras across the different production stages in AlSaratex. Finally, results expected from the proposed solution are discussed.

5.1 APPLICATION OF DEVELOPED MCDM MODELS

5.1.1 Selection of RFID Readers using AHP

Develop Decision Hierarchy

Figure 5-1 shows the breaking down of the decision into a hierarchy of goals, criteria, and alternatives.

![Decision Hierarchies for RFID Reader Selection](image)

Derive priorities (weights) for the criteria

The following criteria are considered when comparing between alternatives:
- Temperature Range
- Cost
- Number of Antenna Port
- Power Source Mode
- Network Connectivity Mode

In order to determine the weights of the criteria, a questionnaire was developed to be filled by the decision maker, refer to Appendix D. The decision maker is required to determine the relative priorities (weights) for the criteria. It is called relative priorities (weights) for the criteria because the obtained criteria priorities are measured with respect to each other.

To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. The fundamental scale of absolute numbers defined by Saaty was used refer to section 2.5.2.

Based on the collected responses from the DMs using the questionnaire, the criteria weights was calculated as shown in Table 5-1.

<table>
<thead>
<tr>
<th></th>
<th>Weight Person 1</th>
<th>Weight Person 2</th>
<th>Weight Person 3</th>
<th>Weight Person 4</th>
<th>Geometric Mean</th>
<th>Final Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.231</td>
<td>0.400</td>
<td>0.199</td>
<td>0.277</td>
<td>0.267</td>
<td>0.277</td>
</tr>
<tr>
<td>No of Antenna Ports</td>
<td>0.138</td>
<td>0.167</td>
<td>0.114</td>
<td>0.140</td>
<td>0.138</td>
<td>0.143</td>
</tr>
<tr>
<td>Network Connection Mode</td>
<td>0.525</td>
<td>0.296</td>
<td>0.505</td>
<td>0.442</td>
<td>0.432</td>
<td>0.447</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>0.033</td>
<td>0.034</td>
<td>0.035</td>
<td>0.034</td>
<td>0.034</td>
<td>0.035</td>
</tr>
<tr>
<td>Power Source Mode</td>
<td>0.073</td>
<td>0.075</td>
<td>0.146</td>
<td>0.098</td>
<td>0.094</td>
<td>0.097</td>
</tr>
</tbody>
</table>

**Determine the local priorities of alternatives**

After setting the weights of criteria the local priorities of alternatives are calculated using the model and are reported in Table 5-2.

**Derive the overall priorities**

The weights are created by summing the priority of each element according to a given criterion by the weights of that criterion.
Table 5-2 Local priorities of alternatives

<table>
<thead>
<tr>
<th></th>
<th>Temperature Range</th>
<th>Cost</th>
<th>Number of antenna ports</th>
<th>Power Source</th>
<th>Network Connection Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.0425</td>
<td>0.1294</td>
<td>0.0667</td>
<td>0.1</td>
<td>0.2027</td>
</tr>
<tr>
<td>A2</td>
<td>0.0425</td>
<td>0.1410</td>
<td>0.1111</td>
<td>0.2</td>
<td>0.1054</td>
</tr>
<tr>
<td>A3</td>
<td>0.0425</td>
<td>0.1614</td>
<td>0.0222</td>
<td>0.1</td>
<td>0.0210</td>
</tr>
<tr>
<td>A4</td>
<td>0.0425</td>
<td>0.0983</td>
<td>0.2000</td>
<td>0.1</td>
<td>0.2027</td>
</tr>
<tr>
<td>A5</td>
<td>0.4084</td>
<td>0.1307</td>
<td>0.2000</td>
<td>0.1</td>
<td>0.0210</td>
</tr>
<tr>
<td>A6</td>
<td>0.1767</td>
<td>0.0894</td>
<td>0.1111</td>
<td>0.1</td>
<td>0.0210</td>
</tr>
<tr>
<td>A7</td>
<td>0.0256</td>
<td>0.1087</td>
<td>0.2000</td>
<td>0.1</td>
<td>0.2027</td>
</tr>
<tr>
<td>A8</td>
<td>0.1767</td>
<td>0.0179</td>
<td>0.0222</td>
<td>0.1</td>
<td>0.0210</td>
</tr>
<tr>
<td>A9</td>
<td>0.0425</td>
<td>0.1232</td>
<td>0.0667</td>
<td>0.1</td>
<td>0.2027</td>
</tr>
</tbody>
</table>

**Final Ranking**

A7 ≻ A4 ≻ A1 ≻ A9 ≻ A2 ≻ A5 ≻ A3 ≻ A6 ≻ A8

### 5.1.2 AHP Results Analysis

Specifications of alternatives according to the five criteria are listed in Table 5-3. According to the results of AHP method, “A7” was considered the best compared to other alternatives. From the perspective of cost, A7 was considered very expensive as there are 5 better alternatives with much lower cost. Moreover, concerning the temperature range, A7 has the lowest performance compared to other alternatives. On the other hand, in terms of number of antenna ports available, A7 was considered among the best alternatives meeting this specific criteria.

Similarly, in the network connection mode criteria, A7 had good performance. Here, the compensatory characteristic of AHP can be clearly seen where although A7 had bad performance in one of the criteria “Cost” and “Temperature Range”, this was compensated by good performance in another criteria “Number of Antenna Ports” as well as “Network Connection Mode”.

As for the worst alternative “A8” was considered the worst. Examining A8 performance with respect to each criteria, had the worst performance in all criteria except for temperature range. A8 has the highest cost, no antenna ports, no Wi-Fi connection option as well as wired power source mode.
Table 5-3 Specifications of alternatives according to the five criteria

<table>
<thead>
<tr>
<th>Alternatives Name</th>
<th>Criteria 1</th>
<th>Criteria 2</th>
<th>Criteria 3</th>
<th>Criteria 4</th>
<th>Criteria 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost ($)</td>
<td>Number of Antenna Ports</td>
<td>Network Connection</td>
<td>Upper Temperature</td>
<td>Lower Temperature</td>
</tr>
<tr>
<td>A1</td>
<td>995</td>
<td>1</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>A2</td>
<td>809</td>
<td>2</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>A3</td>
<td>480</td>
<td>0</td>
<td>Ethernet</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>A4</td>
<td>1495</td>
<td>4</td>
<td>Ethernet</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>A5</td>
<td>975</td>
<td>4</td>
<td>Ethernet</td>
<td>70</td>
<td>-20</td>
</tr>
<tr>
<td>A6</td>
<td>1639</td>
<td>2</td>
<td>Ethernet</td>
<td>55</td>
<td>-40</td>
</tr>
<tr>
<td>A7</td>
<td>1329</td>
<td>4</td>
<td>Wi-Fi/Ethernet</td>
<td>40</td>
<td>-20</td>
</tr>
<tr>
<td>A8</td>
<td>2,789</td>
<td>0</td>
<td>Ethernet</td>
<td>55</td>
<td>-20</td>
</tr>
<tr>
<td>A9</td>
<td>1095</td>
<td>1</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
</tr>
</tbody>
</table>

5.1.3 Model Calculation Using Electre

According to Electre II, in the case of RFID-Reader selection, the Outranking Relation based on each indicator is first constructed as show in Table 5-4. The same marked alternatives represent that the property values are equal in the certain criteria. In order to ensure consistent and fair comparison between the two MCDM methods in ranking the alternatives, same weights defined by the questionnaire was used.

Table 5-4 Sequencing of different alternatives based on the different indicators

<table>
<thead>
<tr>
<th>Criteria/Sequencing</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A5</td>
<td>A6!</td>
<td>A8!</td>
<td>A1=</td>
<td>A2=</td>
<td>A3=</td>
<td>A4=</td>
<td>A9=</td>
<td>A7</td>
</tr>
<tr>
<td>C2</td>
<td>A3</td>
<td>A2</td>
<td>A5</td>
<td>A1</td>
<td>A9</td>
<td>A7</td>
<td>A4</td>
<td>A6</td>
<td>A8</td>
</tr>
<tr>
<td>C3</td>
<td>A4!</td>
<td>A5!</td>
<td>A7!</td>
<td>A2</td>
<td>A6</td>
<td>A1</td>
<td>A9</td>
<td>A8=</td>
<td>A3=</td>
</tr>
<tr>
<td>C5</td>
<td>A1!</td>
<td>A4!</td>
<td>A7!</td>
<td>A9!</td>
<td>A2</td>
<td>A3$</td>
<td>A5$</td>
<td>A6$</td>
<td>A8$</td>
</tr>
</tbody>
</table>

The values selected for the concordance test thresholds and discordance test threshold are the same values set by [84]: $\alpha^+ = 0.7$, $\alpha^0 = 0.65$, $\alpha^- = 0.60$, $d^+ = 0.6$ and $d^0 = 0.5$. Then, the concordance test and the precedence relation of all alternatives are determined. Using a value of $\alpha^- = 0.6$ [84], the weak outranking relation is constructed. If $I_{ik}^1 \geq 1$, $I_{ik} \geq \alpha^-$ exists, then it passes the concordance test. Table 5-5 shows calculation of concordance indices.
### Table 5-5 Calculation of concordance indices

