ARAB ACADEMY FOR SCIENCE, TECHNOLOGY
AND MARITIME TRANSPORT
(AASTMT)

College of Engineering and Technology

Department of Industrial and Management Engineering

INVESTIGATING THE EFFECTIVENESS OF IMPLEMENTING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY FOR PRODUCTS TRACKING IN JOB SHOP PRODUCTION

By

ALY MOHAMED OWIDA

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Supervisors

Prof. Aziz E. El-Sayed
Professor of Industrial Engineering
Department of Industrial and Management Engineering

Dr. Khaled S. El-Kilany
Associate Professor
Department of Industrial and Management Engineering

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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.

(Signature)……………………………………………………….

(Date)…………………………………………………………….

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ABSTRACT

Radio frequency identification (RFID) technology has significant impact on product tracking and identification in manufacturing systems. Most of the business cases that implement the RFID technology in their operations have reduced their operating costs such as labour and inventory costs. Also, it minimizes the operating errors that affect the efficiency of the operations which appears in some key performance indicators such as cycle time, work in process, and resources utilization. In addition, several benefits such as better items monitoring, shorter lead times, higher customer satisfaction, and better inventory control can be achieved by introducing RFID technology in the different phases of production. In particular, recent developments in RFID technology and other supporting technologies have created opportunities for real-time traceability and better visibility of shop floor operations. This work investigates the effectiveness of introducing RFID technology in tracking and identification processes for products flow on a shop floor of a job shop manufacturing facility that produces a large number of customized furniture products in order to improve products' tracking and identification. The current identification system depends on metal tags and will be replaced by radio frequency tags. Simulation is used to assess the impact of introducing the RFID technology on a number of performance measures to that manufacturing setting which are output, throughput, cycle time, work in process, resources utilization, and average waiting time in queues. Analysis and comparison of simulation results for the base and proposed models show that RFID implementation maintains the value of most of the measures while improving the remaining measures. In addition, a cost analysis is conducted to estimate the required investments accompanied with the RFID technology adoption, the operating costs of this technology compared to that of the current identification system, and whether the firm could return this investment or could not. The study shows that RFID technology can improve most of the selected performance measures of the system at the shop floor level with an acceptable cost.

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LIST OF ACRONYMS/ABBREVIATIONS

AIDC	Automatic Identification and Data Capture
Auto-ID	Automated Identification
CAGR	Compound Annual Growth Rate
CV	Coefficient of Variation
CRM	Customer Relationship Management
CT	Cycle Time
DB	Database
EPC	Electronic Product Code
ERP	Enterprise Resource Planning
FMCG	Fast Moving Consumer Goods
HF	High Frequency
ID	Identification
IFF	Identify Friend or Foe
IT	Information Technology
JIT	Just-In-Time
LF	Low Frequency
MES	Manufacturing Execution System
MW	Microwave
OEM	Original Equipment Manufacturing

PBP	Payback Period
R/W	Read/Write
RF	Radio Frequency
RFID	Radio Frequency Identification
ROI	Return On Investment
ROM	Read-Only-Memory
TH	Throughput
UHF	Ultrahigh Frequency
WIP	Work-In-Process
WORM	Writes Once/Read Many
WSC	Winter Simulation Conference

Chapter One

1 INTRODUCTION

Automatic Identification applications can provide manufacturing firms' information systems with the location, identity, and the state of each product or item in the receiving, storage, production, warehouse, and shipping areas automatically. This allows management to monitor, analyze, and decide the upcoming actions required. Global competition, short product life cycle, and information technology (IT) advances have rapidly changed the ways firms operate their businesses. These changes have driven firms to cut costs, innovate their products/services, and redesign their business processes.

The competition to achieve high customer service levels at minimal cost has placed a strong emphasis on the control of information and material flows in today's manufacturing and retail environments. Most companies have made substantial investments in innovative systems enabling them to improve the level of automation of their supply chain processes [1].

Radio Frequency Identification (RFID) technology is one of the emerging technologies that are being used by a number of organizations such as manufacturers, retailers, logistics providers, hospitals, and libraries [2-4]. RFID has been identified as one of the ten greatest contributory technologies of the twenty-first century. Companies are lined up to use RFID and to employ experts in order to improve the efficiency of their operations to gain competitive advantage over time [5]. The swift development of information technology (IT), such as RFID, is one of the decisive factors to improve competitive advantage of enterprises [6]. Currently, efforts to increase the potential of RFID are actively underway in many countries across the world, both in the form of technology development, development of new service models and research on new applications [7].

Personalized products or tailored-made solutions are taking over large shares of the marketplace from mass produced goods and standardized solutions. Therefore, products tracking and identification becomes a very important issue in the manufacturing and logistics. RFID has emerged as part of a new form of inter-organizational system that aims to improve the efficiency of the tracking and identification processes [8].

This work presents the development of a simulation model for a furniture shop floor of a job shop manufacturing facility using the ExtendSim OR 7 simulation environment. The model of the shop floor has been developed with the purpose of containing all of the features that makes a real furniture manufacturing facility.

A number of experiments have been designed and tested using the developed simulation models to assess the impact of implementing the radio frequency identification technology on the performance of this manufacturing facility; which are output, throughput, cycle time, work in process, resources utilization, and average waiting time in queues.

In addition, a cost analysis is conducted to estimate the required investments accompanied with the RFID technology adoption, the operating costs of this technology compared to that of the current identification system, and whether the firm could return this investment or not.

1.1 AIM AND OBJECTIVES OF THE WORK

The management of the selected manufacturing facility is convinced that radio frequency identification technology is the most appropriate identification solution for the factory to be implemented; however, what's unclear are the implications of this implementation on the performance of the factory production system and on the operating costs of the identification process. In addition, it is required to estimate the capital investment needed to introduce such a technology in the selected manufacturing facility and how the factory could return this investment.

1.1.1 Aim of the Work

The aim of this work is to investigate the effectiveness of introducing radio frequency identification technology in tracking and identification processes for products flow inside the shop floor of a job shop manufacturing facility.

1.1.2 Objectives of the Work

Therefore, the objectives of this work include the following:

- To evaluate the impact of adopting RFID technology on different performance measures of a job shop manufacturing facility.
- To conduct cost analysis that estimates the required investments accompanied with the RFID technology adoption, the operating costs of this technology compared with that for the current identification system, and whether the factory could return this investment or could not.

1.2 THESIS OUTLINE

The thesis consists of six main chapters and four appendices.

- Chapter two covers a review of literature of the related work to this research.
- Chapter three covers a detailed description of the system under study which is a leading furniture manufacturing factory. Also, the problem formulation, objectives of the model, conceptual model, and data collection are presented.
- Chapter four details the development of the simulation model for the manufacturing shop floor; including input modelling, model translation, model verification, and model validation.
- Chapter five includes the details of the simulation setup, experimentations, results, and analysis. In addition, the cost analysis is detailed in this chapter.
- Chapter six covers the conclusions and recommendations for future work.

Finally, the thesis includes four appendices; these are:

- Publication Arising from this Work
- Products Selection Classification
- Data Collection
- ExtendSim Library Blocks

Chapter Two

2 LITERATURE REVIEW

A review of the previous work related to this research is presented in this chapter. First RFID technology is presented by an overview and background, with the RFID systems, applications, its impact on manufacturing systems, and the findings of the previous work. Then, the simulation is presented through defining simulation and modelling, describing discrete event simulation and the steps of the simulation study. Finally, explaining simulation applications in manufacturing systems and RFID assessment using simulation.

2.1 RADIO FREQUENCY IDENTIFICATION

RFID is one of the Automatic Identification and Data Capture (AIDC) systems which are used in order to identify and track an item by scanning it using radio waves through the use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum [9-11].

RFID is a wireless sensor technology based on the detection of electromagnetic signals [7]; where, it uses radio waves to provide real-time communication with objects at a distance, without contact or direct line of sight [12]. Data stored on an RFID tag can be retrieved from far places via an RFID device attached to an antenna [13, 14].

Electronic product codes are made by an organization set up to achieve world-wide adoption and standardization of EPCs technology, which is called EPCglobal. The main focus of EPCglobal group currently is to create both a world-wide standard for RFID and the use of the internet to share data via the EPCglobal network. Thus, RFID technology is based on the use of wireless tags and EPCs [15].

2.1.1 Overview and Background

Radio frequency identification (RFID) technology has been gaining a lot of attention in industry and academia in recent years [16-18]. A main reason for that is the fact that the cost of RFID tags has begun to decrease to a point where large scale applications in both the enterprise and consumer space are possible today or within the reach in the near future.

At the same time, the physical size and form of RFID tags is now very practical for many potential applications. International standards on the physical characteristics of RFID such as frequency and coding schemes; are well under way, including ISO 18,000 by the International Standards Organization and electronic product codes (EPC) by EPCglobal Inc.

Such technology development, together with the success of a few high-profile commercial applications; such as the Mobil Speedpass payment system in the USA, has prompted many businesses to investigate the potential of RFID in their own industries.

Moreover, a number of publications and websites dedicated to this subject have been launched, including the RFID Journal (www.RFIDjournal.com), RFID Gazette (www.RFIDgazette.org), RFID News (www.RFIDnews.org), among others [17, 18].

Historical Background

RFID is not a new technology, but it is being applied in new ways supported by other new technologies [10]. It was originally used by the British Royal Air Force to identify friend or foe aircraft (IFF) during the Second World War [19, 20].

Commercially, the RFID technology was applied from the 1980s onwards with increased acceptance by the mid-1990s for use with keyless entry and smart tickets, document information and smart stamps, badge readers, automatic highway and bridge toll collection, and offender tags, tracing livestock movements, tracking and control of nuclear inventories, tracking air freight and automobile manufacturing through assembly lines, railroad and military asset tracking, law enforcement, libraries, and healthcare [21]. Over the last few years, RFID has emerged as an important new technology to track the movement of goods in a supply chain [22].

In the last few years, RFID technology has become commercially viable for automatic identification of physical materials. As of 2006, a simple RFID tag costs in the range of US$0.20 – US$0.40 (as reported by the RFID Journal); however, ongoing efforts by vendors are aiming to reduce the cost to US$0.05 [18].

RFID Advantages and Disadvantages

There are a number of benefits for the RFID technology as well as some disadvantages that are accompanied with the implementation of this technology.

In this section, the advantages and disadvantages of the RFID technology that are reported in literature are listed as follows [16, 20, 23-28]:

Advantages of RFID technology

- Improves the visibility at multiple stages for the supply chain
- Leads to more efficient flow of goods throughout the distribution channels
- Creates benefits for the manufacturers, suppliers, distributors, retailers, and consumers
- Increases the efficiency
- Increases customer satisfaction
- Reduces the cost; therefore prices
- It has the ability to deliver precise and accurate data about tagged items
- Leads to less errors especially human errors
- Reduces theft
- Reduces the effort of collecting data.

Disadvantages of RFID technology

- It does not work properly in dead areas that have weak signals or interference
- Sometimes tag data is read poorly when the tag is rotated into an orientation that does not align well with the reader
- Some security issues such as trials from a company to scan the flow of some products of a competitor.
- Reading multiple tags at the same time, the reader might read a tag that does not exist which is called "Ghost tags" or a tag might not be read
- Tags could not be read well when placed on metal or liquid objects or when these objects are placed between the reader and the tag
- RFID relatively requires high cost to implement compared to other alternatives.
- Tags could be damaged by water, static discharge, or high power magnetic surges

RFID Benefits Over Traditional System (Bar code)

RFID technology has several benefits over the traditional Automatic Identification and Data Capture (AIDC) systems that are applied in many applications, and is based on the use of bar codes, such as [24, 28-30]:

- RFID tags do not require direct line of sight to be read, as in the case of bar codes.
- RFID tags can hold more data than bar codes and they can act as passive tracking devices by sending out signals automatically when they pass near a special scanner, while bar codes must be optically scanned, and contain only generic product information.
- RFID readers can process multiple items at one time.
- RFID tags can be read much faster than bar codes, citing tests indicating that RFID's scanning capability can result in goods moving through the supply chain ten times faster than they do when bar codes are used.
- RFID reader provides strong radio waves enough to respond regardless of location which results in higher inventory efficiency.
- RFID technology has a high cost to implement but it has very high return on investment.
- RFID vulnerability to damage is less than that for bar codes.
- RFID tag could be exposed to temperature extremes, gases, and chemicals which prevent the use of other data collection methods.
- RFID tag can stand in harsh environment.
- RFID technology has long read range.
- Portable reader and database could be attached to the RFID system.
- Supporting database provides full history for an item.
- RFID technology facilitates "Just-in-Time" delivery.
- RFID system reduces lead time.
- RFID system provides higher security.
- RFID technology improves speed of distribution.

2.1.2 RFID Systems

RFID System Components

An RFID system is comprised of different elements that are interlinked together for the purpose of identification of objects. Minimally, RFID system involves an asymmetric RF transmitter or tag and receiver or reader pair, where one is, on request, transmitting its identity to the other [31, 32]. The communication between the tag and the reader is by radio waves [22].

Researches define RFID system elements in several different ways. Such as a transponder, an interrogator and a middleware [12, 33]; reader/programmer, antenna and tag or transponder [34]; RFID tag, RFID reader and its antennas, and computer equipped with configured middleware program [3]; an antenna and transceiver (often combined into one reader) and a transponder (the tag) [35]; simply tags and readers [26, 36, 37]; and, an RFID system consists of hardware, such as RFID tags and readers, and software like RFID middleware [14].

A common classification of the RFID system components found in literature [4, 8, 9, 14, 22] is illustrated in Figure 2-1 and is described as follows:

- *Radio frequency tag:* which is a memory chip and an antenna that is applied to the desired item and it receives the radio signal via the antenna from the reader then responds by transmitting the data stored in the chip to the reader.
- *Reader:* which captures the returned data from the tag via its antenna and decodes it, then transfers the data to the middleware using a cable or a wireless connection.
- *Computing hardware and software:* converts the data sent by middleware into useful information for the user in order to monitor the desired objects.
- *Middleware:* is responsible for gathering, filtering, and aggregating statistics tag information from the reader and sending them to the backend database for further application usages.

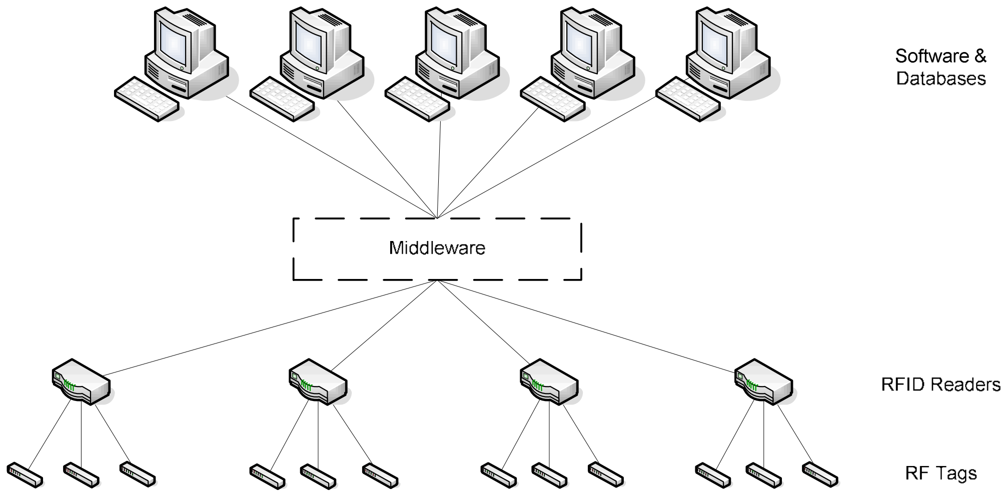


Figure 2-1: RFID system components [38].

Radio Frequency Tags

The tag is made of a chip and an antenna. It contains a unique code that provides the unique identification of each object. According to EPCglobal standards, an Electronic Product Code (EPC) can be stored in the chip of the tag. There are three formats of EPC; 64, 96 and 128 bits. An EPC of 96 bits can identify more than 268 million manufacturers and almost 69 billion articles for each manufacturer [12]. Once the EPC is retrieved from the tag, it can be associated with dynamic data such as where an item originated from or the date of its production or its current location [39].

The tag could be very small as the size of a grain of salt; this small radio can send information specifically about the object to a computer network. RFID tags are, in many cases, forever part of the product and designed to respond when they receive a signal. The tag can be attached to products, unit load devices... etc. [13, 28].

<u>Active and Passive RFID Tags</u>

There are two main types of tags: passive without a battery and active with a battery [6, 14, 31, 37]. An active tag is powered by its own battery, and it can transmit its ID and related information continuously. If desired, an active tag can be programmed to be turned off after a predetermined period of inactivity.

On the other hand, passive tags receive energy from the RFID reader and then transmit their ID to the reader where; the data transmission is triggered and powered by the interrogator, which implies that the transmission is offline [4, 36]. Key advantages of passive tags are that they are relatively small (around 50 mm square and less than 1 mm thick), inexpensive, and, due to having no battery, can operate for very long times [32].

Memory Storage Capabilities

An active tag operates with up to 1MB of memory, and has a greater reading range because of its internal power supply. A passive tag does not rely on an internal power source, therefore have shorter life, shorter reading ranges, and require a higher-powered reader than active tags [40].

RFID supports three types of memory: read-only memory (ROM), read/write (R/W), or writes once/read many (WORM). A ROM tag is similar to a traditional bar code where it comes equipped with a unique identifier after the purchase. R/W tags are more complicated than ROM tags and are more expensive because they can be written in increments and can be erased and reused. Unlike R/W tags, each field of WORM tags can be programmed just once. Information can be changed in the tag only once. All the three RFID types are able to embed context-awareness [41].

EPCglobal RFID Tags Classification

EPCglobal classifies tags into the following six classes [42]:

- *Class 0:* Read Only – programmed by the factory that manufactures the tag.
- *Class 1:* Write Once, Read Many (WORM) – programmed by the factory or the user.
- *Class 2:* Read Write – can be programmed several times based on requirements.
- *Class 3:* Read Write with on-board sensors – to record such parameters as Temperature, etc.
- *Class 4:* Read/Write with integrated transmitters – can communicate independent of readers.
- *Class 5:* Read/Write with integrated transmitters – all Class 4 capabilities along with the ability to communicate with and passive devices.

Reader

The reader has an antenna. It emits radio signals and receives in return responses from tags. The distance of the reading range depends on multiple factors; the frequency that is used, the orientation and polarization of the reader, the environment, etc. Finally the middleware bridges RFID hardware and applications [12].

The reader is mainly used to read tag information, send it to the application system for further processing by wireless technology, and write the data from the application system to the tag. The fixed reader is installed at the main gates for identification of people, goods, or vehicles. The mobile reader is to read or write data nearly everywhere. The RFID system combines the various information technologies, such as database management system, computer network, firewall, etc., to provide an automatic, secure, and convenient real-time control system [6].

RFID System Frequency

Reading ranges of the RFID system depends mainly on the type of frequency that the RFID system is running; where, the frequency of RFID tags can be classified into low frequency (LF), high frequency (HF), ultrahigh frequency (UHF), and microwave (MW) [6, 31].

<u>Low Frequency and High Frequency</u>

Low frequency (LF) (125–134 kHz) and high-frequency (HF) (13.56 MHz) RFID systems are short range systems based on inductive coupling between the reader and the tag antennas through a magnetic field. Some manufacturing firms have already adopted LF or HF RFID technology in their production lines. However, LF or HF RFID technology cannot support plant-wide logistics and inventory control due to its limited reading range.

<u>Ultrahigh Frequency and Microwave</u>

Alternatively, ultra-HF (UHF, 860–960 MHz) and microwave (MW, 2.4 GHz and 5.8 GHz) RFID systems are long-range systems that use electromagnetic waves propagating between the reader and tag antennas. Though UHF has a considerably longer reading distance than HF and LF technologies [14].

2.1.3 RFID Applications

It is becoming increasingly critical for companies to be knowledgeable about an item's instantaneous status, the processes it has gone through, and its history of movements across transactions. An item's instantaneous status includes its unique identity, precise location, physical status, and other key features. An effective and efficient information tracking and tracing system enables a decision maker or an automated system to rapidly intervene in targeted situations to reduce operational cost and increase productivity [37].

RFID has been used in disparate applications to track and trace objects of interest. RFID tags can be used to store and retrieve relevant item-level product information [37]. RFID technology can support real-time control of goods in the supply chain including raw material, work in process (WIP), and finished product. It can enhance the degree of automation, reduce the probability of error, and greatly improve the visibility of supply chain. Thus, the RFID system can be used in the receiving and dispatching of goods, stock management, theft prevention, product assembly, and personnel control [6]. RFID systems occupy an increasingly important role in asset-tracking and inventory management systems [26].

In 2004, it was reported that recent technological developments have opened the door to many new applications of RFID technology that will allow substantial growth over the next 10 years [11]. As more companies along the global supply chain adopt RFID, RFID tags embedded can be expected to proliferate in virtually every industrial product, ranging from computers to automobiles, in the near future [14].

The retail and manufacturing sectors are the key sectors investing in RFID technology either due to the benefits that may be gained from implementing the technology or to meet mandate requirements [43].

The broad applications of RFID technology in retail and manufacturing sectors are inventory management, tracking and tracing, security against theft/fraud, automated shipping/receiving, automated manufacturing, returns/recalls management, asset management, acquire business intelligence, and tracking shopping behaviour [43].

A study conducted for the grocery manufacturers of America states that retailers and manufacturers each lose \$2 million for every \$1 billion in sales due to inaccuracies in data. They predict that if inaccuracies in data were eliminated, it could save $10 billion per year [44].

More and more, RFID technology is expected to take the place of bar codes in the supply chain assuming that the detection equipment is reasonably reliable, RFID should provide more accurate information of the available inventories and its position throughout the chain [45], which makes the implementation of RFID technology in industrial manufacturing and retail supply chain management has seen strong growth in recent years [14].

2.1.4 RFID in Manufacturing

With the increasing competition in the global marketplace, manufacturing enterprises have to strive to become responsive to business changes which have further impacts upon production goals and performance at the shop-floor level. Many business problems manufacturing enterprises are facing now are caused by lack of timely, accurate, and consistent shop-floor manufacturing data [46].

RFID is becoming increasingly important and is used in production, manufacturing, and supply chain management. Many RFID applications are close-loop scenarios devised to solve particular problems in industry when alternative solutions are not feasible [47].

The advent of automated identification (Auto-ID) technology has enabled electronic labelling and wireless identification of objects, which facilitates real-time product visibility and accurate tracking at all levels of the product life cycle. From supply chain level business processes to shop floor level manufacturing execution, this technology presents many opportunities for process improvement and re-engineering [48, 49].

Information gathered by RFID is reliable, precise and dynamic. The technology allows provision for optimal management of products that have come to the end of their work lifetime. An authorized user can access all necessary information about product/part in every phase of the product life cycle, without the need for special knowledge [50].

Many OEM (original equipment manufacturing) companies are seeking technological solutions to overcome shortcomings of job shops. One of the experiments that has recently been conducted is with the emerging RFID (radio frequency identification) or auto-ID (automatic identification) technology. A common expectation is that WIP inventories are traced and tracked throughout the manufacturing processes on a real-time basis. The real-time traceability and visibility of WIP materials and information facilitate the identification of the shop-floor bottleneck and improve shop-floor performance. Such up-to-date shop-floor information is then fed back to ERP (enterprise resource planning) and MES (manufacturing execution system) for better planning, scheduling, and control decisions [51].

The improvement in operational efficiency and visibility came up to be more important for manufacturing than for retail [43]. Many manufacturing companies adapt new information systems to monitor manufacturing activities. These systems can take immediate action to resolve any emergent events that could disrupt production or cause customer dissatisfaction [14, 41].

The dropping cost of RFID technology (tags and readers) have motivated worldwide sporadic piloting efforts across different product sectors ranging from garment, electronic, mechanical, aerospace and automotive products [51, 52].

The Ford Motor Company has successfully implemented RFID to improve products quality on the automated assembly production line at its facility in Cuautitlan, Mexico. In USA, Ford produces cars and trucks using the just-in-time (JIT) manufacturing model. Johnson [18] reports that: "As a vehicle passes through the different stages of production, different parts of the 22- to 23-digit serial number are referenced, indicating what needs to be done at each station".

This is one of the biggest benefits of RFID. Where the former manual coding system required each identification sheet be manually updated at every turn in the production line, RFID allows updates to be written to the tag, so that it is constantly being updated without risk of operator error [34].

Furthermore, RFID technology applications in manufacturing were studied by several researches in order to explore the effectiveness of such a technology in improving the tracking and identification of items in different manufacturing applications such as introducing RFID technology in a shop floor or managing dynamic process flows; where the findings of around 8 papers studied the RFID technology in manufacturing applications are shown as follows:

Tu et al, report the design and development of a framework to use UHF RFID technology in controlling and tracking items on a shop floor in a bicycle firm with mass customization manufacturing instead of bar code labels was reported [14]. Zhang et al, propose to use agent-based workflow management as a mechanism to facilitate interactions among RFID-enabled reconfigurable manufacturing resources using a shop-floor gateway which integrates the concept of agents into workflow management and RFID devices to realise real-time reconfigurable wireless manufacturing; where RFID technologies are used to achieve real-time manufacturing data collection, and enable the dual-way connectivity and interoperability between high-level (i.e. shop-floor level) and work-cell level, and create real-time visibility and traceability throughout the entire enterprise [46]. Chen and Tu propose a multi-agent system framework called agent-based manufacturing control and coordination system, a agent-based framework using ontology, and RFID technology to monitor and control dynamic production flows and also to improve the traceability and visibility of mass customization manufacturing processes for a bicycle firm [41].

Brusey and McFarlane focus on the issue of correctly identifying, tracking, and dealing with aggregated objects in customized production with the use of RFID [32]. Stankovski et al, present a new way for identification of products/parts and their tracking during the whole life cycle, from the manufacture and assembly phase to the disassembly phase [50]. Huang et al, propose a wireless manufacturing framework where RFID devices are deployed to workstations, critical tools, key components, and containers of WIP (work in progress) materials to turn them into so-called smart objects. Smart objects are tracked and traced and shop floor disturbances are detected and fed back to decision makers on a real-time basis [52].

Huang et al, present an affordable approach to shop-floor performance improvement by using wireless manufacturing which relies substantially on wireless devices such as RFID technology or auto-identification sensors and wireless information networks for the collection and synchronization of the real-time field data from manufacturing workshops for better management of WIP (work in progress) inventories in manufacturing job shops with typical functional layouts; where better operational productivity and quality are achieved through fundamentally better flows of WIP materials and information with real-time traceability and visibility. This study replace the paper-based manual data capturing system by an automatic data collection system with real-time communication and interaction with various decision support systems [51].

Wang et al, provide an understanding for the determinants of RFID adoption in the manufacturing industry; where they propose nine variables to help RFID technology adoption in the manufacturing industry which are relative advantage, compatibility, complexity, top management support, firm size, technology competence, information intensity, competitive pressure, and trading partner pressure [53].

The next section shows the description of the job shop production system and some of its characteristics.

Job Shop Production System

Jobbing production is a term for production carried out solely against non-recurring, or potentially non-recurring, customer order. It is characterized by low volume (often one-off) production of a wide range of products with demand for any one single product being difficult to forecast. A typical example of this class of manufacture is the production of capital equipment such as customer specific machine tools [54].

A realistic job shop has to process a number of parts with different processing sequences and different processing times for their respective processes. In many job shops, each process can be performed by one or more machines (labour) capable of performing the process, referred to as parallel machines (labour). This gives rise to routing flexibility of the system [55].

The job shop consists of a set of machines (work stations) and jobs of various types arrive continuously over time in a random manner. Each job requires a specific set of operations that need to be performed in a specified sequence (routing) on the machines and involves certain amount of processing time. The job shop becomes a queuing system: a job leaves one machine and proceeds on its route to another machine for the next operation, only to find other jobs already waiting for the machine to complete its current task, so that a queue of jobs in front of that machine is formed [56].

One of the most serious concerns is the management of work-in-progress (WIP) inventories and tracing and tracking of WIP materials and information [51, 57].

This type of manufacturing systems has high product variety, high equipment flexibility, small runs, and low volume. It is also called job shop production system. In some cases, a job shop manufacturing system depends mainly on human resources instead of machines.

2.1.5 RFID Facts and Figures

Strong competition forces companies to ensure that customer demands are satisfied as well as possible (dependability) and at the lowest possible cost. Thus, companies try to find new solutions to improve the quality of their supply chains and to reduce their operational costs. Recent advances in microelectronics make RFID technologies more efficient and cheaper, enabling more and more applications in various types of supply chains [12]. As costs in the semiconductor industry decrease and data communication standards improve, the use of RFID technology has increased [35]. RFID has emerged as part of a new form of inter-organizational system that aims to improve the efficiency of the processes in the supply chain [8].

RFID technology provides a good alternative to automatically reading and writing product information. In addition to recording the identity of an object, RFID technology also documents its current status, recent past, and immediate future. A product with an RFID tag can be viewed as an intelligent product [14].

RFID opens up new opportunities in the areas of logistics, production and service [8, 25]. The development of information technology (IT), such as the RFID, is one of the decisive factors to improve competitive advantage of enterprises. RFID was classified as one of the ten major innovation technologies in 2004 and one of the ten major IT technologies in 2005 [6].

RFID is emerging as the hottest information tracing technology in supply chain management [37, 58] with its ability to reveal product information at an item-level in a way that is fully automatic, instantaneous, and touch-less [37], which encourages many commercial and industrial enterprises are seriously investigating the feasibility of applying RFID in their businesses [18]. Furthermore, RFID has been identified as one of the ten greatest contributory technologies of the twenty-first century. Companies lined up to use RFID and employ experts to improve the efficiency of their operations to gain competitive advantages over time [5].

Labour cost could be reduced up to 40%, depending on the number of handling points and the degree of technology deployment, due to RFID capabilities in automating most of the operations of a distribution centre [23].

It was reported in 2008 and 2010 that the cumulative number of RFID tags sold over the last 60 years is 3.752 billion, with 27% sold in 2006 and 19% in 2005 [8, 35]. According to two marketing reports, the revenues of the RFID industry will surge from $188 million in 1996 to $3.5 billion in 2004 [11]. The global RFID market was valued at $5 – $7 billion in 2008 and 2009 [2, 5, 7, 53] and will grow to above $26 billion in 2017 or 2018 [7, 35, 53], as it will grow at a moderate compound annual growth rate (CAGR) of around 20.7% during 2008–2016 [2]. In addition, investments in RFID infrastructure that will exceed $1.1 billion by 2007 [11].

The revenue for RFID technology in 2004 was predicted to grow steadily over the next 6 years, and the cost of RFID would decline sharply over next 4 years. The RFID system could support customer relationship management (CRM) and increase customer satisfaction and loyalty [6].

The primary consequence of RFID is, of course, better inventory accuracy. This has financial implications in several areas; including reduced shortage costs, holding costs, handling costs for missing items, and the cost for not-detecting missing or unsalable items in the incoming delivery. In addition, labour cost may be reduced as the requirements for physical count and investigating the causes of inaccuracy are reduced [59].

The manufacturer–retailer supply chain has been widely identified as one key area for business applications of RFID technology. RFID initiatives by such influential organizations as Wal-Mart Stores, Target Stores, Tesco, Metro Stores, and the US Department of Defence in non-weaponry supplies have accelerated the pace of adopting the technology in industry. Many return-on-investment studies have been conducted. Most of them focused on the direct benefits provided by RFID, which typically include reduced labour costs, reduced losses due to inventory shrinkage, and other directly observable benefits [17].

2.2 SIMULATION

This section provides the definition of simulation, the structural components of discrete event simulation, and the steps of a simulation study.

2.2.1 Modelling and Simulation

Modelling

Modelling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features, but it should not be so complex that it is impossible to understand and experiment with it.

An important issue in modelling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output.

Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account).

Simulation

Simulation can be defined as the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies for the operation of the system. The difference, and the power, of simulation is the ability to mimic the dynamics of a real system. Many models, including high-powered optimization models, cannot take into account the dynamics of a real system. It is the ability to mimic the dynamics of the real system that gives simulation its structure, its function, and its unique way to analyze results [60].

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behaviour of the actual system or its subsystem can be inferred [61].

In addition, simulations are often used to analyze systems that are too complicated to tackle via analytic methods [62]; where, it can be used as a powerful tool for the evaluation and analysis of new system designs, modifications to existing systems and proposed changes to control systems and operating rules.

Simulation Model

A simulation is the imitation of the operation of a real-world process or a system over time. The behaviour of a system as it evolves over time is studied by developing a simulation model. Once developed and validated, a simulation model can be used to investigate a wide variety of "what if" questions about the real-world system. Conducting a valid simulation is both an art and a science [63].

Potential changes to the system can first be simulated, in order to predict their impact on system performance. Simulation can also be used to study systems in the design stage, before such systems are built. Thus, simulation modelling can be used both as an analysis tool for predicting the effect of changes to existing systems and as a design tool to predict the performance of new systems under varying sets of circumstances [64].

2.2.2 Discrete Event Simulation

Discrete event simulation is the modelling of systems in which state variables change only at a discrete set of points in time [64]. The structural components of discrete event simulation include; entities and attributes, activities and events, resources, a random number generator, a calendar, statistics collectors [60], and system variables [65].

Entities and Attributes

The best way to understand the function of an entity is understand that entities cause changes in the state of the simulation. Without entities, nothing would happen in a simulation. As a matter of fact, one stopping condition for a simulation model is the condition where there are no active entities in the system.

Entities have attributes. Attributes are characteristics of a given entity that are unique to that entity. Attributes are critical to the understanding of the performance and function of entities in the simulation.

Activities and Events

Activities are processes and logic in the simulation. Events are conditions that occur at a point in time which cause a change in the state of the system. An entity interacts with activities. Entities interacting with activities create events.

There are three major types of activities in a simulation: delays, queues and logic. The delay activity is when the entity is delayed for a definite period of time. Queues are places in the simulation were entities wait for an unspecified period of time. Logic activities simply allow the entity to effect the state of the system through the manipulation of state variables or decision logic.

Resources

In a simulation, resources represent anything that has a restricted (or constrained) capacity. Common examples of resources include workers, machines, and transporters.

Random Number Generator

Every simulation package has a random number generator. The random number generator is a software routine that generates a random number between 0 and 1 that is used in sampling random distributions. Everything that is random in the simulation uses the random number generator as an input to determine values.

It should be noted that random number generators are not completely random and that the user can control how these number are generated, specifically, a user can generate the exact same stream of random numbers by setting the random seed value; hence, random number generator is technically called pseudo-random number generators.

The Calendar

The calendar for the simulation is a list of events that are scheduled to occur in the future. In every simulation, there is only one calendar of future events and it is ordered by the earliest scheduled time first.

Statistics Collector

Statistics collectors are a part of the simulation that collects statistics on certain states (such as the state of a resource), or certain performance statistics based on attributes of an entity.

System Variables

Designing a new system or improving an existing system requires more than simply identifying the elements and performance goals of the system. It requires an understanding of how system elements affect each other and overall performance objectives.

To comprehend these relationships, there are three types of system variables to be understood [65]:

Decision Variables

Decision variables (also called input factors) are sometimes referred to as the independent variables in an experiment. Changing the values of a system's independent variables affects the behaviour of the system. Independent variables may be either controllable or uncontrollable depending on whether the experimenter is able to manipulate them.

Controllable variables are the variables of interest that can be controlled to improve the performance measures. Examples of controllable variables in this work is the availability of resources, uncontrollable variables may include the processing times of operations.

Response Variables

Response variables (sometimes called performance or output variables) measure the performance of the system in response to particular decision variable settings.

In an experiment, the response variable is the dependent variable, which depends on the particular value settings of the independent variable. The experimenter doesn't manipulate dependent variables, only independent or decision variables. Obviously, the goal in system planning is to find the right values or settings of the decision variables that give the desired response values.

A response variable might be the number of units processed for a given period, the average utilization of a resource, or any of the other system performance metrics.

State Variables

State variables indicate the status of the system at any specific point in time. Examples of the state variables are the current number of units waiting to be processed or the current status (busy, idle, down) of a particular resource. State variables are dependent variables like response variables in that they depend on the setting of the independent variables. State variables are often ignored in experiments since they are not directly controlled like decision variables and are not of as much interest as the summary behaviour reported by response variables.

2.2.3 Steps of a Simulation Study

The steps of a simulation study may be summarized as in Figure 2-2, and discussed below [64]. It must be noted that although the figure shows the steps to be carried out independently, most of the time several steps are performed concurrently (e.g. model conceptualization and data collection, verification and validation…).