<table>
<thead>
<tr>
<th>( A_i )</th>
<th>( A_k )</th>
<th>Sum of not Inferior Criteria Weights</th>
<th>Sum of positive Criteria Weights</th>
<th>Sum of negative Criteria Weights</th>
<th>( I_{ik} )</th>
<th>( I'_{ik} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>A1</td>
<td>0.5528</td>
<td>0.5178</td>
<td>0.4472</td>
<td>0.5528</td>
<td>1.1577</td>
</tr>
<tr>
<td>A2</td>
<td>A3</td>
<td>0.7231</td>
<td>0.6880</td>
<td>0.2769</td>
<td>0.7231</td>
<td>2.4844</td>
</tr>
<tr>
<td>A2</td>
<td>A4</td>
<td>0.4094</td>
<td>0.3744</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.6338</td>
</tr>
<tr>
<td>A2</td>
<td>A5</td>
<td>0.8216</td>
<td>0.8216</td>
<td>0.1784</td>
<td>0.8216</td>
<td>4.6043</td>
</tr>
<tr>
<td>A2</td>
<td>A6</td>
<td>0.9650</td>
<td>0.9650</td>
<td>0.0350</td>
<td>0.9650</td>
<td>27.5424</td>
</tr>
<tr>
<td>A2</td>
<td>A7</td>
<td>0.4094</td>
<td>0.4094</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.6932</td>
</tr>
<tr>
<td>A2</td>
<td>A8</td>
<td>0.9650</td>
<td>0.9650</td>
<td>0.0350</td>
<td>0.9650</td>
<td>27.5424</td>
</tr>
<tr>
<td>A2</td>
<td>A9</td>
<td>0.5528</td>
<td>0.5178</td>
<td>0.4472</td>
<td>0.5528</td>
<td>1.1577</td>
</tr>
<tr>
<td>A3</td>
<td>A1</td>
<td>0.4094</td>
<td>0.2769</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.4689</td>
</tr>
<tr>
<td>A3</td>
<td>A4</td>
<td>0.4094</td>
<td>0.2769</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.4689</td>
</tr>
<tr>
<td>A3</td>
<td>A5</td>
<td>0.8216</td>
<td>0.2769</td>
<td>0.1784</td>
<td>0.8216</td>
<td>1.5520</td>
</tr>
<tr>
<td>A3</td>
<td>A6</td>
<td>0.8216</td>
<td>0.2769</td>
<td>0.1784</td>
<td>0.8216</td>
<td>1.5520</td>
</tr>
<tr>
<td>A3</td>
<td>A7</td>
<td>0.4094</td>
<td>0.3120</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.5282</td>
</tr>
<tr>
<td>A3</td>
<td>A8</td>
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<td>0.2769</td>
<td>0.0350</td>
<td>0.9650</td>
<td>7.9045</td>
</tr>
<tr>
<td>A3</td>
<td>A9</td>
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<td>0.2769</td>
<td>0.5906</td>
<td>0.4094</td>
<td>0.4689</td>
</tr>
<tr>
<td>A4</td>
<td>A1</td>
<td>0.7231</td>
<td>0.1434</td>
<td>0.2769</td>
<td>0.7231</td>
<td>0.5178</td>
</tr>
<tr>
<td>A4</td>
<td>A5</td>
<td>0.6880</td>
<td>0.3120</td>
<td>0.3120</td>
<td>0.6880</td>
<td>1.0000</td>
</tr>
<tr>
<td>A4</td>
<td>A6</td>
<td>0.9650</td>
<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
<tr>
<td>A4</td>
<td>A7</td>
<td>0.7231</td>
<td>0.0350</td>
<td>0.2769</td>
<td>0.7231</td>
<td>0.1265</td>
</tr>
<tr>
<td>A4</td>
<td>A8</td>
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<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
<tr>
<td>A4</td>
<td>A9</td>
<td>0.7231</td>
<td>0.1434</td>
<td>0.2769</td>
<td>0.7231</td>
<td>0.5178</td>
</tr>
<tr>
<td>A5</td>
<td>A1</td>
<td>0.5528</td>
<td>0.4554</td>
<td>0.4472</td>
<td>0.5528</td>
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</tr>
<tr>
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<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A5</td>
<td>A7</td>
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<td>0.4472</td>
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</tr>
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<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A5</td>
<td>A9</td>
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<td>0.4554</td>
<td>0.4472</td>
<td>0.5528</td>
<td>1.0182</td>
</tr>
<tr>
<td>A6</td>
<td>A1</td>
<td>0.2758</td>
<td>0.1784</td>
<td>0.7242</td>
<td>0.2758</td>
<td>0.2464</td>
</tr>
<tr>
<td>A6</td>
<td>A7</td>
<td>0.1324</td>
<td>0.0350</td>
<td>0.8676</td>
<td>0.1324</td>
<td>0.0404</td>
</tr>
<tr>
<td>A6</td>
<td>A8</td>
<td>1.0000</td>
<td>0.4203</td>
<td>0.0000</td>
<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A6</td>
<td>A9</td>
<td>0.2758</td>
<td>0.1784</td>
<td>0.7242</td>
<td>0.2758</td>
<td>0.2464</td>
</tr>
<tr>
<td>A7</td>
<td>A1</td>
<td>0.6880</td>
<td>0.1434</td>
<td>0.3120</td>
<td>0.6880</td>
<td>0.4596</td>
</tr>
<tr>
<td>A7</td>
<td>A8</td>
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<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
<tr>
<td>A7</td>
<td>A9</td>
<td>0.6880</td>
<td>0.1434</td>
<td>0.3120</td>
<td>0.6880</td>
<td>0.4596</td>
</tr>
<tr>
<td>A8</td>
<td>A1</td>
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<td>0.0350</td>
<td>0.9650</td>
<td>0.0350</td>
<td>0.0363</td>
</tr>
<tr>
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<td>A9</td>
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<td>0.0350</td>
<td>0.8676</td>
<td>0.1324</td>
<td>0.0404</td>
</tr>
<tr>
<td>A9</td>
<td>A1</td>
<td>0.5797</td>
<td>0.0</td>
<td>0.4203</td>
<td>0.5797</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Highlighted alternatives are alternatives that did not pass the concordance test and will be eliminated. Table 5-6 displays concordance test results including all qualifying alternatives and their precedence relations.

Table 5-6 Concordance Test Results (Weak Outranking Relation)

<table>
<thead>
<tr>
<th>$A_i$</th>
<th>$A_k$</th>
<th>Sum of not Inferior Criteria Weights</th>
<th>Sum of positive Criteria Weights</th>
<th>Sum of negative Criteria Weights</th>
<th>$I_{ik}$</th>
<th>$I'_{ik}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>A3</td>
<td>0.7231</td>
<td>0.6880</td>
<td>0.2769</td>
<td>0.7231</td>
<td>2.4844</td>
</tr>
<tr>
<td>A2</td>
<td>A5</td>
<td>0.8216</td>
<td>0.8216</td>
<td>0.1784</td>
<td>0.8216</td>
<td>4.6043</td>
</tr>
<tr>
<td>A2</td>
<td>A6</td>
<td>0.9650</td>
<td>0.9650</td>
<td>0.0350</td>
<td>0.9650</td>
<td>27.5424</td>
</tr>
<tr>
<td>A2</td>
<td>A8</td>
<td>0.9650</td>
<td>0.9650</td>
<td>0.0350</td>
<td>0.9650</td>
<td>27.5424</td>
</tr>
<tr>
<td>A3</td>
<td>A5</td>
<td>0.8216</td>
<td>0.2769</td>
<td>0.1784</td>
<td>0.8216</td>
<td>1.5520</td>
</tr>
<tr>
<td>A3</td>
<td>A6</td>
<td>0.8216</td>
<td>0.2769</td>
<td>0.1784</td>
<td>0.8216</td>
<td>1.5520</td>
</tr>
<tr>
<td>A3</td>
<td>A8</td>
<td>0.9650</td>
<td>0.2769</td>
<td>0.0350</td>
<td>0.9650</td>
<td>7.9045</td>
</tr>
<tr>
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<td>A5</td>
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<td>0.3120</td>
<td>0.6880</td>
<td>1.0000</td>
</tr>
<tr>
<td>A4</td>
<td>A6</td>
<td>0.9650</td>
<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
<tr>
<td>A4</td>
<td>A8</td>
<td>0.9650</td>
<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
<tr>
<td>A5</td>
<td>A6</td>
<td>1.0000</td>
<td>0.4554</td>
<td>0.0000</td>
<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A5</td>
<td>A8</td>
<td>1.0000</td>
<td>0.4554</td>
<td>0.0000</td>
<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A6</td>
<td>A8</td>
<td>1.0000</td>
<td>0.4203</td>
<td>0.0000</td>
<td>1.0000</td>
<td>Infinity</td>
</tr>
<tr>
<td>A7</td>
<td>A8</td>
<td>0.9650</td>
<td>0.8676</td>
<td>0.0350</td>
<td>0.9650</td>
<td>24.7620</td>
</tr>
</tbody>
</table>

Based on Table 5-6, make the Discordance test. The principles are as follows. The threshold $d_j$, $j=1,2,3,4,5$ of each criteria should be set by the decision makers. For any $j$, if $y_j(x_k) - y_k(x_l) \geq d_j$, then no matter how large the values of the other criteria are, it could not accept the compensation for other criteria, namely $x_l S x_k$ is no longer recognized. The results of Discordance tests are shown in Table 5-7.

Similarly, construct the strong outranking relation. Set $\alpha^* = 0.7$ and $\alpha^0 = 0.65$ and the tables of concordance tests and non-concordance tests and the strong outranking relation are obtained.

Based on the concordance and discordance results, the points on graph are constructed. Construct the strong points- to graph and the weak points- to graph based on the strong Outranking $o_s$ and the weak Outranking Relation $o_w$, as shown in Figure 5-2 and Figure 5-3.
Table 5-7 Discordance test results

<table>
<thead>
<tr>
<th>$A_i$</th>
<th>$A_k$</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>A3</td>
<td>0</td>
<td>0.0204</td>
<td>-0.0889</td>
<td>-0.1</td>
<td>-0.0844</td>
</tr>
<tr>
<td>A2</td>
<td>A5</td>
<td>0.3659</td>
<td>-0.0103</td>
<td>0.0889</td>
<td>-0.1</td>
<td>-0.0844</td>
</tr>
<tr>
<td>A2</td>
<td>A6</td>
<td>0.1341</td>
<td>-0.0516</td>
<td>0.0000</td>
<td>-0.1</td>
<td>-0.0844</td>
</tr>
<tr>
<td>A2</td>
<td>A8</td>
<td>0.1341</td>
<td>-0.1230</td>
<td>-0.0889</td>
<td>-0.1</td>
<td>-0.0844</td>
</tr>
<tr>
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<td>-0.0308</td>
<td>0.1778</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>A3</td>
<td>A6</td>
<td>0.1341</td>
<td>-0.0720</td>
<td>0.0889</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>A3</td>
<td>A8</td>
<td>0.1341</td>
<td>-0.1435</td>
<td>0.0000</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>A4</td>
<td>A5</td>
<td>0.3659</td>
<td>0.0323</td>
<td>0.0000</td>
<td>0</td>
<td>-0.1817</td>
</tr>
<tr>
<td>A4</td>
<td>A6</td>
<td>0.1341</td>
<td>-0.0089</td>
<td>-0.0889</td>
<td>0</td>
<td>-0.1817</td>
</tr>
<tr>
<td>A4</td>
<td>A8</td>
<td>0.1341</td>
<td>-0.0804</td>
<td>-0.1778</td>
<td>0</td>
<td>-0.1817</td>
</tr>
<tr>
<td>A5</td>
<td>A6</td>
<td>-0.2318</td>
<td>-0.0413</td>
<td>-0.0889</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>A5</td>
<td>A8</td>
<td>-0.2318</td>
<td>-0.1127</td>
<td>-0.1778</td>
<td>0</td>
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<td>A6</td>
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<td>-0.0889</td>
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<td>0.0000</td>
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<tr>
<td>A7</td>
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<td>0.1510</td>
<td>-0.0907</td>
<td>-0.1778</td>
<td>0</td>
<td>-0.1817</td>
</tr>
</tbody>
</table>

**Figure 5-2 Strong Outranking Relation**

**Figure 5-3 Weak Outranking Relation**

**Ranking Procedure**

Consider the strong and weak relationship graphs shown in Figure 5-2 and Figure 5-3. The ranking procedure, explained earlier in section 2.5.3, is implemented as follows:
Forward Ranking $v'$

$k = 1$ $Y(1) = G_F$

1) $C = \{1, 2, 4, 7, 9\}$
2) $\overline{U}_f = \{(0)\}$
3) $A(1) = \{1, 2, 4, 7, 9\}$
4) Ranking:
   $v'(1) = v'(2) = v'(4) = v'(7) = v'(9) = 1$
   $Y(k + 1) = Y(2) = Y(1) - A(1) = \{3, 5, 6, 8\}$

$k = 2$ $Y(2) = \{3, 5, 6, 8\}$

1) $C = \{3\}$
2) $\overline{U}_f = \{(0)\}$
3) $A(2) = \{3\}$
4) Ranking:
   $v'(3) = 2$
   $Y(3) = Y(2) - A(2) = \{5, 6, 8\}$

$k = 3$ $Y(3) = \{5, 6, 8\}$

1) $C = \{5\}$
2) $\overline{U}_f = \{(0)\}$
3) $A(3) = \{5\}$
4) Ranking:
   $v'(5) = 3$
   $Y(4) = Y(3) - A(3) = \{6, 8\}$

$k = 4$ $Y(4) = \{6, 8\}$

1) $C = \{6\}$
2) $\overline{U}_f = \{(0)\}$
3) $A(4) = \{6\}$
4) Ranking:
   $v'(6) = 4$
   $Y(5) = Y(4) - A(4) = \{8\}$

$k = 5$ $Y(5) = \{8\}$

Ranking:
$v'(8) = 5$
Reverse Ranking \( (v'') \)

Reverse the directions of the arcs \( U_F \) of \( G_F \) and \( U_f \) of \( G_f \) so as to obtain a mirror image of the direct outranking relationship as shown in Figure 5-4.