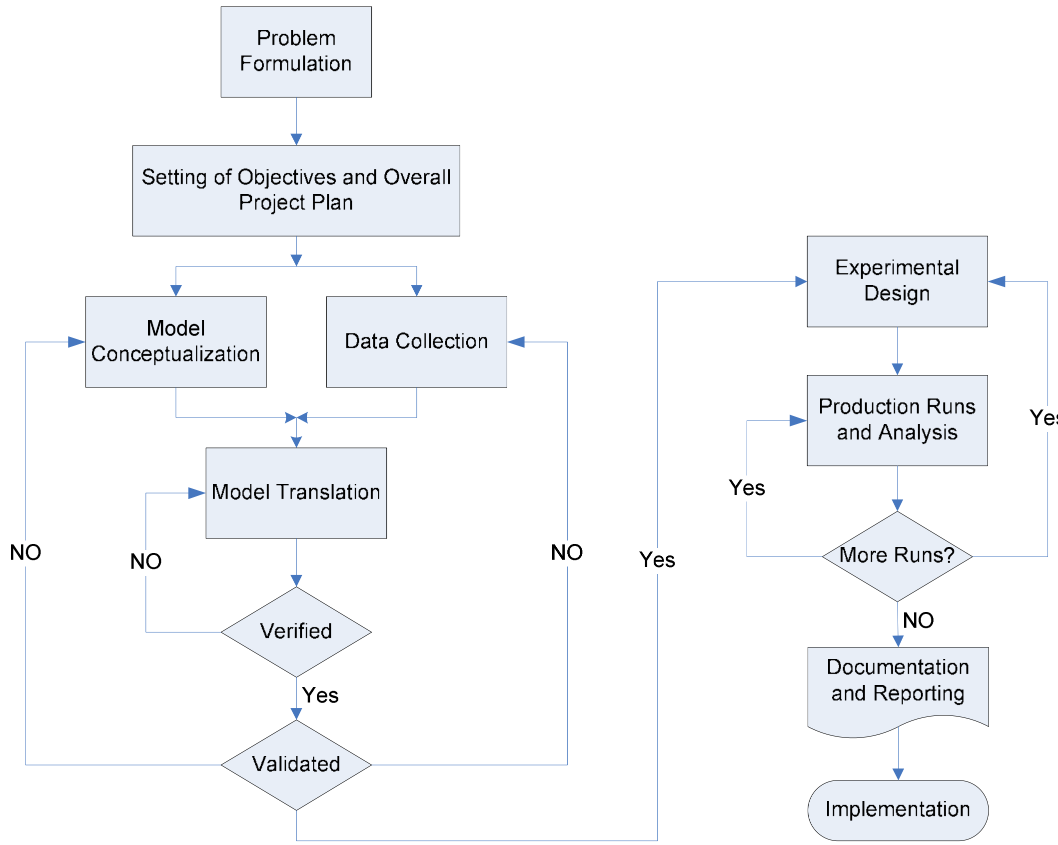


Figure 2-2: Steps in a simulation study [79].

Problem Formulation

Every simulation study begins with a statement of the problem [54] by the decision maker [66]. Furthermore, there are occasions where the problem must be reformulated as the study progresses. In addition, a set of assumptions upon which the problem is based are taken. Finally, all possible alternative designs for the real system must be known to the system-analyst [54].

Setting of Objectives and Overall Project Plan

The objectives indicate the questions that are to be answered by the simulation study [64]. The project plan should indicate a statement of the various scenarios that will be investigated; in addition to the performance measures for evaluating and comparing different systems configurations [54].

Model Conceptualization

The conceptual model, a series of mathematical (formulas, equations…etc.) and logical relationships concerning the components and the structure of the system (block diagrams, flowcharts…etc.). It is recommended that modelling begin simply and that the model grow until a model of appropriate complexity has been developed. Then, special features can be added (animation, user interface…etc.) and final refinement of the model is done [54].

Data Collection

Generally the word data is taken to mean quantitative data, or numbers. Certainly numeric data are very important in simulation modelling and in some cases large quantities of such data are required. The concentration on quantitative data, however, ignores the importance of qualitative data as well. In general terms these are non numeric facts and beliefs about a system that are expressed in pictures and words [67].

The first step in gathering data is to determine the data required for building the model; these can be categorized as structural data, operational data, and numerical data [65].

- Structural Data: Structural data involve all of the objectives in the system to be modelled. This includes such elements as entities (products), resources (labour), and locations (departments). Structural information basically describes the layout or configuration of the system as well as identifies the entities that are processed.
- Operational Data: Operational data explain how the system operates. Operational data consist of all the logical or behavioural information about the system such as routings and resource allocation. If the process is structured and well controlled, operational information is easy to define.
- Numerical Data: Numerical data provide quantitative information about the system. Examples of numerical data include capacities, arrival rates, and activity times. Some numerical values are easily determined, such as resource capacities and working hours. Other values are more difficult to assess, such as time between failures or routing probabilities.

Usually the simulation analyst constructs the model while the data collection is progressing. Also, the required data format must be accurately defined, to facilitate introducing the data to the developed model. Furthermore, the probability distributions for any random variables must be defined at this stage. Finally, data on the performance of the real system, which can be used for validation purposes, must be collected.

Model Translation

Most real world problems result in models that require a great deal of information storage and computation, so the model must be entered into a computer recognizable format [64]. In this step the conceptual model constructed in step 3 is coded into a computer-recognizable form, an operational computer simulation model [54].

Verified?

Verification pertains to the computer program prepared for the simulation model [64]. Verification concerns the operational model, which makes sure that the model is operating as intended by the system-analyst, and ensuring that the computer programming and implementation of the conceptual model are correct [54, 68].

It is highly advisable that verification takes place as a continuing process and not to wait until the entire model is completed to begin the verification process [54].

Validated?

Validation is the determination that the conceptual model is an accurate representation of the real system, and that the model can be substituted for the real system for the purposes of experimentations. An ideal way to validate the model is to compare its output to that of the real system; where, a simulation model (usually referred to as the base model) of the existing system is developed and its output data are compared to those from the existing system itself [54, 66].

Experimental Design

Many of the classic experimental designs can be used in simulation studies and the goal will influence the way the study should be conducted [69]. Carefully planned simulation studies can yield valuable information without an undue amount of computational effort. A wide variety of approaches, methods, and analysis techniques, known collectively as experimental design, have the principal goals of estimating how changes in input factors affect the results, or responses, of the experiment [70].

For each scenario that is to be simulated, decisions need to be made concerning the simulation parameters, which include: length of the simulation run, the number of replications, and the warm-up period [54, 64, 66]. These factors have impact on the confidence in results obtained from a model as discussed in the next section.

Production Runs and Analysis

Production runs, and their subsequent analysis, are used to estimate measures of performance for the scenarios that are being simulated [54, 64].

As the input processes driving a simulation are usually random variables (e.g., inter-arrival times, service times, and breakdown times). The output from the simulation must also be regarded as random. Thus, runs of the simulation only yield estimates of measures of system performance (e.g., the mean customer waiting time). These estimators are themselves random variables, and are therefore subject to sampling error. As a result, these estimates could, in a particular simulation run, differ greatly from the corresponding true characteristics for the model. The net effect is, of course, that there could be a significant probability of making erroneous inferences about the system under study [71, 72].

The following are three major pitfalls in output data analysis have been pointed out [71]:

- Analyzing simulation output data from one run, which might result in a gross underestimation of variances and standard deviations.
- Failure to have a warm up period for steady state analysis.
- Failure to determine the statistical precision of simulation output statistics by the use of a confidence interval.

More Runs?

Based on the analysis of runs that have been completed, the simulation analyst determines if additional runs are needed and if any additional scenarios need to be simulated [54, 64, 66].

Additional runs (replications) may be required if the simulation output exhibits high variability. Output variability can be reduced by using variance reduction techniques by exploiting the ability to control the random number generator driving the simulation, and re-use random numbers to induce helpful correlations that reduce noise in the output (pseudo-random number generator) [73], or even by changing the number of replications required or the run length.

Documentation and Reporting

Documentation is necessary for numerous reasons. If the simulation model is going to be used again by the same or different analysts, it may be necessary to understand how the simulation model operates. This will simulate confidence in the simulation model so that the model users and policy makers can make decisions based on the analysis.

In addition, if the model is to be modified, this can be greatly facilitated by adequate documentation. The result of all the analysis should be reported clearly and concisely. This will enable the model user to review the final formulation, the alternatives that were addressed, the criterion by which the alternative systems were compared, the results of the experiments, and the analyst recommendations, if any [64].

Implementation

Implementation of the model is the last stage in a simulation project. A simulation study whose results are never implemented is most likely a failure. However, the results of a simulation study can be understanding of a system, performance comparison of two systems, or the number of some entity required for efficient system performance. Thus, a simulation study is successful when the results of the study, whatever that may be, is used by the client [54].

2.3 SIMULATION APPLICATIONS

The Winter Simulation Conference (WSC) [74] is an excellent way to learn more about the latest in simulation applications and theory. The applications of simulation are vast [64]; where, applications like construction engineering and project management, military applications, transportation modes and traffic, business process simulation, healthcare and logistics, supply chain, and distribution applications are among the popular application of simulation. In addition to manufacturing applications, which are more related to this work and are discussed in more detail in the next section.

2.3.1 Simulation in Manufacturing

One of the largest application areas for simulation modelling is that of manufacturing systems, with the first uses dating back to at least the early 1960's.

There, a number of specific issues in manufacturing that simulation can be used to address. The following are some of the issues that are closely related to job shop manufacturing and that can be addressed by simulation [75, 76]:

- Number and type of machines for a particular objective
- Number, type, and physical arrangement of transporters, conveyors, and other support equipment (e.g., pallets and fixtures)
- Location and size of inventory buffers
- Evaluation of a change in product volume or mix
- Evaluation of the effect of a new piece of equipment on an existing manufacturing system
- Evaluation of capital investments
- Labour-requirements planning
- Throughput analysis
- Time-in-system analysis
- Bottleneck analysis
- Production scheduling
- Inventory policies
- Quality-control policies
- Times parts spend in queues

- Queue sizes
- Timeliness of deliveries
- Utilization of equipment or personnel.

2.3.2 RFID Using Simulation

Simulation was used as a tool in various researches in order to assess and discover some issues regarding the RFID technology. Around 24 papers were reviewed that made simulation studies and are related to the RFID technology. Some of these researches are shown as follows:

Simulation Technique Used

Simulation studies are used to monitor the dynamic performance of a system or to optimize this performance in which simulation study has several techniques, where some of the reviewed researches used discrete event simulation in different applications such as manufacturing-retail supply chain [18] and logistics of FMCG (fast moving consumer goods) warehouse [77]. Monte-Carlo simulation is used in RFID valuation in ordnance inventory [59].

Application Area

RFID technology was applied in various areas, accompanied with the simulation, such as supply chain [3, 37, 58, 78-82], manufacturer-retailer supply chain [18, 49], inventory management in supply chain [12, 17, 59], retail supply chain [83], retail pricing [84], logistics and reverse logistics [77, 85-88], inventory management of time-sensitive materials on shop floor [48], RFID network [89], and hospitals supply chain and asset management [90, 91].

Performance Measures

Most of these papers are trying to measure the benefits of the RFID technology whatever the application area. Some papers conducted a benefit cost analysis, operating costs, or return on investments (ROI) [12, 18, 59, 80, 85]. Several performance measures were calculated such as inventory performance [17, 49, 81, 83], supply chain performance [78], item-level visibility [37], and logistics operations efficiency [87].

2.4 SUMMARY

- Job shop production system has high work in process levels, high product variety, high equipment flexibility, small runs, and low volume. Some job shops depends mainly on labour which usually has a lot of errors, high variability in processing times, and considered as complicated and unorganized systems.
- Make to order production objective leads to random jobs of various product types; where each type requires specific set of operations that need to be performed in a specific sequence.
- According to the literature review conducted, it is clear that the RFID technology is a hot topic and booming technology in the coming years; since 71% of the literature is done in the last six years; where 50% in the last three years and it is expected that the global RFID market value will grow from $5 - $7 billion in 2008 and 2009 to above $26 billion in 2017 or 2018.
- RFID technology has great advantages and benefits over other automatic identification and data capture technologies in the tracking and identification of objects. It has a lot of applications in several areas and still opening up new opportunities in different applications.
- RFID system has the flexibility to be structured according to the application; such as tag type, tag material, tag storage memory, tag size, read range, reader type, and software type.
- RFID technology has a significant influence on tracking and identification particularly in retail and manufacturing which leads to several implementations by leading companies from a variety of industries.
- Simulation technique has the ability to mimic the dynamics of a real system. It is often used to analyze systems that are too complicated to tackle via analytic methods.
- A valid simulation model can answer “what if” questions about the real system which makes the simulation a very powerful tool in manufacturing applications.
- Several researches use simulation to evaluate the benefits of the RFID technology or measure some indicators after implementation of RFID system.

Chapter Three

3 THE SYSTEM UNDER STUDY

The company under study has been a leading furniture manufacturing business of Egypt for over 60 years. French style furniture is their main line; nevertheless, other custom made furniture is also highly demanded by customers from different parts of the world as well as locally. In addition, the company is well experienced in furnishing all kinds of hotel projects.

3.1 LAYOUT AND OPERATIONS SEQUENCE

3.1.1 Facility Layout

Figure 3-1 represents the layout of the plant. The plant consists of one ground floor with 7 main departments and at the right there is a second floor built for management offices of Production Planning and Control, Research and Development, Quality Control, Accounting, and IT offices.

The main departments in which products passes through during processing are:

1. Machinery department.
2. Carpentry department.
3. Carving department.
4. Veneer department.
5. Sanding department.
6. Painting department (A/B).
7. Brass department.

Raw materials used are received at the receiving area in front of the two storage areas (one for wood and the second is for the other raw materials). Products after being processed are stored at the warehouse (finished goods storage) from which they are being shipped. Outside the plant floor there are workshops for brass, marble storage, veneer storage and auxiliary services (Mosque and Toilets).

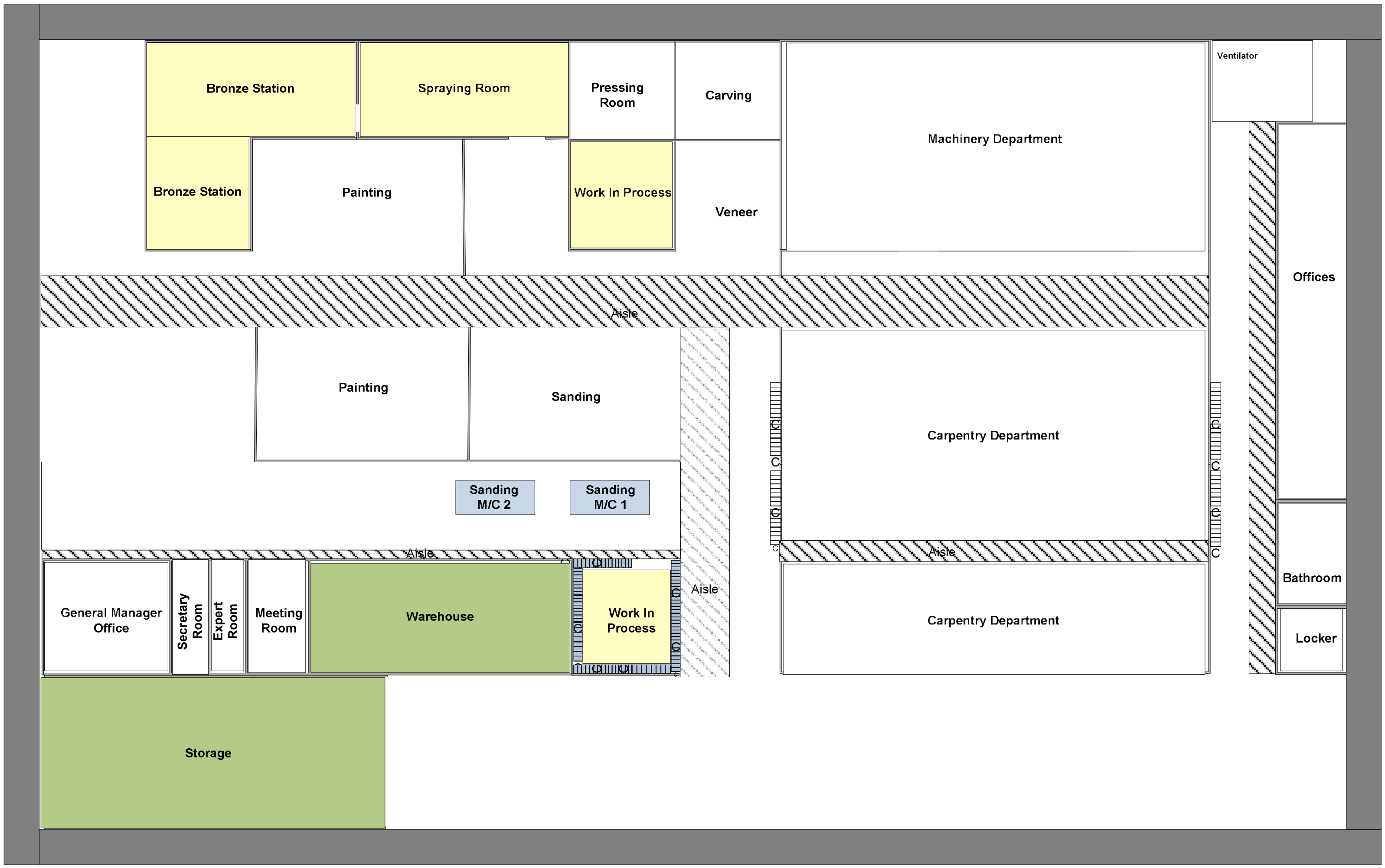


Figure 3-1: Facility layout.

3.1.2 Sequence of Operations

The flow of items among departments varies according to the product itself. Each product has its own features and characteristics that determine the way in which it will be processed. Mostly products start with machining of the wood raw and end with finishing operations. Finishing starts with veneer or sanding then painting, brass, and other outsourced operations. The brass department is considered as a supporting department, which supplies the plant with its need for brass.

3.2 FACTORY PRODUCTS

Products at the company are classified with two main characteristics, which are the style and category. Table 3-1 shows the factory products and their quantities.

Table 3-1: Product variety.

	Style	Louis XIV	Louis XV	Transition	Louis XVI	Rococo	Regance	Empire	Modern	English
Category	ID	1	2	3	4	5	6	7	8	9
Coffee table	10	5	64	2	46	1	9	43	16	9
Vetrine	13	0	2	0	2	0	0	1	2	0
Secretary	14	1	6	0	3	0	0	2	0	5
Comodino	15	1	13	0	17	0	1	6	12	3
Dressing table	16	2	5	0	10	0	1	6	12	3
Bed	17	2	13	0	33	0	2	5	9	6
Console	19	1	18	0	27	0	2	13	2	1
Bahu	20	1	1	1	14	1	1	4	1	2
Commode	21	1	43	1	16	0	0	2	6	3
Desk	22	0	11	0	7	0	0	11	4	1
Dining Table	23	1	5	0	17	1	11	19	4	4
Buffet	25	0	4	0	9	0	2	7	5	4
Delicior	26	0	2	0	5	0	4	3	0	1
Frame	27	2	15	0	28	2	8	9	14	2
Chair	29	1	30	0	28	0	0	17	8	12
Sofa	30	2	22	0	11	0	1	5	6	1
Fauteuil	31	5	31	0	26	1	1	19	8	10
Book Shelf	34	0	4	0	7	0	1	8	6	0
Bahu Vetrine	38	0	5	0	9	0	2	2	0	2
Lamps	39	0	2	0	1	0	0	0	0	0
Paravan	40	0	3	0	3	1	0	0	1	0
Corner Table	42	0	0	0	2	0	0	1	1	0
Chiffonnier	43	0	3	2	5	0	1	2	2	0
Bag Hanger	44	0	0	0	0	0	0	2	1	2
Misc.	47	0	2	0	0	1	1	0	0	13
TV cabinet	49	0	0	0	0	0	2	12	6	5
Side Table	52	0	0	0	1	0	2	0	1	0
Wardrobe	60	0	2	0	1	0	0	0	1	1

The table also shows the number of different products that can be made for the given style and category with different shapes which are 1,142 different products.