Using the same procedure used in ranking \( v' \) the following ranking \( v^0(x) \) is obtained:

<table>
<thead>
<tr>
<th>Nodes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v^0(x) )</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Reverse the ranking using equation and with \( v^0_{max}(x) = 5 \)

\[
v'' = 1 + \max_{x \in X} v^0(x) - v^0(x)
\]

Equation 17, to obtain:

<table>
<thead>
<tr>
<th>Nodes</th>
<th>1+ ( \max_{x \in X} v^0(x) - v^0(x) )</th>
<th>5</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>4</th>
<th>5</th>
<th>5</th>
</tr>
</thead>
</table>

a) Average Order \( \bar{v} \)

<table>
<thead>
<tr>
<th>Nodes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v' )</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>( v'' )</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>( \bar{v} )</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1.5</td>
<td>3</td>
<td>4</td>
<td>2.5</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

**Final Ranking Using Electre II**

\[
2 \succ 4 \succ 3 \succ 7 \succ 9 = 1 = 5 \succ 6 \succ 8
\]
5.1.4 Electre Results Analysis

Analysing the final ranking obtained by Electre method based on the specifications of alternatives given in Table 5-8, A2 was considered the best alternative. Concerning cost, A2 is considered the cheapest after A1. As for the number of antenna ports, A2 has average performance in terms of 2 antenna ports. Moreover, A2 has good performance in terms of network connection mode and temperature range criteria. Finally, in the power source mode, A2 has the best alternative. It can be concluded, that Electre best option has no low performance in any of the criteria. The best option performs as good or average with respect to any criteria.

As for the worst alternative “A8” was considered the worst. Examining A8 performance with respect to each criteria, had the worst performance in all criteria except for temperature range. A8 has the highest cost, no antenna ports, no Wi-Fi connection option as well as wired power source mode.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Cost ($)</th>
<th>Number of Antenna Ports</th>
<th>Network Connection</th>
<th>Upper Temperature</th>
<th>Lower Temperature</th>
<th>Power Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>995</td>
<td>1</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
<td>A2</td>
<td>809</td>
<td>2</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
<td>Wired/Battery Operated</td>
</tr>
<tr>
<td>A3</td>
<td>480</td>
<td>0</td>
<td>Ethernet</td>
<td>50</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
<td>A4</td>
<td>1495</td>
<td>4</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
<td>A5</td>
<td>975</td>
<td>4</td>
<td>Ethernet</td>
<td>70</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
<td>A6</td>
<td>1639</td>
<td>2</td>
<td>Ethernet</td>
<td>55</td>
<td>-40</td>
<td>Wired</td>
</tr>
<tr>
<td>A7</td>
<td>1329</td>
<td>4</td>
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<td>40</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
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<td>2,789</td>
<td>0</td>
<td>Ethernet</td>
<td>55</td>
<td>-20</td>
<td>Wired</td>
</tr>
<tr>
<td>A9</td>
<td>1095</td>
<td>1</td>
<td>Wi-Fi/Ethernet</td>
<td>50</td>
<td>-20</td>
<td>Wired</td>
</tr>
</tbody>
</table>

5.1.5 DSS Results and Analysis

Based upon the final ranking produced by the two approaches (Table 5-9), comparing the two best alternatives (Table 5-10) it can be observed that the best alternative selected using the Electre method was overall better than that selected by the AHP.
The desired reader according to AlSaratex is a reader that can send data wirelessly through Wi-Fi since wired network is not feasible in the shop floor since it need wire connection. Concerning the cost, of course the cheaper the better. Also, DMs were interested in having a reader providing multiple antenna ports.

Finally, concerning the temperature range the higher the better to make sure the reader can perform its function correctly even in high temperature working environment.

<table>
<thead>
<tr>
<th>Table 5-9 Final ranking using AHP and Electre II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranking</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5-10 Comparing best alternative produced using AHP and Electre II</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
</tr>
<tr>
<td>A7</td>
</tr>
<tr>
<td>Network Connection</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Number of Antenna</td>
</tr>
<tr>
<td>Power Source</td>
</tr>
<tr>
<td>Temperature Range</td>
</tr>
</tbody>
</table>

By referring to Table 5-11, the performance of each alternative with respect to each criteria can be examined.

- Concerning “Network Connection” mode criteria, both methods produced criteria with desired network connection mode according to AlSaratex. Both alternative; A7 and A2 has the same performance value in network connection.
Table 5-11 Specification of nine alternatives available after filtering

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Antenna Ports</th>
<th>Cost</th>
<th>Network Connection Mode</th>
<th>Power Mode</th>
<th>Upper temperature</th>
<th>Lower Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>$995</td>
<td>Wireless/Wired</td>
<td>Wired</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>$809</td>
<td>Wireless/Wired</td>
<td>Wired/Battery operated</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>$480</td>
<td>Wired</td>
<td>Wired</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>$1,495</td>
<td>Wireless/Wired</td>
<td>Wired</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>$975</td>
<td>Wired</td>
<td>Wired</td>
<td>70</td>
<td>-20</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>$1,639</td>
<td>Wired</td>
<td>Wired</td>
<td>55</td>
<td>-40</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>$1,329</td>
<td>Wireless/Wired</td>
<td>Wired</td>
<td>40</td>
<td>-20</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>$2,789</td>
<td>Wired</td>
<td>Wired</td>
<td>55</td>
<td>-20</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>$1,095</td>
<td>Wireless/Wired</td>
<td>Wired</td>
<td>50</td>
<td>-20</td>
</tr>
</tbody>
</table>

- Comparing the “Cost” criteria, AHP chose an alternative with a very high price compared to Electre II. This is due to the compensatory characteristic of the AHP where a shortfall in one of the criteria can be compensated by good performance of another criteria.

- DMs in AlSaratex considered the number of antenna ports as the third important criteria as can be seen from observing the final weights of criteria. As the number of antenna ports increase, more antennas can be connected to the same reader hence reading multiple read zones. The AHP alternative has higher performance value concerning “Antenna Ports” than Electre, however, Electre option was still considered good as it had two antenna ports.

- Concerning the “Power Source Mode”, Electre produced an alternative with higher performance value in this criterion as it provides more options; wired and battery operated reader hence it gives the DM more flexibility.

- Finally, examining the “Temperature Range” of both reader, again Electre alternative was better, temperature in AlSaratex can exceed 45° hence, AHP alternative may not work properly in this environment, however, Electre produced an alternative with higher performance value which is translated in higher temperature range.

Using MCDM is essential in setting up an RFID system. As mentioned and explained in detail in section 2.4.2, each component has multiple set of conflicting criteria.
The attempt to select an RFID reader using single preference for a certain criteria may result in choosing an alternative with other criteria which are not fitting to the application requirement. For instance, the selection of a reader based on lowest cost while ignoring other criteria, refer to table, will result in Alternative 3 which has 0 antenna ports which may be infeasible in the application.

Also, in case of selecting based on the maximum number of antenna ports, Alternative 4 and Alternative 7 are the best however, they have a very high cost compared to other alternatives.

Hence, the need for a multi-criteria decision making method was essential in our case in order to differentiate between the available alternatives to be able to select the one satisfying all the criteria to meet the application requirement.

5.2 IOT IMPLEMENTATION IN ALSARATEX

In order to reduce cost as much as possible an IoT solution is proposed taking into consideration the economic factor. Our research was focused on the very first step in the deployment of IoT which is the selection of sensors to meet the application requirement. Through the DSS developed, the DMs can select the best alternative, RFID Reader, to meet the application requirement.

The deployment of IoT in AlSaratex to monitor the progress of a lot can be achieved by binding RFID tags to transportation cans and spindles that will be read by RFIDs readers installed on the entrance and exit of each stage, as a network the Wi-Fi was used since it is already installed in the factory.

In our case, passive RFID tags are selected. Passive tags offer short reading range consequently; this will avoid reading wrong tags of neighbouring machines since machines are placed close to each other in each stage. With passive tags, no need to replace tags occasionally since they have indefinite life. Moreover, passive tags are much cheaper than active tags.

Ultra high frequencies are preferred in our case for many reasons. LF and HF allow very short reading range that is unfitting in our case. Hence, with proper adjustment of UHF components, reaching the required read range is possible to fit our use case conditions. Moreover, UHF cannot
penetrate metal surfaces, which means that signals cannot penetrate machines. Hence, this will guarantee that signals emitted by a specific reader mounted on a specific machine will not detect tags standing on another nearby machine because of signal penetration. Another important feature in UHF, is the ability to read multiple tags simultaneously which is necessary in our tags where multiple bins stand together at each machine.

Tags will be attached on bins and cones made of plastic, therefore there is no fear from the creation of the “dead spot” which usually takes place when conductive materials is used as a result of electromagnetic forces and the creation of dielectric field. Moreover, the size of the bins and the cones are large enough which ensures that normal sized tags will easily fit the objects [95]. Furthermore, flexible tags are selected so that it can be attached to curved objects. Among several attachment methods such as screws, hanging and straps, permanent adhesive will be appropriate as tag attachment method.

In the case of using adhesive as attachment method, surfaces must be cleaned perfectly, and pressure must be applied firmly to ensure that tags are securely attached. Typical cleaning solvents are heptane for oily surfaces or isopropyl alcohol for plastics. Another important point, once the tag is attached, it cannot be pulled off after placement, or else tags will not be attached thoroughly. If the tag fell, the item will no longer be trackable and the application no longer accurate [96].

Cans belonging to the same order will have same colour, for example all green cans and cones belong to “Order 1” while all red cans and cones belong to “Order 2”. All tags attached are programmed with their identity. For example, tags on red cans will have ID name as “Order 1” as well as “Tag ID” this will help in differentiating between the data of different orders so deviation occurring in each order can be examined and analysed.

**5.2.1 IoT Solution for Machines in Preparation Stage**

Since the preparation is the stage which has the largest number of machines, it is not economically feasible to equip each machine with an RFID reader that provides Wi-Fi connection. Since readers with Wi-Fi connection are much more expensive than readers without, readers with Wi-Fi connection are only equipped at the entrance and exit of the preparation stage in order to be able to
calculate the average cycle time spent in preparations stage as well as estimate remaining finish time for the lot to enter the spinning stage.

Hence, re-breaker, stretch breaker, draw framing as well as finishing machines are equipped with readers without Wi-Fi connection except for the machine at the beginning and end of the preparation stage. For illustration, refer to Figure 5-5.

![Figure 5-5 RFID deployment in preparation stage](image)

However, in order to be able to extract data about the time spent of each can on each machine, which is used later for data analytics, tags with high enough memory having enough space to record the exact time of entrance and exit of each can at each machine is used. Hence, as soon as the can, which is equipped with high memory tag, enters in the field of electromagnetic signal generated by the interrogator, it records on its internal memory the arrival and exit time at each machine as seen in Figure 5-6. In this stage readers with read distance up to 6 meters must be used. Also tags with high user memory to store the required data are used.

<table>
<thead>
<tr>
<th>Order Number</th>
<th>Tag ID</th>
<th>Arrival Time</th>
<th>Exit Time</th>
<th>Day</th>
<th>Month</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>13.04</td>
<td>13.23</td>
<td>4</td>
<td>April</td>
<td>2018</td>
</tr>
</tbody>
</table>

![Figure 5-6 Data collected from tags in preparation stage](image)

The estimated total cost for the preparation stage is given in Table 5-12.
Table 5-12: Costs of the IoT solution - preparation stage

<table>
<thead>
<tr>
<th></th>
<th>With Wi-Fi</th>
<th>Without Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reader</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Average cost/</td>
<td>$809</td>
<td>$480</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>$1,618</td>
<td>$9,600</td>
</tr>
<tr>
<td><strong>Tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Average cost/</td>
<td>-</td>
<td>$35</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>-</td>
<td>$1,400</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>$1,618</td>
<td>$11,000</td>
</tr>
</tbody>
</table>

5.2.2 IoT Solution for Spinning Stage

Installation of 13 IP-cameras to the six meter-high ceiling with 92° angle of view and 2.8mm focal length is proposed, which will provide 39m² field of coverage. In the facility layout shown in Figure 5-7, red circles on top of the spinning machines demonstrate the field of coverage of each of the 13 cameras.
Data from these cameras is collected by Wi-Fi access-points and sent to a central processing station in the monitoring office. This station has an artificial intelligent solution that detects the faulty spindles from captured images and signals alarms accordingly. It is advised also to provide LCD panels that provide the location of the faulty spindle when the alarm is signalled to allow the specialized worker to head directly and promptly to the faulty spindle.

The location of the Wi-Fi-access points, depicted in Figure 5-7, has been chosen with diligence. Three factors have been taken into the computation of the link budget of this network according to networking standards [97]. First, the transmitter power (Tx(power)); namely the camera and RFID Wi-Fi-signal transmitter power and their antenna gain. Second, the receiver power (Rx(power)); namely the access point receiving power and gain. Third, the free-space loss of the radio signal (FSPL) taking the attenuation of the machines into consideration.11

\[
Tx(power) - FSPL@2450Mz + Rx(power) > -80dBm@11Mbps
\]

\[
21dBm - (20\log_{10}(d) + 40.23dBm + 6dBm \times N) > -80dBm@11Mbps
\]

Where \(d\) is the distance between the transmitter and receiver in meters and \(N\) is the number of attenuating obstacles between the transmitter and receiver. The transmitting and receiving power has been calculated from the devices’ specifications. We have located the access points in order to keep the distances below 45 meters and the number of obstacles below six obstacles. These constraints kept the link budget within the allowable limit of -80dBm@11Mbps. The access points are also attached to the six meter-high ceiling which diminishes the attenuation of the Wi-Fi-signal. This solution is based on cameras, network as well as software.

**Estimated Total Cost:**

<table>
<thead>
<tr>
<th>Camera</th>
<th>Software minimum $500</th>
<th>Quantity</th>
<th>Cost per Camera $280</th>
<th>Total camera $3,640</th>
<th>Total $4,140</th>
</tr>
</thead>
</table>
Also, to be able to compute the average cycle time of the cones in the spinning stage, two Wi-Fi connected readers are mounted at the entrance and exit of the spinning stage to record the beginning and ending process.

### Estimated Total Cost:

<table>
<thead>
<tr>
<th></th>
<th>With Wi-Fi</th>
<th>Without Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reader</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$480</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$960</td>
<td>-</td>
</tr>
<tr>
<td><strong>Tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$0.50</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$75</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>$1,035</td>
<td>-</td>
</tr>
</tbody>
</table>

### 5.2.3 IoT Solution for Winding Stage

Since winding machines are not placed next to each, this stage will need mounting RFID readers with Wi-Fi connection are mounted on the entrance and exit of the each machine in order to record the average cycle time of the winding stage.

Input to this process are cones which are tagged with tags with very low space memory enough to save only the tag ID. Since the reader is connected online, it can send data in real time manner hence, the time at which the cones enter and leave the winding stage is recorded as soon as the reader send the data to the host computer. UHF reader is used in this stage with read range up to 1.5 meters.

### Estimated Total Cost:

<table>
<thead>
<tr>
<th></th>
<th>With Wi-Fi</th>
<th>Without Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reader</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$480</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2,880</td>
<td>-</td>
</tr>
<tr>
<td><strong>Tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$0.50</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$75</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Cost (Reader +Tag)</strong></td>
<td>$2,955</td>
<td>-</td>
</tr>
</tbody>
</table>
5.2.4 IoT Solution for Twisting Stage

In twisting stage again online readers are used. Only two readers are deployed in this stage. The readers mounted at the entrance and exit of this stage. Also tags with low memory are equipped to the cones since the tag there is no need to record data. UHF reader is used with range up to 1.5 meters since readers are very close to the cones.

Estimated Total Cost:

<table>
<thead>
<tr>
<th></th>
<th>With Wi-Fi</th>
<th>Without Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$480</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$960</td>
<td>-</td>
</tr>
<tr>
<td>Tag</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$0.50</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$75</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$1,035</td>
<td>-</td>
</tr>
</tbody>
</table>

5.2.5 IoT Solution for Shrinkage Stage

Wi-Fi readers are equipped at the beginning and ending of the twisting stage.

Cones are equipped with low memory tags. As soon as tags arrive and leave this stage, the owner get notified.

Estimated Total Cost:

<table>
<thead>
<tr>
<th></th>
<th>With Wi-Fi</th>
<th>Without Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$480</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$960</td>
<td>-</td>
</tr>
<tr>
<td>Tag</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost per unit</td>
<td>$0.50</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$75</td>
<td>-</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$1,035</td>
<td>-</td>
</tr>
</tbody>
</table>

The packaging stage will not be equipped with readers since at this stage yarn on plastic cones are transferred to carton cones ready to be shipped to customer hence it is not feasible to equip RFID tags.
5.2.6 Simulation Normal Yarn Production Using IIOT

**Preparation Stage**

Cans tagged with high space memory enter the preparation stage (Figure 5-8) where they are read by the Wi-Fi reader mounted at the entrance zone, tags send their: Order ID, Tag ID as well as Arrival time and date to the host computer in real time manner.

After that, cans pass through the different processes in the preparation stage namely: Stretch breaker, Re-breaker, Draw-framing as well as finishing process. While tags pass through each process, the tag is reader by the reader (with the Wi-Fi), however, tags using the high memory send their: Order ID, Tag ID as well as arrival time and departure time from each machine. This data will be collected later for analytics.

Finally, cans pass through the reader at the exit of the preparation stage. Where tags send the departure time in real time manner. The benefits of IoT will not be felt by the factory until enough data has been collected to be able to extract insights from statistics and analytics which may take some time depending on the number of shifts and number of working days per month. As soon as the owner get notified that cans have entered the preparation stage, the owner can forecast, based on statistics from previous data, how much time left to exit this stage. The output of this process are plastic cones tagged with low memory RFID tags.

**Spinning Stage**

Cones are transferred to the spinning stage (Figure 5-9) using forklift, each cone equipped with a low memory RFID tag. Workers are asked to make sure to scan cones at the RFID reader at the
entrance of the spinning stage to mark the beginning of the cycle time at spinning. The mounted reader have Wi-Fi connection once workers scan the cones at the entrance, the owner gets notification about the beginning of the spinning stage.

Another important thing that takes place in this step is the detection of faulty yarns. The IP-Cameras, equipped with artificial intelligence software compared each 5 spindles, if the software detected that one spindle has lower height than other spindles, it sends a notification on the LCD panels to aid the worker to go faster to the faulty spindle quickly.

Finally, cones exit the stage, where tags send the departure time from the spinning process in real time manner. Again, the owner get notified that the WIP is entering the winding stage now, as shown in Figure 5-10.
**Winding Stage**

As soon as cones, equipped with low memory tags, are read by the Wi-Fi reader mounted at the entrance of the winding stage (Figure 5-11), the reader records the tag ID and send notification about the arrival of the WIP in the winding stage. Finally, upon exit, cones are again scanned by Wi-Fi connected reader recording the departure time.

![Figure 5-11 IoT Solution for Winding Stage](image)

5.3 **RESULTS OF INDUSTRIAL IOT SOLUTION**

The Industrial Internet provides a way to get better visibility and insight into the company’s operations and assets therefore, it provides a method of transforming business operational processes by using as feedback the results gained from interrogating large data sets through advanced analytics. The business gains are achieved through operational efficiency gains and accelerated productivity, which results in reduced unplanned downtime and optimized efficiency, and thereby profits.

Although the IoT solution presented throughout the previous chapters was not actually implemented in the spinning manufacturing facility; however, the next step after the deployment of IoT technologies is the processing and collection of data through different sensors in the IoT environment. Figure 5-12 shows the IoT solution deployment in AlSaratex.

It must be stressed that **IoT Is Not About Things – It’s About Data**. In a manufacturing facility, immense opportunities are presented by the capability to analyse and utilize huge amounts of IoT data. By examining large data sets it can reveal trends, unseen patterns, hidden correlations, and
new information. Companies and individuals can benefit from analysing large amounts of data and managing huge amounts of information that can affect businesses. Moreover, data analytics aims to immediately extract knowledgeable information using data mining techniques that help in making predictions, identifying recent trends, finding hidden information, improving decision making.

Internet of Things would arise chiefly from productivity improvements, including 10 to 20 percent energy savings and a 10 to 25 percent potential improvement in labour efficiency. Improvements in equipment maintenance, inventory optimization, and worker health and safety are also sources of value in factories [98]. Furthermore, IoT improve asset utilization by reducing maintenance expenses, longer life of machinery and higher plant uptime [99].

The application of IoT is projected to generate $1.2 to $3.7 trillion of value globally by 2025, in four primary forms: 1) operational efficiency; 2) predictive and preventative maintenance; 3) supply chain management; and 4) inventories and logistics [100].
By the deployment of IoT and extracting data insights AlSaratex will benefit as follows:

- RFID readers will detect the arrival and the departure of the lot in order to capture the lot status in real time. Extracting value from variety of manufacturing data can increase operational efficiency and reduce maintenance costs.

- By recording the starting time and the finishing time at each machine, the company will be able to define a standard cycle time for each process as well as record the time delay caused by any type of failure. Consequently, IoT will allow the reduction of downtime by identifying worn tool parts prior to planned maintenance.