The style characteristic determines whether it is a French style, English, Modern, etc. The category characteristic determines the type of the product, whether it is a side table, a buffet, a dining table, etc. The factory has 28 categories that could be produced and 9 styles, but each category could have several shapes in the same style.

3.3 PRODUCTS SELECTION

Due to the large number of products that the factory can produce, as shown in the product mix, an analysis is made to determine which products should be selected to be included in this work.

The analysis is made on actual sales of 2009, which showed that the factory produced 22 categories only in that year. These 22 categories were produced in different styles and shapes leading to a total production of 251 different products, as shown in Table 3-2, which shows the quantity and monetary value of each category (sorted alphabetically).

Table 3-2: Actual sales of 2009 for each category.

Cat.	Row Labels	Qty	Monetary Value (LE)	Cat.	Row Labels	Qty	Monetary Value (LE)
1	ARM CHAIR	64	102,888	**12**	DESK	7	25,126
2	BAHU	5	16,696	**13**	DINING TABLE	40	346,946
3	BAHU-VTRN	7	64,320	**14**	MIRROR	32	93,709
4	BED	13	55,520	**15**	PLCRDS	16	82,625
5	BOOKCASE	4	23,545	**16**	SCREEN	1	7,494
6	BUFFET	46	468,673	**17**	SECRETARY	2	10,075
7	CHAIR	321	299,330	**18**	SOFA	17	78,869
8	CHIFFONIERE	4	10,330	**19**	SPL DÉCOR	1	1,290
9	COMMODE	32	108,479	**20**	TABLE	130	226,584
10	COMMODINO	25	24,945	**21**	VANITY	7	19,527
11	CONSOLE	18	53,985	**22**	VETRINE	5	21,996

The categories have been sorted based on both the quantity and monetary value. Figure 3-2 shows the result of sorting categories based on the quantity sold; where, the percentages shown in the figure represent the quantity sold of each category. It is observed that the chair is the highest one in terms of quantity sold followed by the table.

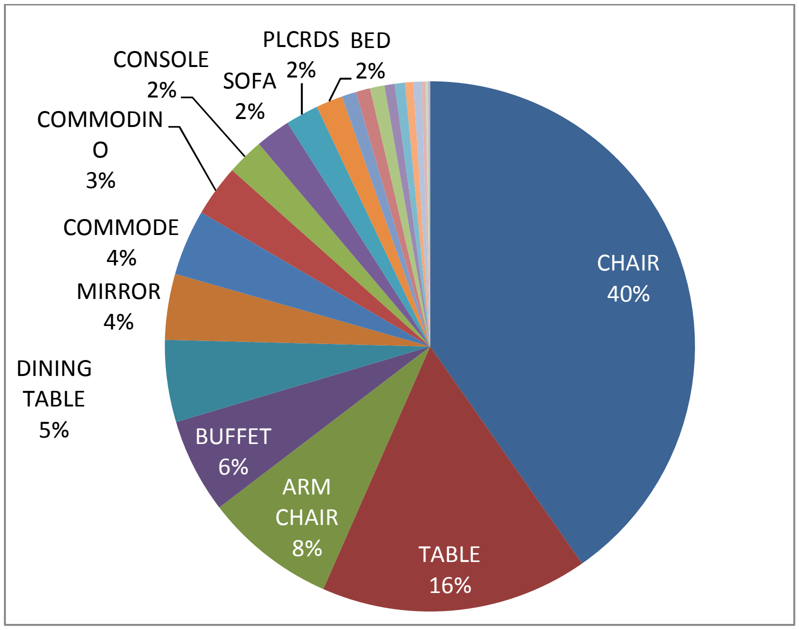


Figure 3-2: Classification of categories in terms of quantities sold.

On the other hand, Figure 3-3 shows the result of sorting the categories based on the monetary value; where, the percentages of each category shown in figure are with respect to the monetary value. It is observed that the buffet category is the highest one in terms of monetary value then the dining table category and the chair category comes third.

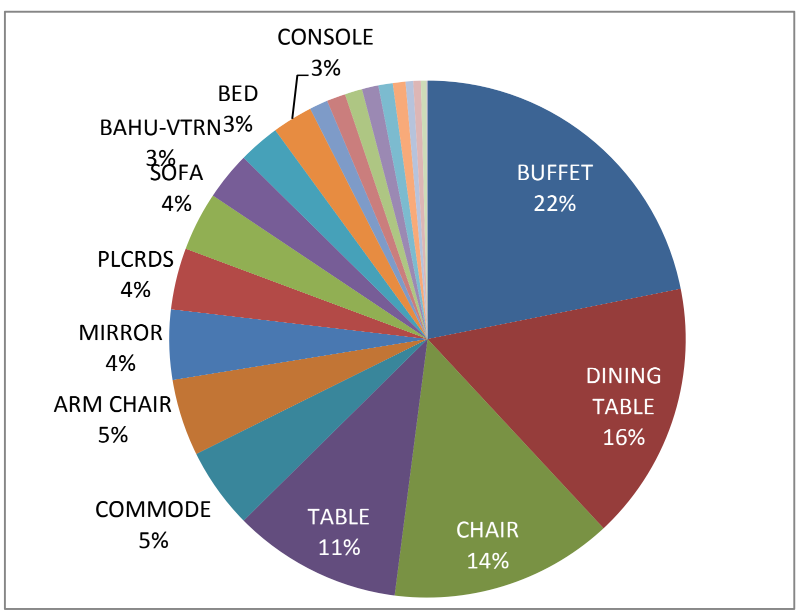


Figure 3-3: Classification of categories in terms of monetary value.

The second classification is better as the quantity alone does not reflect the real value of the category due to the variation in selling price. Therefore, a classification of the actual sold products in the year 2009 was made according to the monetary value of each single product not according to the monetary value of each category.

As mentioned earlier, the total number of products sold in this year was 251 different products. Thus, the same classification method used for categories' selection is adopted for selection of products.

Table 3-3 represents a sample of the classification, while the whole classification is illustrated in Appendix B. It is clear from that table that the top 9 products, in terms of monetary value, in this classification belong to the first 3 categories; namely, buffet, dining table, and chair categories.

Table 3-3: Sample of the classification of sold products monetary value.

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cumulative %	Cumulative #
1	25	BUFFET	721	11	13,475	148,228	6.92%	6.92%	0.4%
2	23	DINING TABLE	662	11	10,683	117,511	5.48%	12.40%	0.8%
3	25	BUFFET	254010	7	11,209	78,462	3.66%	16.06%	1.2%
4	29	CHAIR	294015	74	950	70,266	3.28%	19.34%	1.6%
5	23	DINING TABLE	234016	7	8,844	61,910	2.89%	22.23%	2.0%
6	25	BUFFET	718	6	9,324	55,943	2.61%	24.84%	2.4%
7	29	CHAIR	294036	42	1,018	42,737	1.99%	26.83%	2.8%
8	25	BUFFET	736	4	9,523	38,091	1.78%	28.61%	3.2%
9	25	BUFFET	252696	3	11,677	35,032	1.63%	30.25%	3.6%
10	38	BAHU-VTRN	511	4	7,951	31,802	1.48%	31.73%	4.0%
11	29	CHAIR	792	38	812	30,870	1.44%	33.17%	4.4%
12	23	DINING TABLE	657	3	9,301	27,902	1.30%	34.47%	4.8%
13	23	DINING TABLE	678	4	6,664	26,656	1.24%	35.72%	5.2%
14	29	CHAIR	778	30	813	24,375	1.14%	36.85%	5.6%

The 251 different products are classified into three main classes, in terms of monetary value. Table 3-4 shows the percentage of monetary value, percentage of items, and number of items for the 3 main classes.

Table 3-4: Products classification.

Class	Percentage of Monetary Value	Percentage of items	Number of items
A	22%	2%	5
B	52%	33%	83
C	26%	65%	163
Total	100%	100%	**251**

In this case study, class A items shown in Figure 3-4 will only be considered, which are:

1. Buffet 721.
2. Dining Table 662.
3. Buffet 254010.
4. Chair 294015.
5. Dining Table 234016.

Figure 3-4: Selected products in the study.

3.4 IDENTIFICATION AND TRACKING OF PRODUCTS

3.4.1 Description of the Identification and Tracking Process

An aluminium tag is produced and attached to each item, using one 2cm nail, after its assembly for identification purposes. The aluminium tag is made by engraving certain numbers on a blank aluminium sheet. This tag is used also in the tracking process in order to meet the delivery due dates. Figure 3-5 shows a blank aluminium sheet before and after engraving the identification numbers.

Figure 3-5: Aluminium tag sheet before and after engraving numbers.

A worker from the carpentry department, who is referred to in the text as the *tag resource*, is responsible for producing the aluminium tags upon request of the production department. Production of one tag takes on average 2 minutes to complete.

A *production engineer* revises the tags before attaching it to the items. Usually, the *production engineer* finds some errors that require producing new tags. Some assembled items do not start their finishing operations due to waiting for the aluminium tag, which leads to delays. After attaching the tag to the item, the *production engineer* revises its location and sometimes asks the worker to relocate the tag.

The aluminium tag dimensions are 3.5 × 5.5 cm and it costs 0.5 LE. An example of the numbers engraved on an aluminium tag is showed in Figure 3-6.

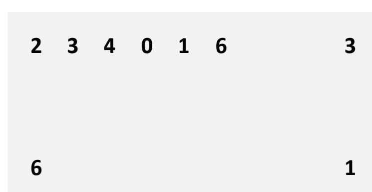


Figure 3-6: Example of numbers engraved on aluminium tags.

Where, the engraved numbers represents the following:

- The upper left number; Number 234016, is the item code.
- The upper right number; Number 3, means that it is the third time for the factory to manufacture this item.
- The lower left number; Number 6, means that the number of items that will be manufactured at this working order is 6.

- The lower right number; Number 1, means that it is the first piece from the total, which is 6 items.

Production department sets the production plan and monitors its progress on daily basis to update the next day plan. Two employees are responsible for monitoring the progress of each item on the shop floor by recording its data and its actual processing time taken at each operation; these are referred to as *recording employees*.

A bronze tag is produced using the same method used before in producing the aluminium tag, similar data are engraved on the tag but done by a worker from the brass department. The bronze tag has the same dimensions of the aluminium one but it costs 8 LE. Figure 3-7 shows the bronze tag before and after engraving numbers. Each bronze tag requires four 3cm nails to be attached to the item using the four holes in its corners.

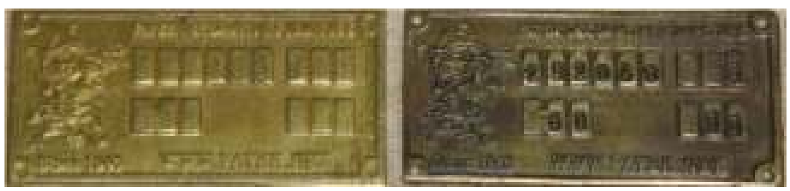


Figure 3-7: Sample of bronze tags before and after engraving numbers.

The aluminium tag is replaced by the bronze one in order to have better look. Large number from the produced items is shipped to the customer without changing the tag due to shortage of time; the brass department does not start in producing these tags till the production department asks for them or sometimes produced for the exported products only.

Before leaving the system, items are packaged and put together in the shipping area to be revised in the presence of the customer. This process takes a long time because the customer checks his order while a shipping employee has to check the products using printed images and to revise numbers on tags too.

In case of exported products, the shipping employee takes the responsibility of revising the whole order and putting it in a container that comes specifically to take this order. The container has limited time to stay in the factory which is seven hours. If the container stays more than that, the factory pays a penalty for each hour of delay.

Usually the exported order consists of 250 items that must be revised and put in the container during this limited period of time.

3.4.2 Issues Associated with the Current Identification and Tracking Process

Normally, the tag can be removed from the item and re-attached to it up to three to four times during the finishing stages to avoid the tag damage or disappearance. Attachment and removal of tags is done more than once. This can result in losing some tags, attaching the wrong tag to an item, or attaching the tag in the wrong place. The process of attaching the tag to the item takes on average 1 to 5 minutes; removing it takes on average 2 to 10 minutes. Tags removal takes more time as tags are usually attached to the item in hidden locations and the worker spends more time looking for the tag.

The *tag resource* comes from the carpentry department each time the tag is removed from or attached to the item. This resource has other tasks in the carpentry department and is usually busy doing these tasks, which can result in delaying the tagging process.

The tag has limited storage capacity for data regarding the customer name, delivery date, and other extra information that could help the production department and management in their planning and operating decisions, in addition to affecting customer satisfaction. Brass workers have to go to the storage to bring the accessories related to each item which is determined by reading its code. Usually, workers bring a wrong accessory which discovered by the *production engineer* later and takes a long period of time to be resolved.

In addition, the tag is small, the numbers are not clear, some workers do not know how to read it, some locations requires good light to read it, and tags are painted in the spray room with the whole item or in other processes, which make its reading even more difficult (Figure 3-8).

Figure 3-8: Sample of aluminium tag after some kind of tint.

Finally, for the cushioning process, which is made for chairs only, a batch of 8, 10, or 12 chairs is outsourced after finishing and takes about 6 working days to come back. The problem is the tag location which disappears under the cushion. Therefore, the chairs can no longer be identified after the cushioning process.

3.4.3 Impact of Wrong Identification and Tracking

Based on the issues presented earlier, the two *recording employees* are suffering every day to track and identify about 200 items moving on the shop floor; especially, in reading and recording the data engraved on the tags, which leads to errors in the monitoring process and in the recorded actual processing times. These recording errors affect all departments of the firm such as:

- Costing department: misdirecting cost of labour wages, cost of materials, and indirect production costs on the cost centre.
- Accounting department: makes inventory evaluation errors which give wrong financial statements to the management.
- Production department: makes wrong updates for the production plan therefore wrong planning decisions.
- Technical office: evaluates and analyzes data that has big factor of error which affects the right operational decisions that taken to improve production and measure performance.
- Sales department: has wrong information about stock to sell from and wrong update about client orders that being tracked in production for scheduling delivery.
- Logistics department: ships wrong items to wrong destinations locally and worldwide.
- After sales: Customers come after several years to make some maintenance processes which require the identification of the item. Worker tries to find the tag to read it but if the item is chair, it is impossible to find the tag as long as the cushion is in a good state.

The accounting department is working every month in order to prepare the financial statements of the firm, which requires the determination of the inventory level (which consists of WIP and finished products). This is done using physical count that takes from 20 - 30 days to be done or 7 days in case of stopped production. Therefore, the accounting department makes the physical count twice a year in the middle of the year and at the end of the year. The physical count is made based on the recorded processing times which have errors up to 15 - 20% after inspection has been done by two employees, while the errors are about 35% after data entry errors and before inspection.

Management estimated that 50% of the accounting department salaries are lost because the required information is not available through 10 months from the whole year while 10 - 15% of these salaries are lost in the other two months that includes the physical count. From costing department point of view, 20 - 30% of the annual profit of the company is lost due to the unavailability of the financial statements.

3.5 PROBLEM FORMULATION AND OBJECTIVES

Based on the discussion presented in the previous section, it is evident that probably the major problem in the studied system is to track and identify products on the shop floor because of the presence of about 200 items moving between workstations and departments every day.

Management is convinced that implementing an RFID system for identification and tracking of these items is the solution to that problem. Where, a basic RFID system comprised of tags and readers only is considered for implementation in the near future. However, it is not quite clear how would that affect the overall performance of the system. Also, management would like to know whether the costs involved in implementing such a system is justifiable or not.

3.5.1 Problem Statement

Therefore, this work is investigating the operational and economical feasibility of implementing radio frequency identification technology for tracking and identification of items on the shop floor in a job shop manufacturing environment.

Implementation of the RFID system without predicting its effect on the operational performance of the system can be very disruptive to its operation; in addition, the costs involved might be unjustifiable. For this reason, the problem is tackled by simulation of the manufacturing system.

3.5.2 Objectives

The objectives of this simulation study include the following:

- To evaluate the impact of the implementation of the RFID technology in the selected manufacturing system on the output, throughput, cycle time, work in process, resources utilization, and average waiting time in queues to assess the operational feasibility of RFID technology adoption.
- To predict the values of the variables that is used in the cost analysis to assess the economical feasibility of RFID technology adoption.

3.6 MODEL CONCEPTUALIZATION

The actual products which are processed in the factory reach 251 different products, while the model developed will focus on only 5 products which are:

1. Buffet 721
2. Dining Table 662
3. Buffet 254010
4. Chair 294015
5. Dining Table 234016

These products represent 22% of the total monetary value of the company, which are chosen according to the products selection analysis described earlier in this chapter.

3.6.1 Assumptions

The simulation model will be developed under the following assumptions:

- The factory produces only 5 products.
- Manufacturing processes starts after carpentry.
- Processes that are performed outside finishing area are considered delays due to unavailability of data about their resources such as some carpentry processes that take place during the finishing stages of the item.
- Travel times between departments and rework of items due to quality checks are ignored as RFID implementation will not affect them.

- Processing times are in minutes; where, one working week is equivalent to 3,600 minutes.
- Batching chairs together before being outsourced to the cushioning process is based on a constant batch size of 8 chairs.

3.6.2 Process Flows

The model developed describes the flow of the 5 products selected for this study after the end of carpentry operations, which is the assembly process, and moving forward till their shipping. Each product of these has its own flow, where common flows can be found especially for buffets and dining tables.

Figure 3-9 shows the flow of products (buffet 721 and buffet 254010) in which the highlighted process made for buffet 721 only and not for buffet 254010.