- Using IoT the company can trace root causes for those deviations whether it is a result of machine downtime, machine settings in each step e.g. speed, worker absence or carelessness, or poor quality of raw materials received from suppliers. For example, by analysing data the company may correlate that each time the company buys raw material from a certain supplier, cycle time increase.

- IoT will allow to speed the response time to issues on the plant floor, this will improve quality with the ability to track the manufacturing process in real time leading to early identification of issues.

- Since the company has different machines with different efficiencies, as stated earlier, it is expected that the same process ran on different machines will have different cycle time. Hence, the company will be able to define a cycle time for each machine.

- It will also help in providing an accurate estimation on the remaining finish time that will improve the scheduling of customer shipments. As a result, IoT will improve customer experience since it become easier to answer customer questions about order status.
CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK
6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This work has addressed a challenging research area “Internet of things” that is still an on-going focus of the research community in multi-disciplinary fields. This chapter is dedicated to discussing the most important findings and conclusions of this research. In addition, recommendations and opportunities for potential future work that can be carried out are also highlighted to pave the way for further possible extensions for this work.

6.1 CONCLUSIONS

The set of conclusions that have been established through this work are as follows:

6.1.1 Conclusions from literature review

- Due to the novelty of the topic “Internet of Things”, few publications, especially those concerned with IoT applications, are found in literature.

- The literature about IoT solutions for SMEs is very limited.

- RFIDs is still the most extensively used Auto-ID in IoT applications. Although this technology has been around for more than half century, it is only in recent years when this technology has gained increasing momentum due to convergence of lost cost and increased capabilities.

- IoT security represents the main hurdle for the implementation of IoT in real life.

- Trust and information privacy is another key challenge facing the IoT. Users need to build trust in IoT based systems.

- More research is needed in the field of Big Data Analytics. Since benefiting from IoT implementation mainly depends on extracting insights from data for analysis.
6.1.2 Conclusions from the development of the decision support system

- MCDMs are classified as compensatory and non-compensatory methods. The AHP and Electre are the most widely adopted MCDMs in the literature.

- Compared to AHP, Electre is much complicated in implementation as well as coding.

- Electre needs less input compared to AHP, it eliminates the necessity for pairwise comparisons.

6.1.3 Conclusions from case study

- The AHP best ranked alternative has low performance value in cost and temperature range.

- The Electre method solution produced a ranking where the best alternative does not have significant low values in one of the criteria.

- Both methods choose the same alternative as worst ranking.

6.2 RECOMMENDATIONS FOR FUTURE WORK

The following are possible future avenues for further research:

- Expansion of the DSS to include the remaining components of the RFID system which includes the RFID tags and RFID Antenna.

- Expansion of the DSS to include other Auto-IDs as well as other IoT technologies such as network connection such as Bluetooth, Zigbee and so on.

- The implementation of a mini-pilot run of the selected RFID components in the shop floor and the collection of real time data.

- Applying Data Analytics to extract trends from the data to improve the manufacturing processes. Data analytics aims to immediately extract
knowledgeable information using data mining techniques that help in making predictions, identifying recent trends, finding hidden information, improving decision making.

- Performing a cost benefit analysis, to compare the cost of setting the IoT solution and the benefits reflected in increased efficiency and productivity which can be measured in terms of increased profits.

- More research is needed to study the social impact of IoT deployment in labor intensive facilities. IoT solutions makes it possible to monitor workers constantly, workers may find this inconvenient. Also, IoT may change the way workers do their tasks hence workers which necessitates providing training to workers.
REFERENCES
REFERENCES


APPENDICES

Appendix A: Publications Arising from this Work

Appendix B: Summary of MCDM Literature

Appendix C: RFID Reader Alternatives

Appendix D: Questionnaire

Appendix E: Excel Visual Basic Code for the DSS covering AHP and Electre II
Appendix A

PUBLICATIONS ARISING FROM THIS WORK

A publication has been submitted and accepted to the 47th International Conference on Computers & Industrial Engineering that was held on 11th - 13th of October 2017 Lisbon, Portugal with the title of “INDUSTRIAL INTERNET OF THINGS IN AN EGYPTIAN LABOUR INTENSIVE TEXTILE INDUSTRY”.
Appendix B

SUMMARY OF MCDM Literature

Each publication reviewed has been classified according to the publication year, publication type as well as the MCDM method used.
<table>
<thead>
<tr>
<th>#</th>
<th>Author(s)</th>
<th>Year</th>
<th>Publication Type</th>
<th>MCDM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AHP</td>
</tr>
<tr>
<td>1</td>
<td>M.Behzadian et al.</td>
<td>2010</td>
<td>Journal</td>
<td>✔</td>
</tr>
<tr>
<td>2</td>
<td>A.Afshari et al</td>
<td>2010</td>
<td>Conference</td>
<td>✔</td>
</tr>
<tr>
<td>3</td>
<td>H.Lin</td>
<td>2010</td>
<td></td>
<td>✔</td>
</tr>
<tr>
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<td>G.Polat et al. [123]</td>
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<td>I.Temiz et al. [124]</td>
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<td>42</td>
<td>Z. Durmusglu et al [126]</td>
<td>2018</td>
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MCDM: AHP, ANP, ELECTRE, TOPSIS, PROMOTHEE, MAVT, MAUT, Review
Appendix C

In this appendix, the RFID reader alternatives are attached. Those alternatives have been collected from reputable online stores which sell well-known brands of RFID readers. The table below represents the name of the RFID reader including the link of the product.

<table>
<thead>
<tr>
<th>Alternative Number</th>
<th>Name</th>
<th>Link</th>
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</thead>
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<td>10</td>
<td>2.4GHz Active RFID Reader -DL580</td>
<td><a href="http://www.rfid-in-china.com/2.4ghz-active-rfid-reader--dl580.html">http://www.rfid-in-china.com/2.4ghz-active-rfid-reader--dl580.html</a></td>
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<td>12</td>
<td>THINGMAGIC M6 UHF RFID READER (4 PORT) - WI-FI</td>
<td><a href="https://www.atlasrfidstore.com/thingmagic-m6-uhf-rfid-reader-4-port-wi-fi/">https://www.atlasrfidstore.com/thingmagic-m6-uhf-rfid-reader-4-port-wi-fi/</a></td>
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<tr>
<td>16</td>
<td>Metra Tec® QuasarMX HF RFID Reader</td>
<td><a href="http://www.therfidshop.com/images/Datasheet_QuasarMX_r1-0.pdf">http://www.therfidshop.com/images/Datasheet_QuasarMX_r1-0.pdf</a></td>
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<tr>
<td>17</td>
<td>TSL 1059 Multi-ISO HF RFID Reader RFID Readers</td>
<td><a href="https://www.barcodequality.com/catalog/tql/1059.htm#">https://www.barcodequality.com/catalog/tql/1059.htm#</a></td>
</tr>
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<td>19</td>
<td>YongKaiDa 902-928mhz lector 5m rfid antenna rs232/rs485 8dbi long distance reader</td>
<td><a href="https://www.aliexpress.com/item/YongKaiDa-902-928mhz-lector-5m-rfid-antenna-rs232-rs485-8dbi-long-distance-reader/32832156383.html">https://www.aliexpress.com/item/YongKaiDa-902-928mhz-lector-5m-rfid-antenna-rs232-rs485-8dbi-long-distance-reader/32832156383.html</a></td>
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<tr>
<td>20</td>
<td>1134 LOW FREQUENCY RFID READER FOR MOTOROLA MC55/65/67</td>
<td><a href="https://www.barcodesinc.com/tsl/">https://www.barcodesinc.com/tsl/</a></td>
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<td>22</td>
<td>ATID AT880 handheld reader</td>
<td><a href="http://www.geipl.com/rfid-readers">http://www.geipl.com/rfid-readers</a></td>
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<td>24</td>
<td>HARTING HA-VIS-RF-R300 UHF RFID READER</td>
<td><a href="https://www.atlasrfidstore.com/harting-ha-vis-rf-r300-uhf-rfid-reader/">https://www.atlasrfidstore.com/harting-ha-vis-rf-r300-uhf-rfid-reader/</a></td>
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<td>27</td>
<td>RFID Desktop Reader EVO LF</td>
<td><a href="http://www.rfid-europe.com/RFID-Desktop-Reader-EVO-LF">http://www.rfid-europe.com/RFID-Desktop-Reader-EVO-LF</a></td>
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<td>31</td>
<td>TURCK (U GROK IT) UHF RFID READER FOR SMARTPHONES</td>
<td><a href="https://www.atlasrfidstore.com/turck-u-grok-it-uhf-rfid-reader-for-smartphones/">https://www.atlasrfidstore.com/turck-u-grok-it-uhf-rfid-reader-for-smartphones/</a></td>
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<tr>
<td>38</td>
<td>KEONN ADVANREADER-10 USB RFID READER (1-PORT)</td>
<td><a href="https://www.atlasrfidstore.com/keonn-advanreader-10-usb-rfid-reader-1-port/">https://www.atlasrfidstore.com/keonn-advanreader-10-usb-rfid-reader-1-port/</a></td>
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Appendix D

QUESTIONNAIRE

All questions must be answered. The slider allow you to decide which criterion is more important than the other, a scale of 1 to 9 is used. Please make sure to be consistent in your pairwise comparisons.

Scale Explanation
1 Equal Importance
2 Weak
3 Moderate Importance
4 Moderate Plus
5 Strong Importance
6 Strong Plus
7 Very Strong
8 Very Very strong
9 Extremely More Important

When scoring towards the direction of a certain criterion, this means this criterion is more important for you. Finally, please make sure to evaluate criteria according to what is more suitable to your case study.

Which criteria concerning the selection of the RFID reader component are more important for you? And by how much important? i.e. Which criteria would you prioritize more than the other?
1. When selecting an RFID reader, how much is "Cost" most important for you than "Power Source Mode"?
   By Power Source Mode we mean whether it is operated by battery, direct current, by USB connection or maybe by PowerOverEthernet (PoE).

2. When selecting an RFID reader, how much is "Cost" more important for you than "Network Connection Mode"?
   By Network Connection Mode we mean the type of network available, whether the reader can send data through Ethernet connection or Wi-Fi, or Bluetooth. For example, you may prefer to choose a reader which can send data through wireless network such as Wi-Fi instead of wired network example Ethernet.

3. When selecting an RFID reader, how much is "Cost" more important for you than "Number of antenna ports" available?
   Number of antenna ports are ports which allow antennas to be connected to the reader, as number of ports increase more antennas can be connected hence more tags can be read by same reader.

4. When selecting an RFID reader, how important is "Network Connection Mode" compared to "Power Source Mode"? i.e. For example having a Wi-Fi connection could be more important than having a reader battery operated.

5. When selecting an RFID reader, how much is "Network Connection Mode" more important than "Temperature Range".
6. When selecting an RFID reader, how important is "Cost" to you compared to "Temperature Range"?
   By temperature range we mean selecting a reader with much higher temperature range than required in your use case, or is it enough to have temperature range just high enough to fit your use case.

7. When selecting an RFID reader, how much is "Power Source Mode" more important than "Temperature Range"?

8. When selecting an RFID reader, how much is "Number of Antenna Ports" more important than "Temperature Range"?

9. When selecting an RFID reader, how important is "Network Connection Mode" compared to "Number of Antenna Ports"?

10. When selecting as RFID reader, how much is "Power Source Mode" important compared to "Number of antenna"
Appendix E

Excel Visual Basic Code for Decision Support System

Development for the RFID Reader Selection

This appendix presents the code that was written and developed in Excel Visual Basic Programming language. The code was written in Microsoft Excel 2010. The following code does the following tasks:

- Receive Input from the User and based on the user’s input filters alternatives
- Implementation of AHP method
- Construct Dynamic tables according to the number of filtered alternatives

Reset Button

Option Explicit

Dim Selection1Made As Boolean
Dim Selection2Made As Boolean
Dim Selection3Made As Boolean
Dim Selection4Made As Boolean
Dim Selection5Made As Boolean
Dim Selection6Made As Boolean
Dim Selection7Made As Boolean
Dim filteredalternatives As range
Dim numberofalternatives As Integer
Dim NumberofCriteria As Integer
Dim loopcounter As Integer
Dim Loopcounter2 As Integer
Dim loopcounter4 As Integer
Dim firstcellinarray1 As Integer
Dim lastcellinarray1 As Integer
Dim Nplus1 As Integer
Dim MaxCost As Integer
Dim MinCost As Integer
Dim Numerator As range
Dim NumeratorValue As Double
Dim denominator As range
Dim denominatorValue As Double
Dim Weight As range
Dim space As Integer
Dim numRows As Integer
Dim numOfColumns As Integer
Dim shift As Integer
Dim loopCounter As Integer
Dim CopyRange As range
Dim N As Integer

Sub ValidatingSelection1()
If FixedReaderOption.Value = False And HandheldReaderOption.Value = False Then
Selection1Made = False
ElseIf FixedReaderOption.Value = True Or HandheldReaderOption.Value = True Then
Selection1Made = True
End If
End Sub

Sub ValidatingSelection2()
If Readrange10.Value = False And Readrange30.Value = False And ReadRange100.Value = False Then
Selection2Made = False
ElseIf Readrange10.Value = True Or Readrange30.Value = True Or ReadRange100.Value = True Then
Selection2Made = True
End If
End Sub

Sub ValidatingSelection3()
If RealtimeDataOn.Value = False And RealTimeDataOff.Value = False Then
Selection3Made = False
ElseIf RealtimeDataOn.Value = True Or RealTimeDataOff.Value = True Then
Selection3Made = True
End If
End Sub

Sub ValidatingSelection4()
If MultipleTagOp1.Value = False And MultipleTagOp2.Value = False And MultipleTagOp3.Value = False Then
Selection4Made = False
Selection4Made = True
End If
End Sub

Sub ValidatingSelection5()
If ExcessiveDirtCB1.Value = False And ExcessiveDustCB2.Value = False And ExcessiveLiquidCB3.Value = False And NoExcessiveCB4.Value = False Then
Selection5Made = False
End If
End Sub

Sub AfterUpdateFormattingEnvironmentalConditionSelection()
ExcessiveDirtCB1.BackColor = rgbWhite
ExcessiveDustCB2.BackColor = rgbWhite
ExcessiveLiquidCB3.BackColor = rgbWhite
NoExcessiveCB4.BackColor = rgbWhite
End Sub

Sub ValidatingSelection6()
If UL1.Value = False And UL2.Value = False And UL3.Value = False Then
Selection6Made = False
ElseIf UL1.Value = True Or UL2.Value = True Or UL3.Value = True Then
Selection6Made = True
End Sub

Sub ValidatingSelection7()
If LL1.Value = False And LL2.Value = False And LL3.Value = False Then
Selection7Made = False
ElseIf LL1.Value = True Or LL2.Value = True Or LL3.Value = True Then
Selection7Made = True
End If
End Sub

Private Sub CommandButton1_Click()
If FixedReaderOption.Value = True Then
Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=16, Criteria:= _">">1000", Operator:=xlAnd
ElseIf Readrange30.Value = True Then
Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=16,
Criteria:= _">">30", Operator:=xlAnd
ElseIf Selection5Made = True Then
MsgBox "Please Make a 'Read Range' Selection", vbExclamation
Readrange10.BackColor = rgbPink
Readrange30.BackColor = rgbPink
ReadRange100.BackColor = rgbPink
End If
End Sub

'Network Connection
If RealtimeDataOn.Value = True Then
Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=14,
Criteria:= _"=Yes", Operator:=xlAnd
ElseIf RealTimeDataOff.Value = True Then
Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=14,
Criteria:= _"=No", Operator:=xlAnd
ElseIf Selection3Made = False Then
MsgBox "Please Make 'Network Connection' Selection", vbExclamation
RealtimeDataOn.BackColor = rgbPink
RealTimeDataOff.BackColor = rgbPink
End If

'Multiple Tag Reading
If MultipleTagOp1.Value = True Then
Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=17,
Criteria:= _">">1", Operator:=xlAnd
ElseIf MultipleTagOp2.Value = True Then
End If
If Selection5Made = False Then
    MsgBox "Please Make 'Multiple Tag Reading' Selection", vbExclamation
ElseIf Selection4Made = False Then
    MsgBox "Please Make 'Multiple Tag Condition' Selection", vbExclamation
End If

ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
ElseIf NoExcessiveCB4.Value = True And ExcessiveDirtCB1.Value = True And ExcessiveLiquidCB3.Value = True Then
    Worksheets("Alternatives").ListObjects("Table1").range.AutoFilter Field:=23
Public Sub tableformatting1()
    'MsgBox "n" & NumberofAlternatives
    End Sub

    Private Sub CommandButton2_Click()
        Call AfterUpdateFormattingEnvironmentalConditionSelection
        FixedReaderOption.Value = False
        FixedReaderOption.BackColor = rgbWhite
        HandheldReaderOption.Value = False
        HandheldReaderOption.BackColor = rgbWhite
        Readrange10.Value = False
        Readrange30.Value = False
        ReadRange100.Value = False
        ReadRange100.BackColor = rgbWhite
        ReadTimeDataOff.Value = False
        ReadTimeDataOff.BackColor = rgbWhite
        RealtimeDataOn.Value = False
        RealtimeDataOn.BackColor = rgbWhite
        MultipleTagOp1.Value = False
        MultipleTagOp1.BackColor = rgbWhite
        MultipleTagOp2.Value = False
        MultipleTagOp2.BackColor = rgbWhite
        MultipleTagOp3.Value = False
        MultipleTagOp3.BackColor = rgbWhite
        ExcessiveDirtCB1.Value = False
        ExcessiveDirtCB1.BackColor = rgbWhite
        ExcessiveDustCB2.Value = False
        ExcessiveDustCB2.BackColor = rgbWhite
        ExcessiveLiquidCB3.Value = False
        ExcessiveLiquidCB3.BackColor = rgbWhite
        NoExcessiveCB4.Value = False
        NoExcessiveCB4.BackColor = rgbWhite
        UL1.Value = False
        UL1.BackColor = rgbWhite
        UL2.Value = False
        UL2.BackColor = rgbWhite
        UL3.Value = False
        UL3.BackColor = rgbWhite
        LL1.Value = False
        LL1.BackColor = rgbWhite
        LL2.Value = False
        LL2.BackColor = rgbWhite
        LL3.Value = False
        LL3.BackColor = rgbWhite
        Criteria1:= _
            "<1.000", Operator:=xlAnd
        ElseIf LL3.Value = True Then
            MsgBox "Please Make 'Lower Limit'
        End If
        End Sub

        Private Sub CommandButton2_Click()
            Call AfterUpdateFormattingEnvironmentalConditionSelection
            FixedReaderOption.Value = False
            FixedReaderOption.BackColor = rgbWhite
            HandheldReaderOption.Value = False
            HandheldReaderOption.BackColor = rgbWhite
            Readrange10.Value = False
            Readrange30.Value = False
            ReadRange100.Value = False
            ReadRange100_BackColor = rgbWhite
            ReadTimeDataOff.Value = False
            ReadTimeDataOff.BackColor = rgbWhite
            RealtimeDataOn.Value = False
            RealtimeDataOn.BackColor = rgbWhite
            MultipleTagOp1.Value = False
            MultipleTagOp1.BackColor = rgbWhite
            MultipleTagOp2.Value = False
            MultipleTagOp2.BackColor = rgbWhite
            MultipleTagOp3.Value = False
            MultipleTagOp3.BackColor = rgbWhite
            ExcessiveDirtCB1.Value = False
            ExcessiveDirtCB1.BackColor = rgbWhite
            ExcessiveDustCB2.Value = False
            ExcessiveDustCB2.BackColor = rgbWhite
            ExcessiveLiquidCB3.Value = False
            ExcessiveLiquidCB3.BackColor = rgbWhite
            NoExcessiveCB4.Value = False
            NoExcessiveCB4.BackColor = rgbWhite
            UL1.Value = False
            UL1.BackColor = rgbWhite
            UL2.Value = False
            UL2.BackColor = rgbWhite
            UL3.Value = False
            UL3.BackColor = rgbWhite
            LL1.Value = False
            LL1.BackColor = rgbWhite
            LL2.Value = False
            LL2.BackColor = rgbWhite
            LL3.Value = False
            LL3.BackColor = rgbWhite
            Criteria1:= _
                "<1.00", Operator:=xlOr
            ElseIf LL1.Value = True Then
                MsgBox "Please Make 'Lower Limit'
            End If
        End Sub
Worksheets("AHP TABLES").cells(2 + 1 + N, 1 + 2 + N + space + N + 1 + 2).Address, Cells(2 + N + 1, 2 + N, Address)
    Call tableformatting(table1)
    table1.Copy
    Worksheets("AHP TABLES").range(Cells(2, 2), Address)
    Call tableformatting(table1)
    table1.Copy
    Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(0, N + space + 1 + N + 1).PasteSpecial
    numrows = Selection.Rows.Count
    numcolumns = Selection.Columns.Count
    Selection.Resize(numrows, numcolumns + 1 + 1).Select
    Selection.Borders(xlInsideHorizontal, .LineStyle = xlContinuous, .ColorIndex = 0)
With Selection
Call tableformatting1
End With
Worksheets("AHP TABLES").Cells(2 + N * 2 + 1 * 2 + space + 3 + 1, 1).FormulaR1C1 = "=MMULT(R[1]:R[7]:C[1]:C[4];R[3]:R[7]:C[1]:C[4])"
<table>
<thead>
<tr>
<th>Worksheet</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;AHP TABLES&quot;</td>
<td>( \text{Cells}(2 + N * 2 + 1 * 3 + space + 2 + 2 + 3 + 3, 2).Address.OffSet(0, N + space + 1 + N + 1).Value = &quot;Inconsistency&quot; )</td>
</tr>
</tbody>
</table>

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 3 + 1 * 4 + space + 5 + 3 * 3, 2).Value = "Power Source"

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4, 2).Value = "Network Connection Mode"

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4, 2).Value = "Network Connection Mode"

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4, 2).Value = "Network Connection Mode"

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4, 2).Value = "Network Connection Mode"