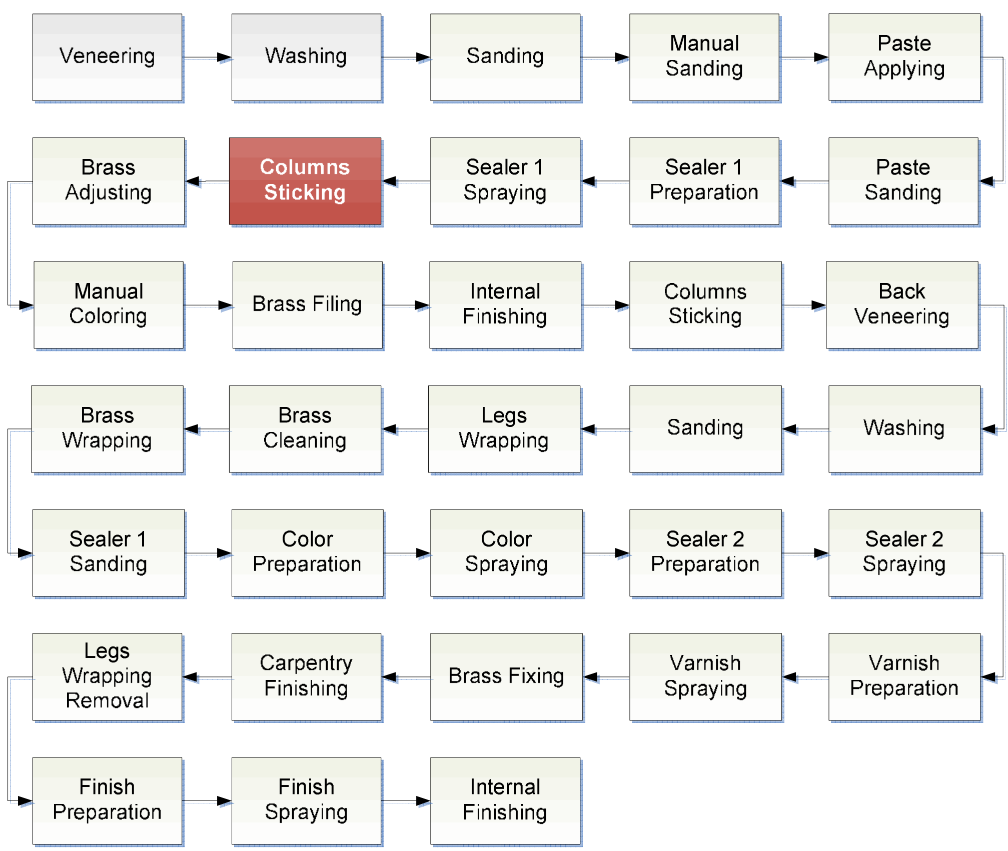


Figure 3-9: Buffets process flow.

Figure 3-10 shows the flow of products dining table 234016 and dining table 662 in which the highlighted process made for dining table 234016 only and not for dining table 662.

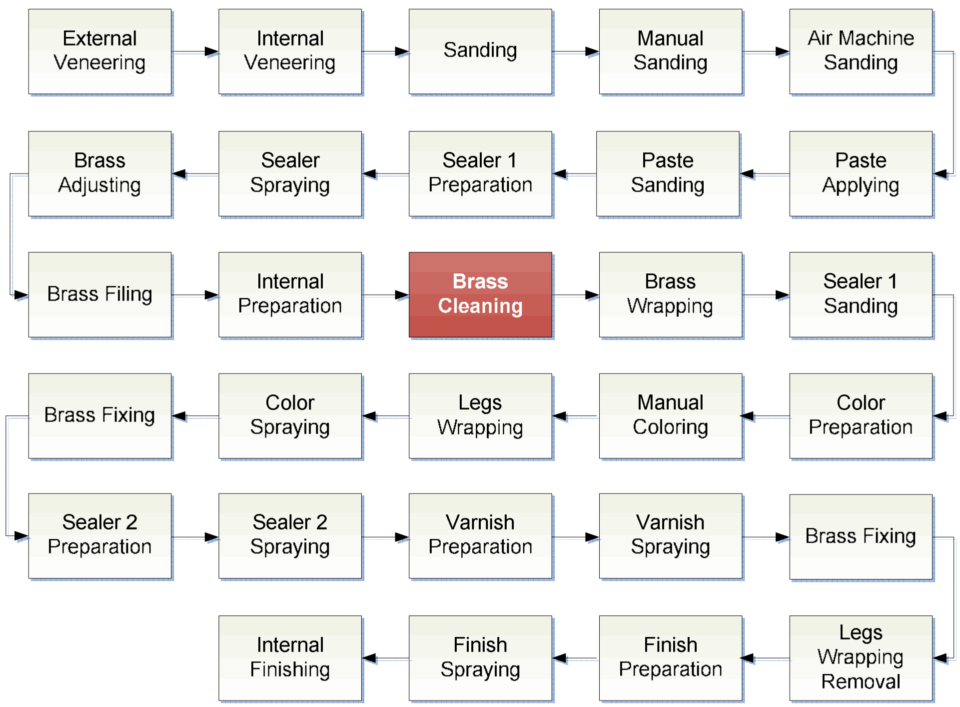


Figure 3-10: Dining tables process flow.

Figure 3-11 shows the flow of Chair 294015.

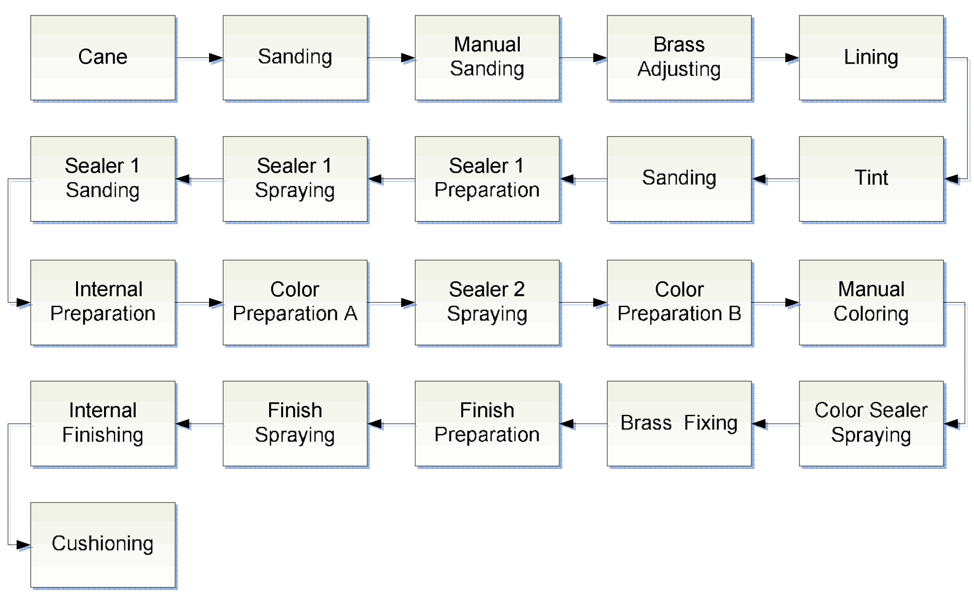


Figure 3-11: Chair process flow.

3.7 DATA COLLECTION

The process of building the model depends on a set of data that can be categorized into three main groups: structural, operational, and numerical. Several visits have been made to the manufacturing facility in order to collect the different data required.

3.7.1 Structural Data

Structural data involve all of the objectives in the system to be modelled; where it basically describes the configuration of the system as well as identifies the entities that are processed. The structural data is the data related to the finishing stages under study and includes the following:

Location

All finishing stages, after the assembly of the item till its shipping. These include veneer, sanding, painting A/B, and brass departments in addition to other additional operations.

Entities

5 different products

- Buffet 721
- Buffet 254010
- Dining Table 234016
- Dining Table 662
- Chair 294015

Activities

Include all processes needed from carpentry, veneer, sanding, painting A/B, and brass departments to produce the selected 5 products. Table 3-5 shows all activities (processes) with their codes and departments.

Table 3-5: Departments and Processes.

Department	Process Code	Process Name
Cane	705C	Cane
Veneer	701B	Veneering
	702B	Back Veneering
	703T	External Veneering
	704T	Internal Veneering
Sanding	501	Washing
	502	Sanding
	503	Manual Sanding
	506	Air machine sanding
Painting	201	Paste Applying
	202	Paste Sanding
	203	Sealer 1 Preparation
	205	Internal Preparation
	206	Internal Finishing
	207	Sealer 1 Sanding
	208	Colour Preparation
	209	Manual Colouring
	211	Sealer 2 Preparation
	213	Varnish Preparation
	215	Finish Preparation
	221	Wrapping
	222	Brass Cleaning
	204	Sealer 1 Spraying
	210	Colour Spraying
	212	Sealer 2 Spraying
	214	Varnish Spraying
	216	Finish Spraying
	204A	Sealer 1 Spraying
	204B	Sealer 2 Spraying
	217	Lining
	218	Tint
	219	Sanding
Brass	305	Brass Filing
	311	Brass Adjusting
	312	Brass Fixing
Outsourced	706C	Cushioning

In addition, Table 3-6 shows data for other additional activities. These are estimated distributions from the general manager of the factory and other departments' managers.

Table 3-6: Additional processes.

Department	Process Code	Process Name
Carpentry	N/A	Aluminium Tag Production
	N/A	Tagging
	N/A	Tag Releasing
	N/A	Tag Search

Production	N/A	Tag Inspection
	N/A	Order Revising 1
	N/A	Order Revising 2
	N/A	Order Revising 3
	N/A	Correcting Accessories
	N/A	Tracking
Quality	N/A	Quality Checking
Brass	N/A	Bronze Tag Production

Delays

Processes performed outside previous departments are considered as delays due to unavailability of information. Table 3-7 shows these delays and their departments.

Table 3-7: Different sources of delay.

Department	Process Code	Process Name
Carpentry	129A	Columns Sticking
	129B	Carpentry Finishing
Storage	N/A	Accessories Preparation
Shipping	N/A	Packaging (Local)
	N/A	Packaging (Exported)

Resources

The manufacturing facility produces handmade furniture and is thus a labour intensive industry. Two main types of resources are considered in this model; labour who carry out the different manufacturing processes and employees such as *recording employees*, *quality assurance employees*, and *production engineers*. The different types of labour and their allocation are provided in the next section. Different employees are involved in tracking and identification of items include *quality assurance employees* who assure quality of products after certain stages or processes, *production engineers* who supervise labours and follow-up the achievement of the production plan, *recording employees* that record data and track each item on the shop floor, and *tag resource* which is a carpentry worker who attaches and releases the metal tags. In addition to other resources that are not related to a certain department such as cane process resources.

3.7.2 Operational Data

Operational data explain how the system operates. It includes all the logical or behavioural information about the system such as routings and resource allocation.

Products Routing

The different routings of the selected five products are illustrated in Figure 3-12.

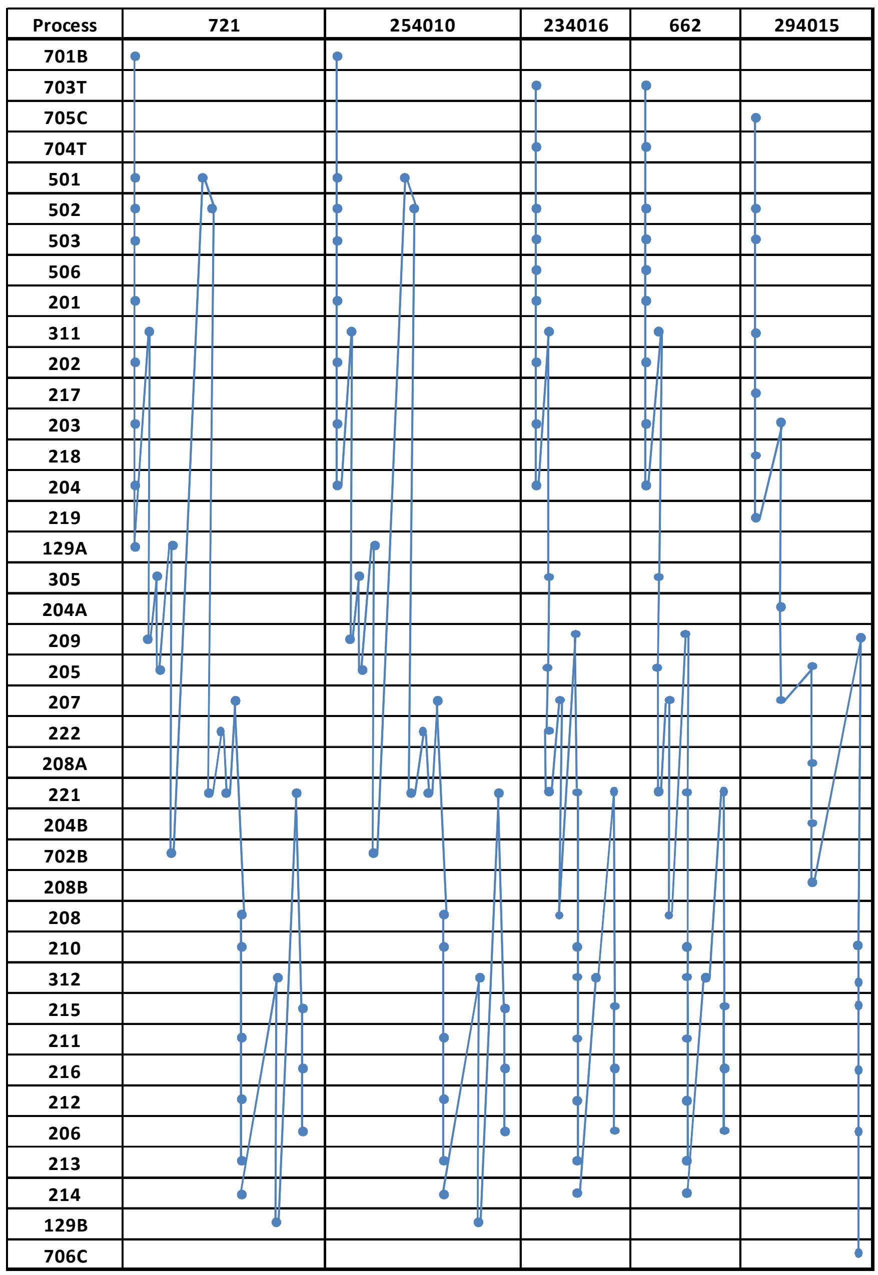


Figure 3-12: Multi-column process chart for selected products.

Description of the Process

Figure 3-13 is a flow chart that describes the manufacturing process for the different product categories selected for this study, which are buffet, dining table, and chair. The chair has a significantly different sequence of operations than the other product types. For that reason, the flow chart was developed to identify where these differences are.

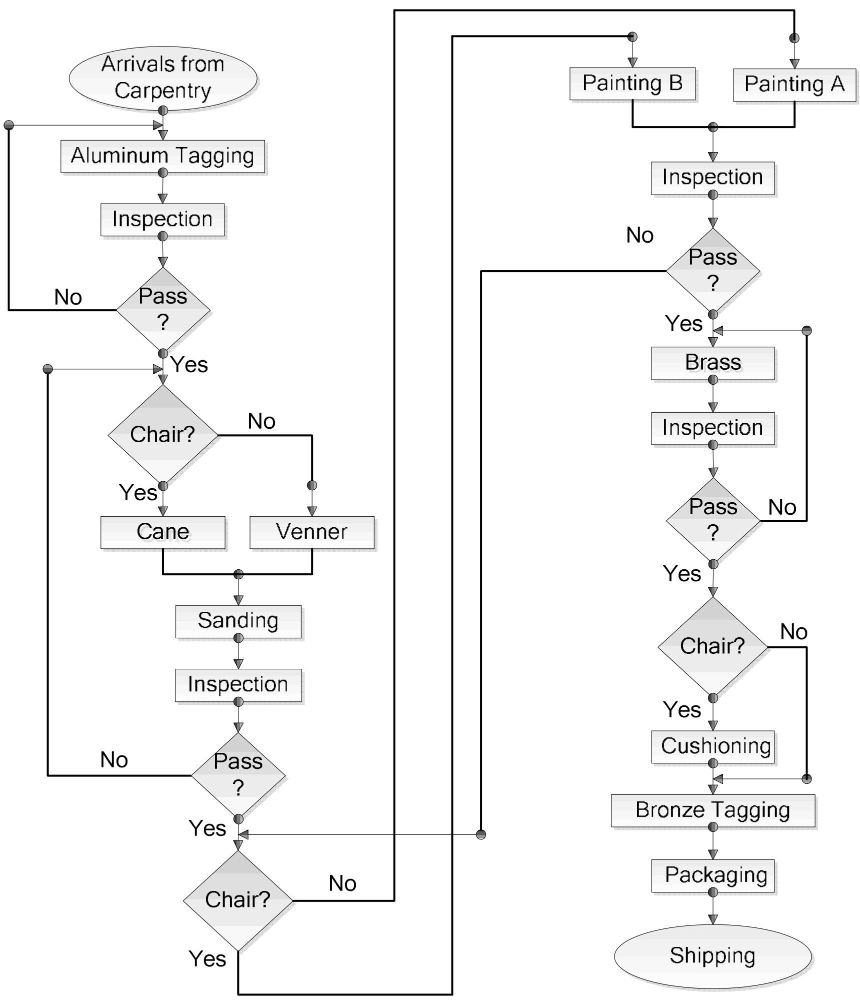


Figure 3-13: Flow chart for selected products.

After finishing the carpentry processes, aluminium tags are produced and attached to each item. Items are usually sent to veneer and sanding departments. Then items are routed to their next station, where buffets 721/254010 and dining tables 234016/662 go through painting A department processes, while chair 294015 goes through painting B department processes.

Items transfers through finishing stages according to their category, style, and shape. Several inspections are made at certain stages during finishing stages in order to assure the quality and accuracy of processes performance, if items fail they are reworked.

The aluminium tags are attached to and removed from the items several times in different departments to facilitate the finishing of the item and to avoid the tag damage or disappearance. At the end, before exiting the system, bronze tags are produced and attached to items before being packaged.

Resource Allocation

Table 3-8 to Table 3-12 show the available resources at each department and how they are allocated to the different processes. Labour names are substituted by letters and numbers that represent the department and processes are given by their codes.

The symbol (●) indicates that the labour is allocated to the corresponding process. The capacity column determines how many resources are allocated to the process and the quantity column determines how many labours are required to perform that process.

Table 3-8: Veneer department resources allocation.

Process	**Capacity**	**Qty**	**V/1**	**V/2**	**V/3**	**V/4**
701B	4	1	●	●	●	●
702B	4	1	●	●	●	●
703T	4	1	●	●	●	●
704T	4	1	●	●	●	●

Table 3-9: Sanding department resources allocation.

Process	**Capacity**	**Qty**	**S/1**	**S/2**	**S/3**	**S/4**	**S/5**	**S/6**	**S/7**	**S/8**	**S/9**	**S/10**	**S/11**	**S/12**	**S/13**	**S/14**
501	3	1	●	●	●											
502	8	1	●			●	●	●	●	●	●	●				
503	12	1	●			●	●	●	●	●	●	●	●	●	●	●
506	2	1	●									●				

Table 3-10: Painting A department resources allocation.

Process	Capacity	Qty	F/1	F/2	F/3	F/4	F/5	F/6	F/7	F/8	F/9	F/10	F/11	F/12	F/13	F/14	F/15	F/16	F/17	F/18	F/19	F/20	F/21	S/1
201	1	1	●																					
202T	1	1																						●
202B	1	1	●																					
203	11	1		●	●	●	●	●	●	●	●	●	●	●										
204	2	2													●	●								
207T	3	1									●				●									●
207B	10	1		●	●	●	●	●	●	●		●	●	●										
208	8	1		●	●	●	●	●	●	●	●													
209	8	1		●	●	●	●	●	●	●	●													
210	2	2													●	●								
211	11	1		●	●	●	●	●	●	●	●	●	●	●										
212	2	2													●	●								
213	6	1					●	●	●	●	●	●												
214	2	2													●	●								
215	6	1					●	●	●	●	●	●												
216	2	2													●	●								
221	1	1		●																				
222	1	1										●												
205	7	1															●	●	●	●	●	●	●	
206	3	1															●	●	●					

Table 3-11: Painting B department resources allocation.

Process	Capacity	Quantity	CF/1	CF/2	CF/3	CF/4	CF/5	CF/6	CF/7	CF/8	CF/9
217	7	1	●	●	●	●	●	●	●		
218	7	1	●	●	●	●	●	●	●		
219	7	1	●	●	●	●	●	●	●		
203	7	1	●	●	●	●	●	●	●		
204A	2	2								●	●
207	7	1	●	●	●	●	●	●	●		
205	7	1	●	●	●	●	●	●	●		
208A	7	1	●	●	●	●	●	●	●		
204B	2	2								●	●
208B	7	1	●	●	●	●	●	●	●		
209	2	1	●	●							
215	6	1	●	●	●	●	●	●			
206	7	1	●	●	●	●	●	●	●		

Table 3-12: Brass department resources allocation.

Process	Capacity	Quantity	B/1	B/2	B/3	B/4	B/5	B/6	B/7	B/8
305	4	1					●	●	●	●
311	5	1	●	●	●	●	●			
312	5	1	●	●	●	●	●			

Schedules and Downtimes

Labours work one (ten hours) shift plus a break of 1 hour. Because operations are performed by workers not machines, downtimes rarely occur, except for absence of workers; thus, downtimes are ignored.

3.7.3 Numerical Data

The numerical data includes quantitative information and values about the system. These values can either be deterministic (constant) or stochastic (probabilistic).

Due to the large processing times of the products it would be impossible to collect several readings for each process of different products. Historical data of processing times for year 2009 were used; which are presented as follows:

Deterministic Data

The processing time such as tag production, tag inspection and packaging are shown in Table 3-13 and Table 3-14, which show these processing times in minutes for the base and proposed models; respectively.

Table 3-13: Deterministic processing times in the base model.

Base Model	
Process Name	**Processing Time (min)**
Tag Inspection	1
Packaging (Local)	5
Packaging (Exported)	15

Table 3-14: Deterministic processing times in the proposed model.

Proposed Model	
Process Name	**Processing Time (min)**
Tag Inspection	1
Tracking	1
Order Revising2	2
Packaging (Local)	5
Packaging (Exported)	15

Stochastic Data

The developed model is stochastic due to the following random inputs:

Inter-arrival Rate

The inter-arrival of items is exponentially distributed with a mean of 117 minutes, which is equivalent to 1,594 items per year which is calculated as follows:

- Number of minutes in one hour = 60 min/hr
- Number of working hours per day = 10 hrs/day
- Number of working days per week = 6 days/ week
- Number of working weeks per year = 52 weeks/year
- Number of units produced per year = 1,594 units/year

$$\therefore exponential\ mean\ of\ arrivals = \frac{60 \times 10 \times 6 \times 52}{1{,}594} = 117\ minutes$$

Product Types

The five different product types produced buffet 721, dining table 662, buffet 254010, chair 294015, and dining table 234016 follow an empirical distribution with probabilities 0.1, 0.1, 0.064, 0.673, and 0.064; respectively as shown in Table 3-15.

Table 3-15: Selected products probability of occurrences.

Product Type	Item Code	Quantity	Prob. of Occurrence
Buffet	721	11	10.0%
Dining Table	662	11	10.0%
Buffet	254010	7	6.4%
Chair	294015	74	67.3%
Dining Table	234016	7	6. 4%
	TOTAL	110	100%

IF-THEN Rules

A number of IF-THEN rules are used to address different operational aspects of the manufacturing process such as acceptance or rejection of items after a quality check. These have been modelled as a 2-way empirical distribution with different probabilities for each. These are presented in Table 3-16.

Table 3-16: Questions related to the manufactuirng process.

Questions	Yes	No
Is the aluminium tag production accepted?	0.95	0.05
Is the aluminium tag attaching accepted?	0.98	0.02
Did the worker revise the order before preparing accessories?	0.95	0.05
Are the accessories prepared for items 721 and 254010 are right without order revising?	0.98	0.02
Are the accessories prepared for items 662 and 234016 are right without order revising?	0.7	0.3
Did the worker revise the order before starting the internal finishing process?	0.9	0.1
Is the aluminium tag lost in the painting department during the finishing of the product?	0.7	0.3
Is the RFID tag programming accepted?	0.99	0.01
Will the order be exported	0.5	0.5

Non-Manufacturing Processes

Processes concerned with tagging, orders revising, tracking, quality checking, and accessories in the base model are illustrated in Table 3-17.

Table 3-17: Stochastic processing times in the base model.

Process Name	Distribution Type	Distribution Parameters		
		a	b	c
Aluminium Tag Production	Uniform	1	2	
Tagging	Triangular	1	2	1
Order Revising1	Triangular	20	30	20
Tracking	Triangular	2	10	3
Tag Releasing	Triangular	2	10	3
Quality Checking	Uniform	10	15	
Order Revising2	Uniform	2	5	
Accessories Preparation	Triangular	10	20	15
Correcting Accessories	Triangular	60	90	90
Order Revising3	Triangular	10	12	10
Tag Search	Triangular	120	300	240
Bronze Tag Production	Triangular	2	5	3

Processes concerned with tagging, orders revising, quality checking, and accessories in the proposed model are illustrated in Table 3-18.

Table 3-18: Stochastic processing times in the proposed model.

Process Name	Distribution Type	Distribution Parameters		
		a	b	c
RF Tag Programming	Uniform	1	2	
Tagging	Triangular	1	2	1
Order Revising1	Triangular	5	10	5
Quality Checking	Uniform	3	5	
Accessories Preparation	Triangular	10	20	15
Order Revising3	Uniform	5	7	

Manufacturing Processes

The processing times for the five products in several departments are random. Data were collected for each product on each process according to the product's flow. Collected data points for each process ranges from 10 to 25 points. The data collection is illustrated in Appendix C.

Input modelling is done for the collected data. This is the first step in developing the simulation model and is presented in the next chapter.

Chapter Four

4 MODEL DEVELOPMENT

After presenting the problem formulation, objectives of the study, and the different data collected for the system under study; detailed description of the simulation model development is presented in this chapter.

The chapter will start by presenting the input modelling process which is used to determine the different distributions and their parameters for all the manufacturing processes of the five products followed by a detailed description of developing the model using the ExtendSim simulation environment. Finally, the verification and validation of the developed model is presented at the end of the chapter.

4.1 INPUT MODELLING

After gathering the desired data for all required processes, data analysis is done using StatFit (Statistical Analysis Software). Data for different products in each process are put in the StatFit to analyze them and determine the most appropriate distribution fitting that represents the behaviour of the data. This section presents the results obtained from StatFit.

The distribution parameters for each fitted distribution are also determined using the software. These are given the letters *a*, *b*, *c*, and *d*. These letters represent the following depending on the fitted distribution type:

- For uniform distribution; *a*: Minimum and *b*: Maximum
- For beta distribution; *a*: Shape 1, *b*: Shape 2, *c*: Maximum, and *d*: Location
- For gamma distribution; *a*: Scale, *b*: Shape, and *c*: Location
- For exponential distribution; *a*: Mean and *b*: Location
- For triangular distribution; *a*: Minimum, *b*: Maximum, and *c*: Most Likely
- For lognormal distribution; *a*: Mean, *b*: Standard Deviation, and *c*: Location
- For weibull distribution; *a*: Scale, *b*: Shape, and *c*: Location

Table 4-1 to Table 4-3 show all the processes required for each product category and the fitted distribution types and parameters. It also shows whether the distribution determined is specific to one of the products within the product category or the distribution is applicable to all products in the category.

Table 4-1: Distribution fitting for buffet 721 and buffet 254010.

Process Code	Product Type	Distribution Fitting				
		Type	Parameters			
			a	*b*	*c*	*d*
201	All Buffets	Beta	25	180	1.12	1.44
202	Buffet 721	Beta	137	262	0.649	0.853
202	Buffet 254010	Beta	135	262	0.616	0.823
203	All Buffets	Uniform	25	45		
204	All Buffets	Beta	45	105	1.07	0.777
205	All Buffets	Uniform	105	245		
206	Buffet 721	Lognormal	115	5.42	0.373	
206	Buffet 254010	Uniform	285	526		
207	All Buffets	Exponential	20	140		
208	Buffet 721	Gamma	405	1.76	81.3	
208	Buffet 254010	Uniform	211	588		
209	Buffet 721	Uniform	129	302		
209	Buffet 254010	Triangular	177	365	177	
210	All Buffets	Uniform	33	173		
211	Buffet 721	Uniform	67	184.98		
211	Buffet 254010	Uniform	67	185		
212	All Buffets	Uniform	24	117		
213	Buffet 721	Uniform	213	400		
213	Buffet 254010	Beta	212	467	1.53	1.74
214	All Buffets	Triangular	32	147	32	
215	All Buffets	Uniform	27	180		
216	All Buffets	Uniform	11	63		
221	All Buffets	Uniform	47	135		
222	All Buffets	Beta	70	181	2.01	2.16
305	Buffet 721	Uniform	118	490.02		
305	Buffet 254010	Weibull	118	1.56	56.2	
311	All Buffets	Beta	198	307	2.57	3.22
312	All Buffets	Triangular	134	536	134	
501	All Buffets	Uniform	105	561		
502	All Buffets	Uniform	135	537		
503	All Buffets	Beta	11	115	8.82	59.1
129A	Buffet 721	Uniform	198	307		
129A	Buffet 254010	Beta	198	307	2.55	3.23
129B	Buffet 721	Uniform	67	185		
129B	Buffet 254010	Uniform	105	245		
701B	All Buffets	Uniform	300	430		
702B	Buffet 721	Gamma	118	0.506	148	
702B	Buffet 254010	Uniform	118	490		

Table 4-2: Distribution fitting for dining table 234016 and dining table 662.

Process Code	Product Type	Distribution Fitting				
		Type	Parameters			
			a	*b*	*c*	*d*
201	All Dining Tables	Triangular	14	157	14	
202	Dining Table 234016	Beta	39	140	1.09	1.33
202	Dining Table 662	Triangular	44	138	44	
203	Dining Table 234016	Uniform	40	245		
203	Dining Table 662	Weibull	12	1.85	26.2	
204	Dining Table 234016	Beta	12	60	1.76	2.55
204	Dining Table 662	Triangular	22	71.6	22	
205	Dining Table 234016	Triangular	21	71.7	21	
205	Dining Table 662	Uniform	60	185		
206	All Dining Tables	Beta	137	262	0.61	0.825
207	All Dining Tables	Weibull	33	2.63	141	
208	Dining Table 234016	Uniform	475	600		
208	Dining Table 662	Exponential	85	36.5		
209	All Dining Tables	Beta	198	307	2.57	3.22
210	All Dining Tables	Uniform	12	60		
211	All Dining Tables	Uniform	67	185		
212	All Dining Tables	Triangular	6	22.1	6	
213	All Dining Tables	Triangular	44	202	44	
214	All Dining Tables	Triangular	21	71.7	21	
215	All Dining Tables	Triangular	44	239	44	
216	All Dining Tables	Uniform	7	77		
221	All Dining Tables	Uniform	23	169		
222	Dining Table 234016	Triangular	44	139	44	
305	All Dining Tables	Uniform	67	185		
311	All Dining Tables	Uniform	127	284		
312	All Dining Tables	Triangular	134	536	134	
502	All Dining Tables	Weibull	5	1.59	110	
503	All Dining Tables	Uniform	30	220		
506	All Dining Tables	Beta	70	181	2.01	2.16
703T	All Dining Tables	Beta	137	262	0.616	0.823
704T	All Dining Tables	Triangular	44	202	44	

Table 4-3: Distribution fitting for chair 294015.

Process Code	Distribution Fitting				
	Type	Parameters			
		a	*b*	*c*	*d*
705C	Exponential	118	34.1		
502	Exponential	15	69		
503	Weibull	30	1.52	77.1	
311	Uniform	5	13.8		
217	Uniform	22	90		
218	Triangular	21	73.5	21	
219	Uniform	15	30		
203	Triangular	5	134	5	

Process Code	Distribution Fitting				
	Type	Parameters			
		a	*b*	*c*	*d*
204A	Uniform	1	20		
207	Uniform	15	170		
205	Uniform	15	45		
208A	Uniform	7	220		
204B	Beta	12	45	1.29	1.06
208B	Uniform	7	220		
209	Uniform	7	114		
210	Uniform	15	45		
312	Beta	57	506	1.05	8.69
215	Beta	10	70	0.575	0.764
216	Weibull	12	1.85	26.2	
206	Beta	15	27	31.7	144
706C	Constant	3,600			

4.2 MODEL TRANSLATION

A simulation model for the factory has been developed using the ExtendSim, from Imagine That, Inc. This part presents in details the model development process. ExtendSim is characterized by a set of features the most important of these are [92]:

- Drag and drop modelling from a set of libraries.
- Built-in database.
- Integrated statistical analysis software.

Further details about all blocks used in the models to follow are found in Appendix D. This description is extracted from the ExtendSim 7 user's guide [93].

4.2.1 Base Model

The base model represents the flow of the five products on the shop floor using the current identification system. To translate this flow from the conceptual model to a simulation model, several functions and features of the software are used. These are explained in the following points:

Attributes

Two types of attributes have been used in the developed model. The first type is *Value Attribute* which is used to hold a real number as its attribute value. The second type is

DB (database) Address Attribute which contains a single value that represents a processing time in a database. Details of value attributes used are as follows:

- *ProductType*: to identify the five different product types as each product type has certain routing.
- *Return*: to determine the route of certain product that should go to a certain activity for the second or third time.
- *ResourceName*: to identify the different resource pools used by an activity.
- *TNow*: to determine the time in which the item arrived to the system which is used in cycle time calculation.
- *CorrectTag*: to determine whether the produced tag is correct or not before being attached to the item and also to determine whether the tag is attached to the item in the right location or not before starting in finishing the item.
- *OrderRevising*: to determine whether or not the brass worker and the *production engineer* will revise the order before bringing the accessories from the storage and whether or not the painting worker will revise the order before starting in the process of internal preparation to check if the customer wants a certain colour.
- *CorrectAccess*: to determine whether or not the accessories will need to be changed as long as the brass worker did not revise the order before bringing these accessories from the storage.
- *TagLost*: to determine whether or not a tag is lost at any of the finishing stages.
- *OrderType*: to differentiate between the two order types which are local products and exported products.

Built-in Database

ExtendSim has a built-in database that can be used for storing and managing model data. Mainly, the database is used in order to contain all the processing times of each process for each product type used in the model whether this processing time is constant or random.

As mentioned earlier, data in the database can be stored as DB attribute values, which are in turn retrieved as needed within the model. In this model there is DB attribute defined for each process and the attribute value is retrieved at a process to determine the processing time at that particular process.

Figure 4-1 shows a snapshot of the database created for the model; where, the database has different tables; one for each product type in addition to a table for additional activities modelled. Furthermore, Figure 4-2 shows the data stored in one of these tables that are relevant to processes codes and processing distribution type and parameters.

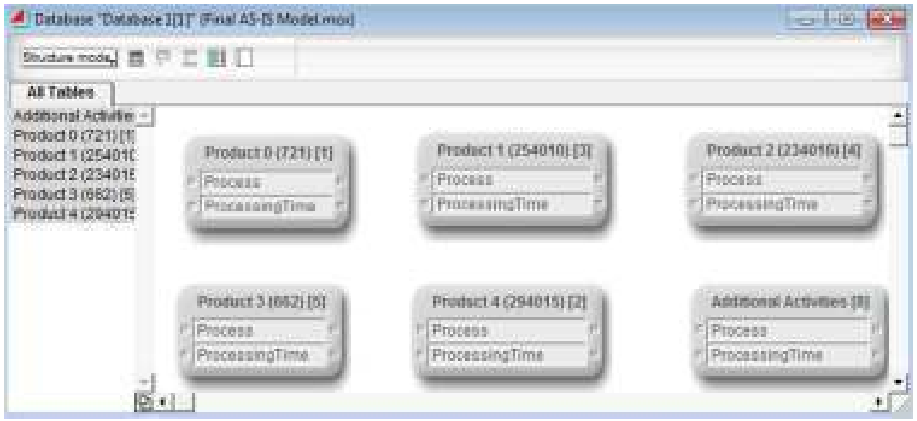
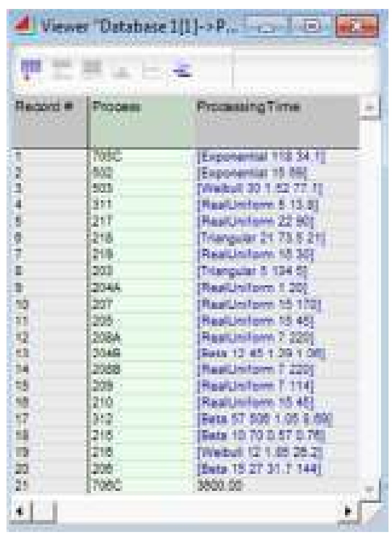


Figure 4-1: Tables constructed in the database.



Record #	Process	ProcessingTime
1	705C	[Exponential 118 34.1]
2	502	[Exponential 15 88]
3	503	[Weibull 30 1.52 77.1]
4	211	[RealUniform 5 13.8]
5	217	[RealUniform 22 90]
6	218	[Triangular 21 73.5 21]
7	219	[RealUniform 15 30]
8	203	[Triangular 5 134 5]
9	204A	[RealUniform 1 20]
10	207	[RealUniform 15 170]
11	205	[RealUniform 15 45]
12	208A	[RealUniform 7 220]
13	204B	[Beta 12 45 1.39 1.06]
14	208B	[RealUniform 7 220]
15	209	[RealUniform 7 114]
16	210	[RealUniform 15 45]
17	212	[Beta 57 508 1.05 8.69]
18	215	[Beta 10 70 0.57 0.76]
19	216	[Weibull 12 1.85 26.2]
20	206	[Beta 15 27 31.7 144]
21	706C	3600.00

Figure 4-2: Sample table from the database.

Products' Arrivals

Figure 4-3 shows a snapshot of part of the model that is responsible for creating items for the model. A Create block (Block 1) introduces the items to the model based on the inter-arrival rate. Information about the number of items that entered the system is captured by the Information block (Block 2), which is used for calculating the work-in-process level (discussed later in reporting). Block group 3 is responsible for setting a number of database attributes for stochastic processes (other than manufacturing) and writing the values of these attributes using the built-in database. Finally, Block group 4 includes the following:

- A *Set* block that is used to set the value attributes such as *ProductType*, *Return*, *ResourceName*, and *TNow*. These are used later in the model for products routing, assigning resources, and for calculating cycle time.
- A *Random Number* block is used to generate the probabilities of product types.
- A *Time* block for determining the time at which the item arrived to the system.