For loopcounter = 1 To N Step 1

Worksheets("AHP TABLES").Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4, 2).Value = "Network Connection Mode"
+= 4 \cdot 4, 2 + N \cdot 2 + 1 + 1 + space. Formula R1C1 =
"=AVERAGE(R[1:C-1] & N & ":R[C-1]"");
Next loopcounter
For loopcounter = 1 To N Step 1
Worksheets("AHP TABLES").Cells(2 + N * 2 + 1 * 2 + space + 3 + 1) = 3.
Formula R1C1 = "=MMULT(R[R][C-1] & firstcellinarray1 & ":R[C-1]"
& lastcellinarray1 & ":R[-1]:R[-7]"");
Next loopcounter
End Sub
Private Sub RankingButton_Click()
NumCriteria = 5
N = numberofalternatives
space = 3
shift = 2 + N + 1 + 1
For loopcounter = 1 To N Step 1
For Loopcounter2 = 1 To NumCriteria Step 1
For Loopcounter3 = 0 To NumCriteria
Worksheets("AHP TABLES").Cells(2 + loopcounter, 2 + N * 2 + 1 * 2 + space + 3 + loopcounter).Value =
Worksheets("CriteriaSheet").Cells(0 + loopcounter, 1).Value
Worksheets("AHP TABLES").range(Cells(2 + 1 + (shift * Loopcounter3), 2 + 1 + N + space + 3 + 1 + N).Address).Copy
Worksheets("AHP TABLES").range(Cells(2 + N * 2 + 1 + 1 + space + 1 + N).Address).Copy
Next Loopcounter3
Next Loopcounter2
Next Loopcounter
Private Sub CommandButton3_Click()
Dim answer As VbMsgBoxResult
Dim answer2 As VbMsgBoxResult
answer = MsgBox("This will clear any constructed tables, are you sure you want to proceed?", vbYesNo + vbExclamation, "WARNING")
If answer = vbYes Then
answer2 = MsgBox("Any entered data will be cleared out, are you sure you want to proceed?", vbYesNo + vbExclamation, "WARNING")
If answer2 = vbYes Then
Application.ScreenUpdating = False
Call BUILDMORETABLES
Worksheets("Pastesheet").Cells(1, 1).Select
Sheets("Alternatives").Select
ActiveCell.CurrentRegion.Copy
Sheets("PasteSheet").Select
Sheets("PasteSheet").range("A1").Columns.AutoFit
Application.CutCopyMode = False
With Selection
.HorizontalAlignment = xlCenter
.VerticalAlignment = xlBottom
.WrapText = False
.Orientation = 0
.AddIndent = False
.IndentLevel = 0
.ShrinkToFit = False
.ReadingOrder = xlContext
.MergeCells = False
End With
Call constructingfirststtableinAHP
Call BUILDMORETABLES
MsgBox "Please make Pairwise Comparisons then enter 'Rank Criteria' Button"
End Sub
Private Sub CommandButton4_Click()
Dim answer2 As VbMsgBoxResult
Dim answer As VbMsgBoxResult
answer = MsgBox("This will clear any constructed tables, are you sure you want to proceed?", vbYesNo + vbCrLf)
If answer = vbYes Then
answer2 = MsgBox("Any entered data will be cleared out, are you sure you want to proceed?", vbCrLf)
If answer2 = vbYes Then
Application.ScreenUpdating = False
Call BUILDMORETABLES
Worksheets("Pastesheet").Cells(1, 1).Select
Sheets("Alternatives").Select
ActiveCell.CurrentRegion.Copy
Sheets("PasteSheet").Select
Sheets("PasteSheet").range("A1").Columns.AutoFit
Application.CutCopyMode = False
With Selection
.HorizontalAlignment = xlCenter
.VerticalAlignment = xlBottom
.WrapText = False
.Orientation = 0
.AddIndent = False
.IndentLevel = 0
.ShrinkToFit = False
.ReadingOrder = xlContext
.MergeCells = False
End With
Call constructingfirststtableinAHP
Call BUILDMORETABLES
MsgBox "Please make Pairwise Comparisons then enter 'Rank Criteria' Button"
End Sub
Private Sub ExcessiveDirtCB1_Change()
If ExcessiveDirtCB1.Value = True Then
ExcessiveDirtCB1.BackColor = rgbWhite
ExcessiveDustCB2.BackColor = rgbWhite
ExcessiveLiquidCB3.BackColor = rgbWhite
End If
End Sub
Private Sub ExcessiveDirtCB2_Click()
Call AfterUpdateFormattinEnvironmentalConditionSelection
End Sub
Private Sub ExcessiveDirtCB2_Change()
If ExcessiveDirtCB2.Value = True Then
ExcessiveDirtCB2.BackColor = rgbWhite
ExcessiveDustCB2.BackColor = rgbWhite
ExcessiveLiquidCB3.BackColor = rgbWhite
End If
End Sub
Private Sub ExcessiveDirtCB3_Click()
Call tableformatting1
Worksheets("CriteriaSheet").Select
Table.Copy
Worksheets("CriteriaSheet").range.Cells(2 + NumberofCriteria + space2, 3).Address).Offset(space2, 0).PasteSpecial
numrows2 = Selection.Rows.Count
numcolumns = Selection.Columns.Count
Selection.Resize(numrows2, numcolumns + 1).Select
Worksheets("CriteriaSheet").range.Cells(2 + NumberofCriteria + space2, 3).Address).Offset(space2, NumberofCriteria + 1).Value = "Weights"
For loopcounter = 1 To NumberofCriteria Step 1
Worksheets("CriteriaSheet").range.Cells(2 + NumberofCriteria + space2 * 2 + loopcounter, 3 + NumberofCriteria + 1).Address).FormulaR1C1 = ">
Application.CountA(filteredalternatives) =
NumberofCriteria = numrows
Application.CutCopyMode = False
space2 = 2
space = 3
Set Nrcriteria = Worksheets("CriteriaSheet").range("A1", range("A1").End(xlDown))
numrows = Nrcriteria.Rows.Count
NumberofCriteria = numrows
For loopcounter = 0 To NumberofCriteria - 1
Worksheets("CriteriaSheet").Cells(2, 4 + loopcounter) =
Worksheets("CriteriaSheet").Cells(1 + loopcounter, 1).Value
Worksheets("CriteriaSheet").Cells(3 + loopcounter, 3) =
Worksheets("CriteriaSheet").Cells(1 + loopcounter, 1).Value
Worksheets("CriteriaSheet").Cells(3 + loopcounter, 4 + loopcounter).Value = 1
Worksheets("CriteriaSheet").Cells(3 + NumberofCriteria, 3 + 1 + loopcounter).FormulaR1C1 = ">
Next loopcounter
Worksheets("CriteriaSheet").Cells(3 + NumberofCriteria, 3).Value = "Sum"
ActiveWindow.DisplayGridlines = False
Call tableformatting1
Set Table = Worksheets("CriteriaSheet").range.Cells(2, 3).Address, Cells(2 + NumberofCriteria + 1, 3 + NumberofCriteria).Address
Worksheets("CriteriaSheet").Select
Table.Select
Call tableformatting1
Worksheets("CriteriaSheet").Select
Table.Copy
Calculating Inconsistency for Table 1

For loopcounter = 1 To N
Set RowOfTable1 = Worksheets("AHP TABLES").range(Cells(2 + 1, 2 + loopcounter, 2 + 1).Address, Cells(2 + loopcounter, 2 + N).Address)
For Each SingleCellTable1 In RowOfTable1
If SingleCellTable1.Value = "" Then
    total = total + vbNewLine + "Cell Reference : & SingleCellTable1.Address"
End If
Next SingleCellTable1
Next loopcounter
If total <> "" Then
    MsgBox "Input Missing in Table1" & vbNewLine & total
End If

Set Array2 = Worksheets("AHP TABLES").range(Cells(2 + 1, 2 + N + space + N + 1 + 2).Address, Cells(2 + N, 2 + N + space + N + 1 + 2).Address)
Worksheets("AHP TABLES").Select
Space = 3
NumberofCriteria = 5
Set Array2 = Worksheets("AHP TABLES").range(Cells(2 + 1, 2 + N + space + N + 2).Address, Cells(2 + N, 2 + N + space + N + 2).Address)
Worksheets("AHP TABLES").Select
Space = 3
NumberofCriteria = 5
For loopcounter = 1 To N Step 1
Set Array1 = Worksheets("AHP TABLES").range(Cells(2 + loopcounter, 2 + 1 + N - 1).Address)
Worksheets("AHP TABLES").Cells(2 + loopcounter, 2 + N + space + N + 1 + 1).Value = "" & Application.WorksheetFunction.VLookup(N, MatrixOrderNumber, 2, True)
End If

Select Case Array2.Value
Case "IR"
    Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = "IR"
End Select
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = N
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = N
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = "ICR"
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = N
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = N
Worksheets("AHP TABLES").range(Cells(2, 2).Address).Offset(N + 3, N + space + 1 + N + 1).Value = "ICR"
3 + space + 2 + 3 + N + 3, 2 + N + space + 1 + N + 1).Address)

' For loopcounter = 1 To N Step 1
'Set Array6 = Worksheets("AHP TABLES").range(Cells(2 + N * 2 + 1 * 3 + space + 2 + 3 + 3 + loopcounter, 2 + 1).Address).Cells(2+N*2+1*3+space+1+N+1,1).Value = "Sum"

'Worksheets("AHP TABLES").Cells(2+N*2+1*3+space+2+3+3+loopcounter, 2+N+space+1+N+1).Address = Application.WorksheetFunction.MMult(Array6, Array5)

'Next loopcounter
'Worksheets("AHP TABLES").Cells(2+N*2+1*3+space+2+3+3+N+1,2+N+space+1+N+1).Value = "IC"

'Worksheets("AHP TABLES").Cells(2+N*2+1*3+space+2+3+3+N+1,2+N+space+1+N+1).Value = "IC"  

'Worksheets("AHP TABLES").Cells(2+N*2+1*3+space+2+3+3+N+1,2+N+space+1+N+1).Value = "IC"

'Worksheets("AHP TABLES").Cells(2+N*2+1*3+space+2+3+3+N+1,2+N+space+1+N+1).Value = "IC"

'For loopcounter = 1 To N Step 1
'Set Array8 = Worksheets("AHP TABLES").range(Cells(2+N*3+1*4+space+5+3*3+3,2+1).Address).Cells(2+loopcounter+N*3+1*4+space+5+3*3+3,2+1+N-1).Address)

'Worksheets("AHP TABLES").Cells(2+N*3+1*4+space+5+3*3+3+loopcounter, 2+N+space+1+N+1+1).Value = Application.WorksheetFunction.MMult(Array8, Array7)

Next loopcounter
'Worksheets("AHP TABLES").Cells(2+N*3+1*4+space+5+3*3+3+N+1,2+N+space+1+N+1).Address)

'Worksheets("AHP TABLES").Cells(2+N*3+1*4+space+5+3*3+3+N+1,2+N+space+1+N+1).Address = Application.WorksheetFunction.MMult(Array8, Array7)

For loopcounter = 1 To N Step 1
'Set Array9 = Worksheets("AHP TABLES").range(Cells(2+N*4+1*5+space+8+3*4*1+2,1+N+1).Address).Cells(2+N*4+1*5+space+8+3*4*1+2+N+1).Address)