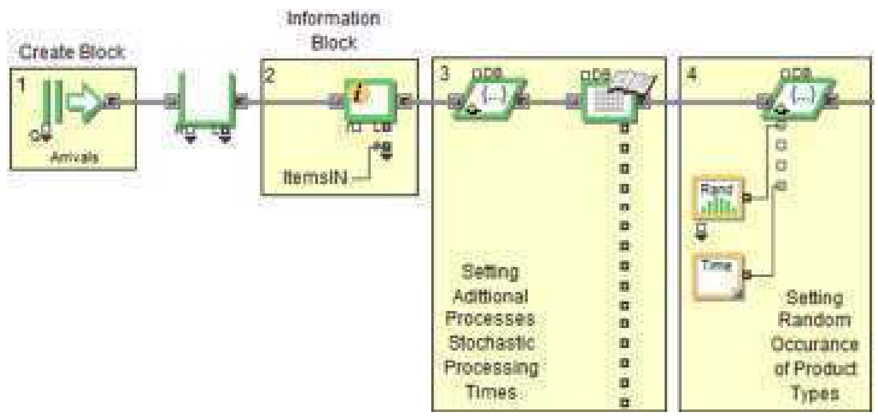


Figure 4-3: Products arrivals.

As mentioned earlier in the data collection section, arrival of products is distributed exponentially with a mean of 117 minutes per arrival. This value is set in the Create block as shown in Figure 4-4.

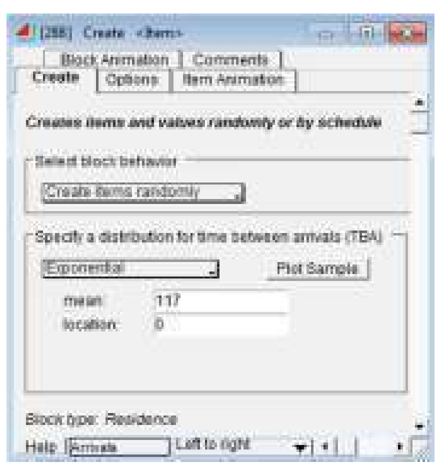


Figure 4-4: Arrivals distribution.

On the other hand, Figure 4-5 shows using a Set block to define the activities that are common between items such as tag activities, order revising, tracking, and others as database attributes. A Read block is used to access the database and read the values of these processing times.

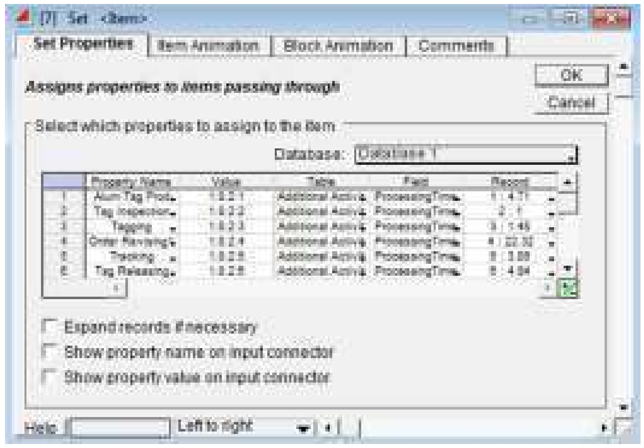


Figure 4-5: Setting the additional activities.

Finally, arrivals are divided into five different products according to an empirical distribution with probabilities 0.1, 0.064, 0.064, 0.1, and 0.672; respectively. Figure 4-6 shows the dialogue of the Random Number block to set these probabilities.

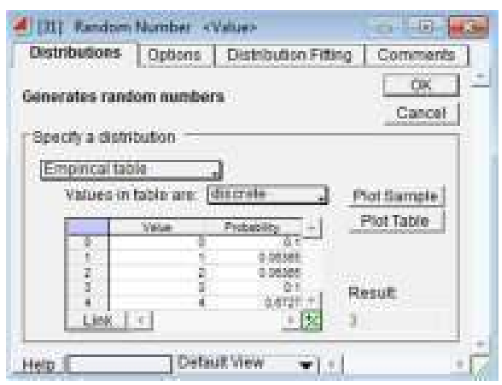


Figure 4-6: Products probability of occurrence.

Setting the Processing Times

Figure 4-7 illustrates how the processing time for manufacturing process is set for all products. Block 1 is a Get block that gets the value of the *ProductType* attribute that was set earlier. The value retrieved from the Get block is used by the Select Item Out block (Block 2) that has five outputs for each of the five products.

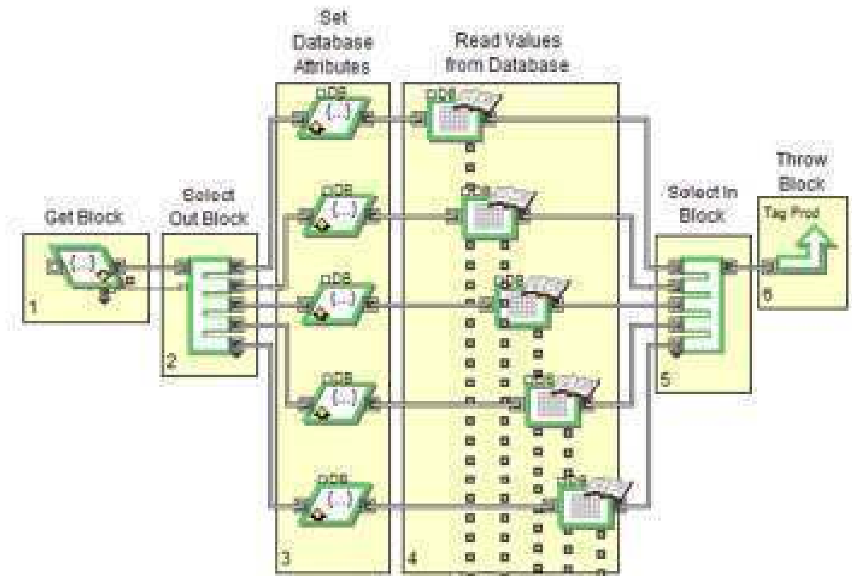


Figure 4-7: Setting the processing time for the five products.

Blocks Group 3 is comprised of five Set blocks that are used to define the database attributes of the processing times for all manufacturing processes required for each product type. Five Read blocks (Blocks Group 4) are then used to read the value from the database of the processing times related to each product as shown in Figure 4-8.

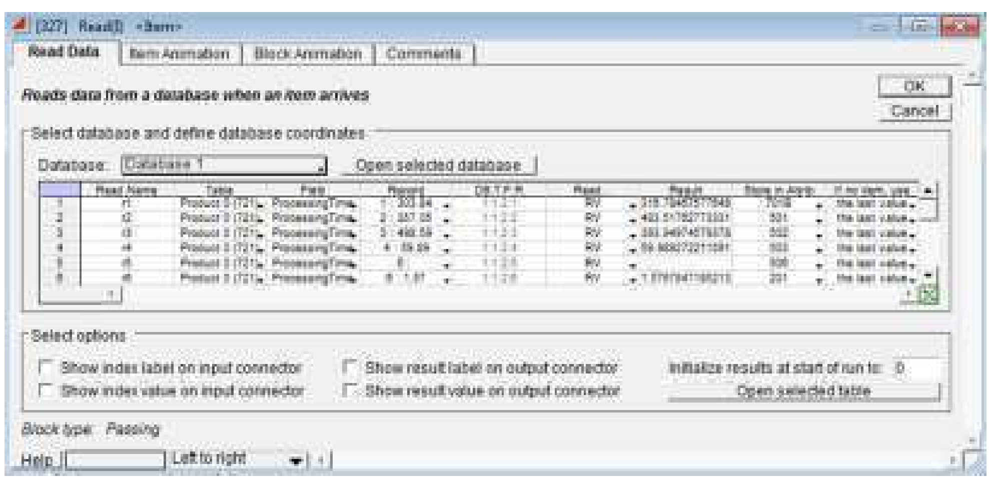


Figure 4-8: Read block dialogue.

At that point all required processing times have been determined. After that, a Select Item In block (Block 5) is used to collect the five product types. Finally, a Throw Item block (Block 6) is used to route the products to start their production (further discussed in the next section).

Products Routing

Routing of items can be done in different ways in ExtendSim. These include Throw Item and Catch Item blocks and Select Item Out blocks combined with Get and Equation blocks.

<u>Throw and Catch</u>

Figure 4-9 shows different examples of products' routings. All products start with tag production; these are received by the Catch Item block (Block 1); where, products are originally sent by a Throw Item block (Block 6 in Figure 4-7).

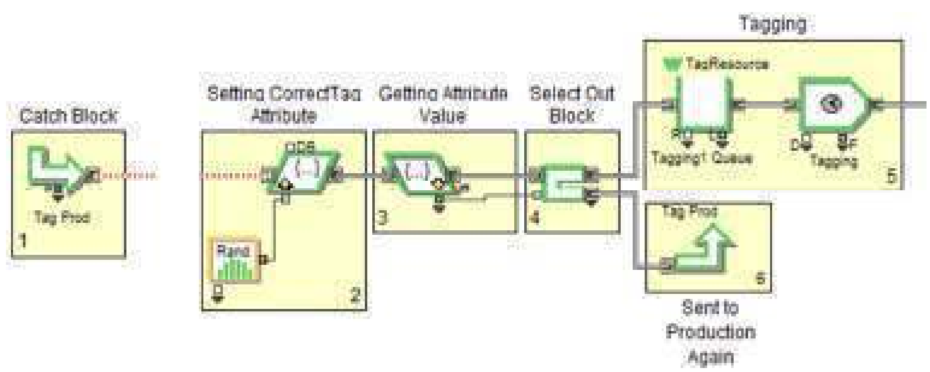


Figure 4-9: Examples of products' routing.

The figure also features another way of routing for items. Aluminium tag production may have some errors that require producing a new tag for a product. After the tag is produced the *CorrectTag* attribute is set using a Random Number block Throw Item (Blocks Group 2).

The Get block (Block 3) retrieves the value of *CorrectTag* attribute and reports this value to the Select Item Out block (Block 4). The Select Item Out block, shown in Figure 4-10, routes the product to tagging (Blocks 5) if the produced tag is accepted; or routes the products to production again (Block 6), which is a Throw Item block that sends the product back to tag production; Block 1.

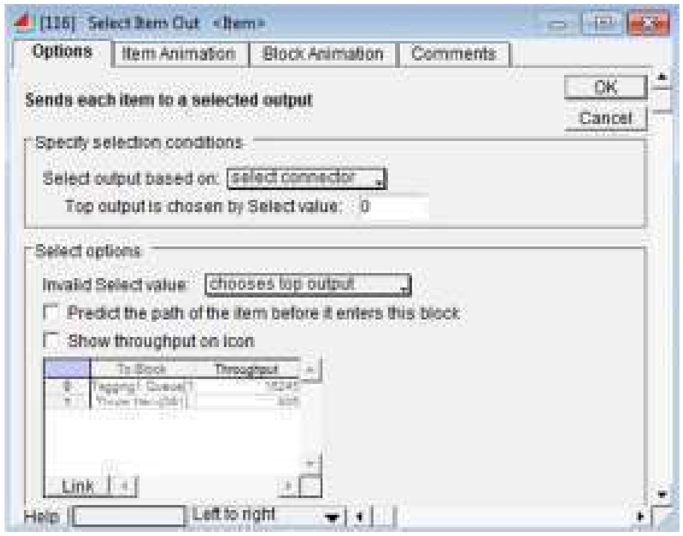


Figure 4-10: Select Item Out block.

The Random Number block, shown in Figure 4-11, generates a value of 0 with a probability of 0.95, representing the acceptance of produced tag; and 1 with a probability of 0.05, representing the rejection of the tag.

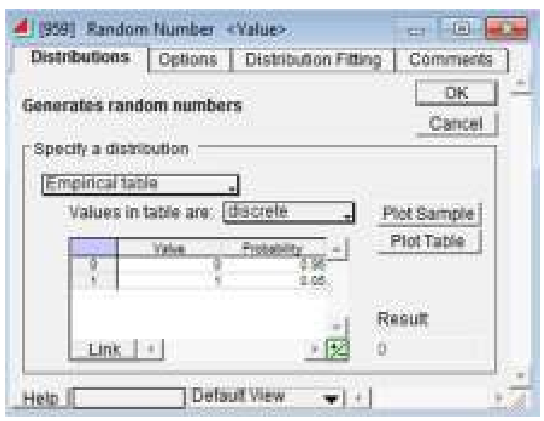


Figure 4-11: Sample of random number block.

Another products routing example; where, an Equation block is used to control routing of the items for the five different products. Each product type has its own flow; yet, products still share some of the routings. Some items are re-entrant in nature and are processed two or three times in the same activity, which requires returning the item to a previous process using Equation block.

Figure 4-12 shows an Equation block (Block 1) that directs the finished item to four different routes depending on two value attributes which are *ProductType* and *Return*.

The result of the Equation block is reported through an output connector that is connected to a Select Item Out block (Block 2). The value of the output connector ranges from 1 to 4 and is used to route the items from top to bottom based on that value using the Throw Item blocks (Blocks Group 3).

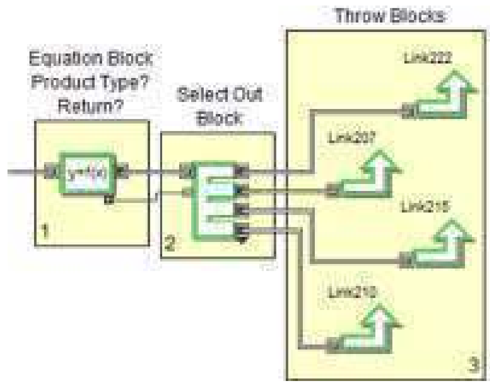


Figure 4-12: Sample of equation block that distribute products according to their attributes.

Figure 4-13 shows the dialogue of the Equation block; where, the two value attributes are shown in the left upper table representing the inputs of the Equation block and the right upper table that represents the outputs; a connector value. The lower part of this figure shows the IF statements that are used to control the routing of the different items based on these attributes.

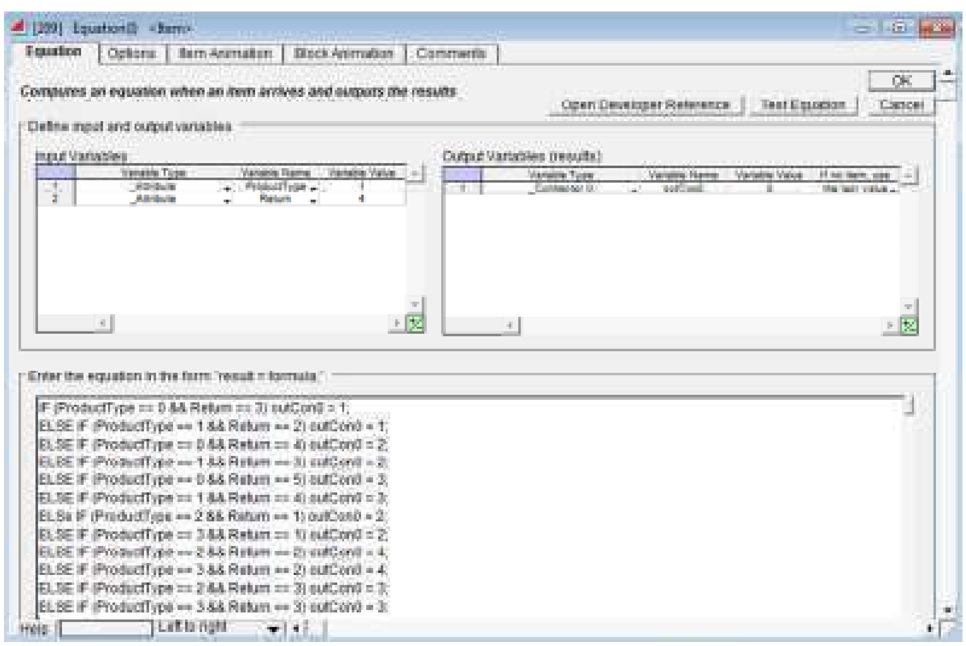


Figure 4-13: Sample of equation statements.

Resources

As mentioned before in data collection section, there are a number of resources that are used in this model. These resources are either labour working at the different departments such as veneer, cane, sanding, painting, and brass departments; or employees working on the whole shop floor such as tag resource, quality assurance employees, and production engineers.

Figure 4-14 shows how to model these resources in ExtendSim. Block 1 is a Queue block that holds products till the required resources are available. The Queue block checks the availability of the resource in the resource pools (Blocks Group 4) assigned to it. If the resource(s) is available the product leaves the queue and starts its processing using the Activity block, Block 2; otherwise, it remains waiting in queue. After processing ends, the product passes by a Resource Pool Release block (Block 3) that returns the resource to the resource pool once again.

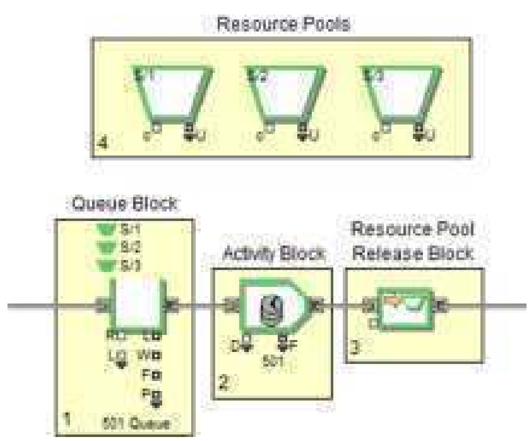


Figure 4-14: Modelling resources using resource pools.

Resource Pool blocks shown in Figure 4-15 are all the blocks used to model the various resources represented in the model. Also, a Shift block is shown in the same figure, which is used to set a schedule for the resource from the carpentry department (*TagResource*) as this resource is usually busy doing different tasks in the carpentry department.

As mentioned earlier, carpentry department is not included in the model and this Shift block implicitly represents the tasks of the *TagResource* in that department.