Next loopcounter
'Worksheets("AHP TABLES").Cells(2+N*4+1*5+space+8+3*4*1+2+N+1).Address)

For loopcounter = 1 To N Step 1
'Set Array10 = Worksheets("AHP TABLES").range(Cells(2+N*4+1*5+space+8+3*4*1+2+N+1).Address)

Next loopcounter
'Worksheets("AHP TABLES").Cells(2+N*4+1*5+space+8+3*4*1+2+N+1).Address)
Private Sub ValidateInputBeforeInconsistencyCalculation()
    Call CountingnumberofAlternativesAfterFiltering
    Dim N As Integer

    N = numberofalternatives
    'Validating Table1
    For loopcounter = 1 To N
        Set RowTable1 = Worksheets("AHP TABLES").range(Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4 + N + 2, 2 + N + space + 1 + N + 1).Address)
        If SingleCelltable.Value = "" Then
            MsgBox ""Input Missing in Table1"" & vbCrLfNewLine & total1
            Exit Sub
        End If
        Next SingleCelltable1
        Next loopcounter

        total1 = total + vbCrLfNewLine + "Cell Reference : " & SingleCelltable1.Address
        End If

        'Validating Table4
        For loopcounter = 1 To N
            Set RowTable4 = Worksheets("AHP TABLES").range(Cells(2 + N * 4 + 1 * 5 + space + 8 + 3 * 4 + N + 2, 2 + N + space + 1 + N + 1).Address)
            If SingleCelltable.Value = "" Then
                MsgBox ""Input Missing in Table4"" & vbCrLfNewLine & total4
                Exit Sub
            End If
            Next SingleCelltable4
            Next loopcounter

        total4 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable4.Address
        End If

        Dim AlternativeRange As Range
        Application.CountA(filteredalternatives) = N
        AlternativeRange = Application.CountA(filteredalternatives)
        Dim NumberofCriteria As Integer
        NumberofCriteria = 5
        Dim AlternativeRange As Range
        Set AlternativeRange = Worksheets("AHP TABLES").range(Cells(2 + N + space + space + 2 + N + space + 1 + N + 1 + 3 + 2).Address)
        If AlternativeRange.Count = AlternativeRange.Count Then
            MsgBox "Input Missing in Table5" & vbCrLfNewLine & total5
            Exit Sub
        End If
        Next SingleCelltable5
        Next loopcounter

        total5 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable5.Address
        End If

    Private Sub CommandButton4_Click()
        Set filteredalternatives = Sheets("PasteSheet").range("A2:G" & N).End(xlDown)
        Set filteredalternatives = Application.CountA(filteredalternatives)
        Dim N As Integer
        N = numberofalternatives
        AlternativeRange = Worksheets("AHP TABLES").range(Cells(2 + N + space + space + 2 + N + space + 1 + N + 1 + 3 + 3).Address)
        If AlternativeRange.Count = AlternativeRange.Count Then
            MsgBox "Input Missing in Table5" & vbCrLfNewLine & total5
            Exit Sub
        End If
        Next SingleCelltable5
        Next loopcounter

        total5 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable5.Address
        End If

    'Validating Table2
    For loopcounter = 1 To N
        Set RowTable2 = Worksheets("AHP TABLES").range(Cells(2 + N + 1 + space + 3 + loopcounter + 2, 2 + 1).Address, Cells(2 + N + 1 + space + 3 + loopcounter + 2, 2 + N).Address)
        For Each singleCelltable2 In RowTable2
            If singleCelltable2.Value = "" Then
                total2 = total2 + vbCrLfNewLine + "Cell Reference : " & singleCelltable2.Address
                Exit Sub
            End If
        Next singleCelltable2
        Next loopcounter

        total2 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable2.Address
        End If

        'Validating Table3
        For loopcounter = 1 To N
            Set RowTable3 = Worksheets("AHP TABLES").range(Cells(2 + N * 2 + 1 + space + 11 + loopcounter + 2, 2 + 1).Address, Cells(2 + N * 2 + 1 + space + 11 + loopcounter + 2, 2 + N).Address)
            For Each singleCelltable3 In RowTable3
                If singleCelltable3.Value = "" Then
                    total3 = total3 + vbCrLfNewLine + "Cell Reference : " & singleCelltable3.Address
                    Exit Sub
                End If
            Next singleCelltable3
            Next loopcounter

        total3 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable3.Address
        End If

        'Validating Table5
        For loopcounter = 1 To N
            Set RowTable5 = Worksheets("AHP TABLES").range(Cells(2 + N * 4 + 1 + space + 15 + loopcounter + 12, 2 + 1).Address, Cells(2 + N * 4 + 1 + space + 15 + loopcounter + 12, 2 + N).Address)
            For Each singleCelltable5 In RowTable5
                If singleCelltable5.Value = "" Then
                    total5 = total5 + vbCrLfNewLine + "Cell Reference : " & singleCelltable5.Address
                    Exit Sub
                End If
            Next singleCelltable5
            Next loopcounter

        total5 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable5.Address
        End If

        Dim AlternativeRange As Range
        Set AlternativeRange = Worksheets("AHP TABLES").range(Cells(2 + N + space + space + 2 + N + space + 1 + N + 1 + 3 + 3).Address)
        If AlternativeRange.Count = AlternativeRange.Count Then
            MsgBox "Input Missing in Table5" & vbCrLfNewLine & total5
            Exit Sub
        End If
        Next SingleCelltable5
        Next loopcounter

        total5 = total + vbCrLfNewLine + "Cell Reference : " & singleCelltable5.Address
        End If

With ActiveWorkbook.Worksheets("AHP TABLES").Sort
    .SetRange AlternativeRange
    .Footer = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
End Sub

Private Sub RankingButton_Click()
    Set filteredalternatives =
        Sheets("PasteSheet").range("A2",
        Sheets("PasteSheet").range("A2").End(xlDown))
    numberofalternatives =
        Application.CountA(filteredalternatives)
    NumberofCriteria = 5
    N = numberofalternatives
    space = 3
    shift = 2 + N + 1 + 1 + 3
    For loopcounter = 1 To N Step 1
        "We added two columns here"
        Worksheets("AHP TABLES").Cells(2 +
        loopcounter, 2 + N * 2 + 1 * 2 + space +
        3 + 2).Value =
        Worksheets("PasteSheet").Cells(1 +
        loopcounter, 1)
    Next loopcounter
    "We added two columns here again"
    For loopcounter4 = 1 To N Step 1
        Worksheets("AHP TABLES").Cells(2,
        2 + N * 2 + 1 * 2 + space +
        3 + 2).Value =
        Worksheets("CriteriaSheet").Cells(0 +
        loopcounter4, 1).Value
    Next loopcounter4
    "For Loopcounter4 = 0 To"
    For loopcounter = 1 To N Step 1
        Set AlternativaArray =
            Worksheets("AHP TABLES").range(Cells(2 +
            loopcounter, 2 + N * 2 + 1 * 2 + space +
            3 + 2).Address, Cells(2 + loopcounter, 2 + N * 2 + 1 * 2 + space +
            3 + 2 + NumberofCriteria).Address)
        AlternativaArray.Select
        Worksheets("AHP TABLES").Cells(2 +
            N + space + space + loopcounter, 2 + N +
            space + 1 + N + 1 + 3 + 2).Value =
        WorksheetFunction.SumProduct(AlternativaArray,
        WeightArray)
    Next loopcounter
End Sub

Public Sub tableformatting1()
    With Selection
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlThin
    End With
End Sub

With
    .Borders(xlEdgeBottom).LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlThin
End With

With
    .Borders(xlEdgeRight).LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlThin
End With

With
    .Borders(xlInsideVertical).LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlThin
End With

With
    .Borders(xlInsideHorizontal).LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlThin
End With

With
    .Borders(xlDiagonalDown).LineStyle = xlNone
    .Borders(xlDiagonalUp).LineStyle = xlNone
    .Cells.Columns.AutoFit
    .HorizontalAlignment = xlCenter
    .VerticalAlignment = xlBottom
    .VerticalAlignment = True
    With .Borders(xlEdgeLeft)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlThin
    End With
    With .Borders(xlEdgeTop)
ملخص

لقد دخل العالم عصرًا تكنولوجيًا جديدًا يُعرف باسم "إنترنت الأشياء" (IoT) مما يتيح التواصل بين كل شيء. تتيح خدمة إنترنت الأشياء إمكانية تتبع ومراقبة مختلف الأنظمة والأشياء في الوقت الفعلي بناءً على اقتناء البيانات في الوقت الفعلي ومشاركتها. بواسطة إنترنت الأشياء، يمكن إجراء المراقبة والتحكم في الأجهزة اليومية عن بعد من أي مكان وفي أي وقت من خلال الإنترنت. ويتم ذلك من خلال تقنيات تمكين إنترنت الأشياء بما في ذلك تقنيات الاستشعار وتحديد الهوية. نظرًا لحداثة هذا الموضوع، لا تزال هناك العديد من التحديات التي تحتاج إلى الأبحاث. ويتمثل أحد هذه التحديات في مشكلة نشر إنترنت الأشياء في النظم الصناعية القديمة، التي يعالجها هذا العمل.

ويؤدي إدخال إنترنت الأشياء في البيئة الصناعية إلى ثورة صناعية رابعة تعرف باسم (Industry 4.0). يتطلب نشر تكنولوجيا إنترنت الأشياء في بيئات تصنيع تخطيطًا دقيقًا للتأكد من تلبية متطلبات التطبيق. هذا ينطوي على اختيار أجهزة الاستشعار المناسبة بين العديد من أجهزة الاستشعار المتاحة في السوق. اختيار المستشعر المناسب يتطلب إجراء تقييم دقيق لمعايير متضاربة ومتعددة باستخدام الأساليب المتعددة المعتمدة.

في هذه الدراسة يتم توظيف IoT في إحدى المصانع المصرية المصنفة كمؤسسة صغيرة ومتوسطة، حيث يتم اتخاذ القرار بشأن اختيار المستشعرات المناسبة لها حسب طبيعة العمل بها. وبناءً على ذلك تم بناء نظام دعم القرار لمساعدة على اختيار أفضل مستشعر ملائم لهذا المصنع، وبالتحديد أجهزة استشعار المعتمدة على تكنولوجيا الراديو (Radio Frequency Identification Systems RFIDs) وتتناول في الابد وهما العملية الهرمية التحليلية (Analytical Hierarchal Process والتي تنتمي إلى النماذج التعويضية وطريقة الاختيار المترجم إلى واقع (Elimination and Choice Translating to Reality التي تنتمي إلى النماذج الغير موضوعية وباستخدام كلتا الطريقتين أنتجت النتائج النهائية بدلاً مثالياً لتفصيلات صانع القرار.
إقرار لجنة التحكيم والمناقشة
جيدا إيهاب علي

تم مناقشة هذه الرسالة وإجازتها بتاريخ: ١٤ / ٥ / ٢٠١٨

أ.د. خالد سعيد الكيلاني

أ.د. هالة أحمد فاروق

أ.د. محمد حمدي علواني

أ.د. محمد جابر أبو علي

أ.د. خالد سعيد الكيلاني

أودعت هذه الرسالة بالمكتبة بتاريخ / /