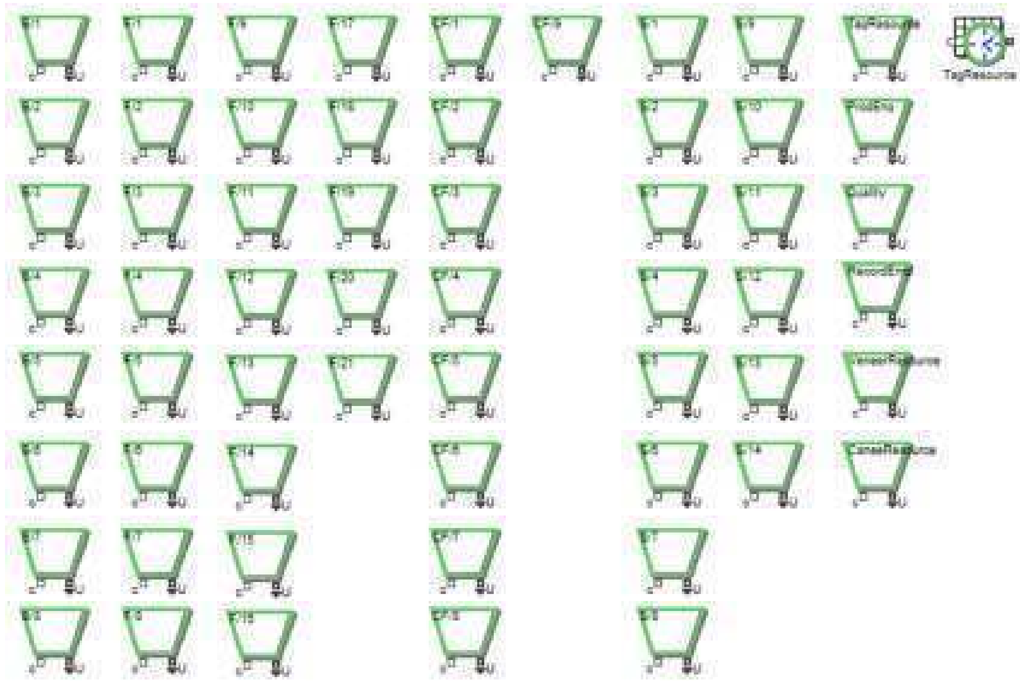


Figure 4-15: Resource pools and resource shift.

Figure 4-16 shows a Queue block for a certain process, where several resources can perform that process. These are the ones listed in the table shown in figure.

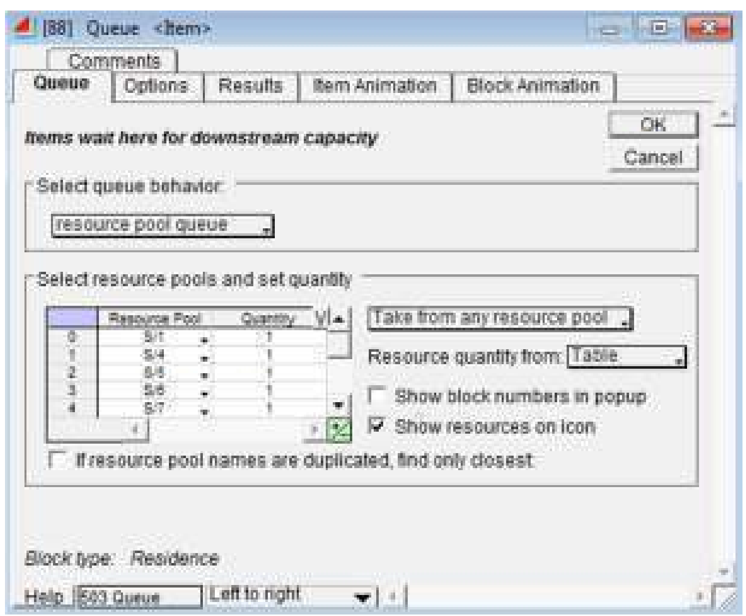


Figure 4-16: Sample of queue block that assign resources to the process.

Figure 4-17 shows the Resource Pool Release block for a certain process, which releases the resource according to its name.

Figure 4-17: "Resource Pool Release" block that releases resources after a finishing process.

Batching Operations

Batching operations are characteristic of the Chair product. Figure 4-18 starts by determining whether the product is a chair or not; if it is a chair it is sent to batching, if not it is sent to the next processing step (Blocks 1 and 2). Block 3 is a Batch block, which collects every 8 chairs to be outsourced as a batch to the cushioning process. After the cushioning process (Block 4) completes an Un-batch block (Block 5) is used to split the batch into the 8 products. Select Item In block (Block 6) combines all products again and proceeds to the next process.

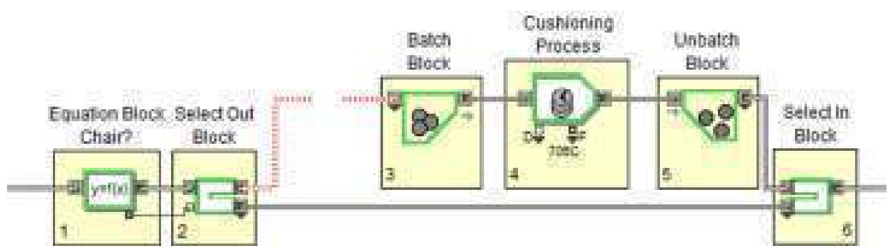


Figure 4-18: Batching for chairs before being outsourced to the cushioning process.

Reporting

This section is one of the most important parts in the model translation process in order to report the results of the model. Figure 4-19 shows the part of the model responsible for calculating the key performance measures of the system under study. Blocks Group 1 are two Information blocks that are used to count the number of items that leaved the system which is called "ItemsOUT", to calculate the current throughput (TH), and also to calculate the current cycle time (CT) for each item using timing attribute *TNow* that was initially set at arrival of products. The second Information block is used to report the average TH and CT. Figure 4-20 shows the second Information block dialogue box.

A Math block (Blocks Group 2) is used to calculate the actual work in process (WIP) by subtracting “ItemsOUT” from “ItemsIN”; where, “ItemsIN” is the number of items that entered the system and counted using Information block at the beginning of the model.

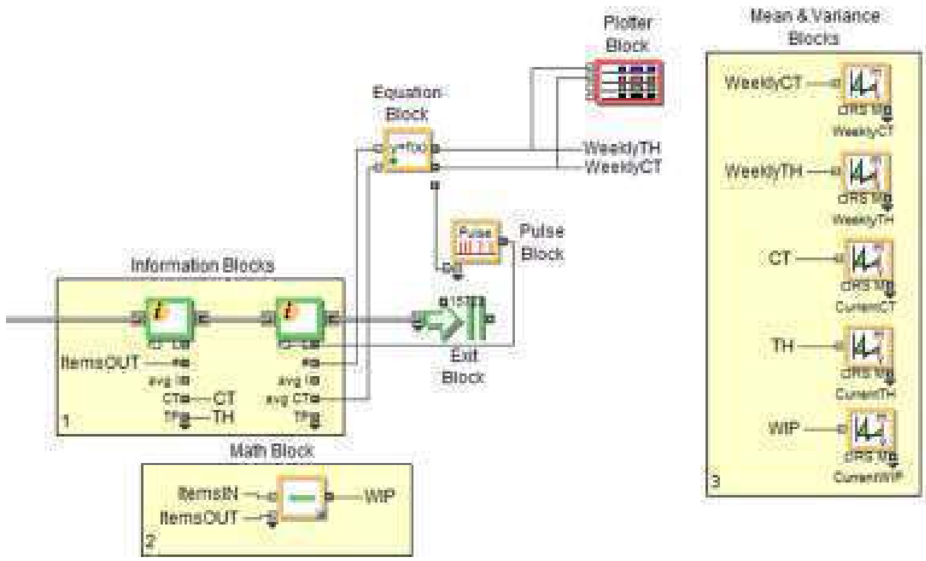


Figure 4-19: Information blocks that retrieve information for items.

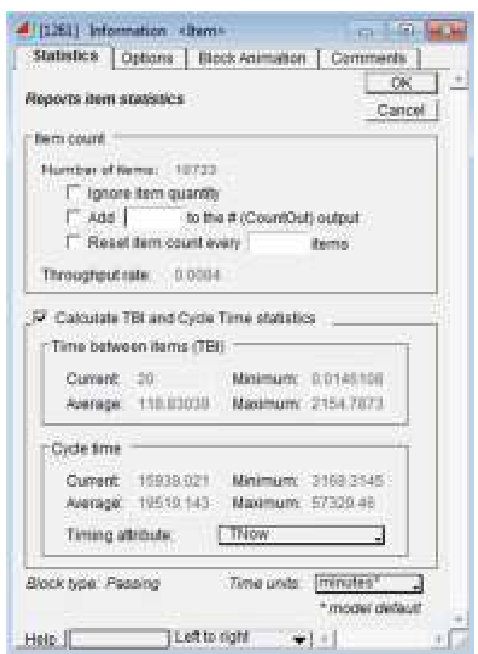


Figure 4-20: Sample of information block.

Finally, Blocks Group 3 are Mean & Variance blocks that are used to calculate the average and the dispersion of the weekly throughput, weekly cycle time, current throughput, current cycle time, and current work in process.

<u>Calculation of Weekly TH and CT</u>

An Equation (Value) block is used to calculate the weekly TH and weekly CT. Figure 4-21 shows the details inside the Equation block where the number of items and the average CT were shown in the left upper table that contains the inputs of the Equation block and the right upper table that contains the outputs which are weekly TH, weekly CT, and connector to Pulse block.

The lower part of this figure shows details of the equation which is first output connector equals the first input connector (number of items leaved the system in a week), the second output connector equals the second input connector (average CT for items leaved the system in a week), and the third output connector equals 3,600 (the number of working minutes in a week) which is directed to a Pulse block.

It is set in the options of this block to compute the values every 3,600 minutes which is the number of working minutes in a week. Pulse block is used to reset the third Information block on a weekly basis, which is after each 3,600 minutes.

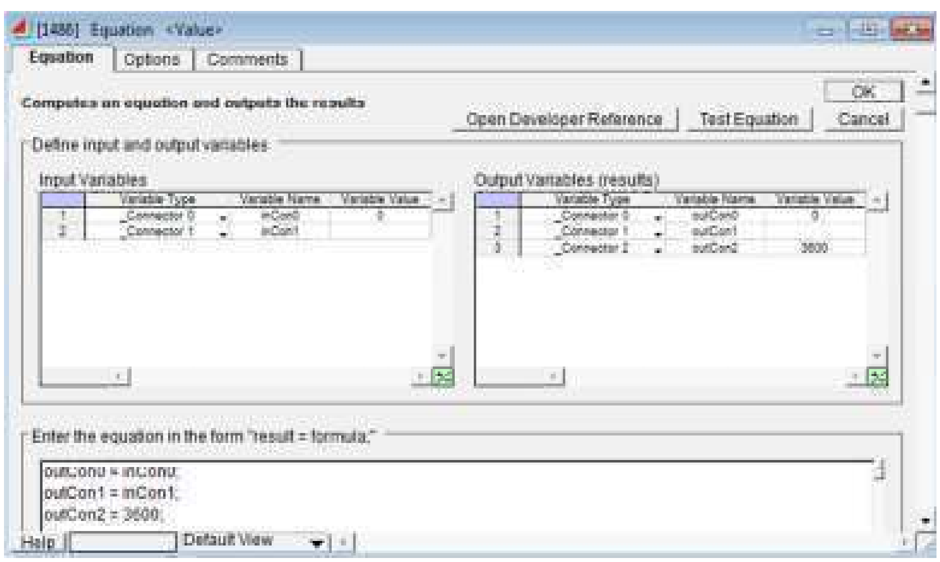


Figure 4-21: Equation block that is used in the calculation of weekly TH and CT.

Plotter, Discrete Event block is used to take the values of the weekly TH and weekly CT from the output of the Equation block and plot them as shown in Figure 4-22.

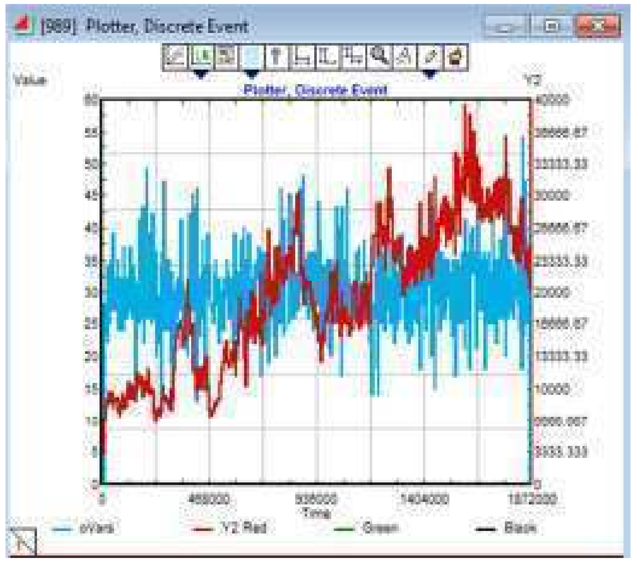


Figure 4-22: Plotter that illustrates results curves.

Statistics block is used several times in the model to report the number of items leaving the system which is read from the Exit block (output), resource pools utilization and availability, and queues average waiting time. It is also used to read the mean and variance of throughput, cycle time, and work in process.

Clear Statistics block is used to reset the results of the first year in the run length because it represents the warm up period. Statistics and Clear Statistics blocks are shown in Figure 4-23.

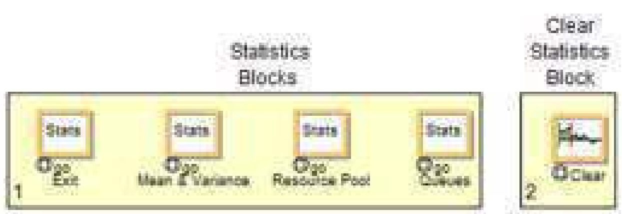


Figure 4-23: Statistics and clear statistics blocks.

Clear Statistics block is used to reset the Activities, Mean and Variance, Resources, and Queues blocks as shown in Figure 4-24.

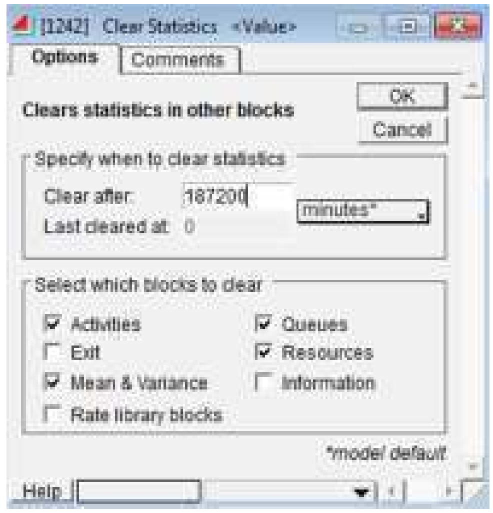


Figure 4-24: Clear Statistics block.

4.2.2 Proposed Model (RFID Modifications)

The proposed model represents the flow of the five products on the shop floor using the radio frequency tags instead of the aluminium tags used in the base model. Some modifications were made in the base model to represent the predicted flow and conditions of items after implementing the radio frequency identification technology. These modifications are explained in the following points:

- Tag production process is replaced by tag programming process to put the required data of the item on the RF (radio frequency) tag memory.
- The probability of error in the process of tag programming decreased from 5% in the base model to 1%.
- Tagging process is made once for any item after its assembly and tag releasing process is eliminated from the proposed model. Because the radio frequency tag is embedded inside the wood. This allows the RF tag to be far from finishing stages.
- The tagging process is done by the production engineer instead of the carpentry worker which eliminates the probability of attaching the RF tag in wrong location.
- Order revising process, before finishing stages start, is distributed according to triangular distribution (5, 10, 5) instead of (20, 30, 20) in the base model, because the production engineer has to move the item from its location, try to

find the aluminium tag, and try to read it carefully to revise what is required by the customer.

- Order revising process before bringing accessories from the storage is done with a probability of 100% because the production engineer makes it instead of giving the brass worker the opportunity to read it or ask the production engineer. Therefore, the error of wrong accessories and the process of correcting accessories were eliminated. Also other order revising processes are done with a probability of 100%.
- It is impossible to lose a tag, because tags are not released from the items. Therefore, tag search process is eliminated.
- The process of producing bronze tags is eliminated too.

Example of removed processes in the proposed model is shown in Figure 4-25; where, the figure clearly shows a certain part of the model in which tag is released before process 501 and the same part in the proposed model in which the tag releasing process is eliminated. The upper part of the figure shows the flow before implementing the RFID technology; which refers to the base model, and the lower part shows the flow after implementing the RFID technology; which refers to the proposed model.

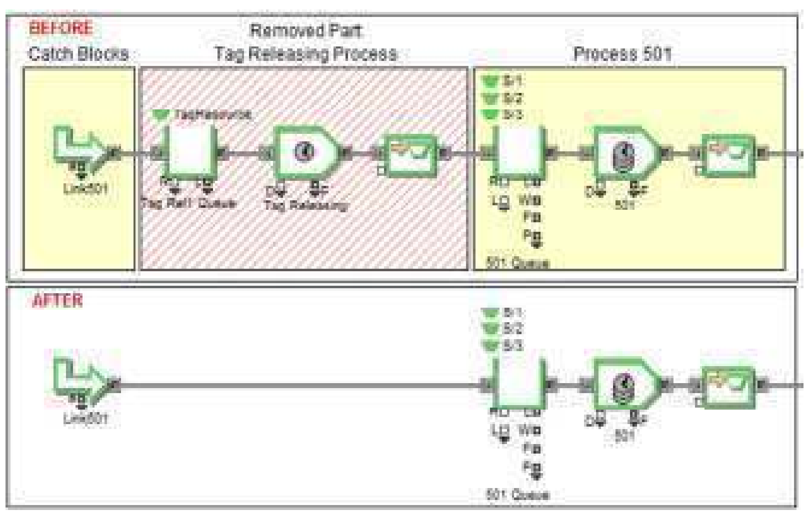


Figure 4-25: Example of removed processes after implementing RFID technology.

Example of removed errors that occurred before implementing RFID technology is shown in Figure 4-26; which is losing a tag during the finishing stages. This error occurs due to the current identification system, but it will not occur in the proposed model after implementing RFID technology. The upper part of the figure shows the flow before implementing RFID technology while the lower part shows the flow after implementing RFID technology.

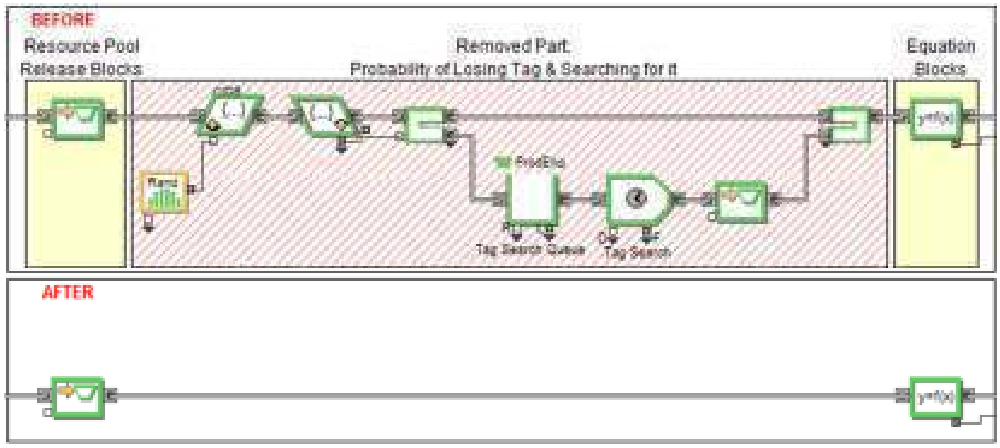


Figure 4-26: Example of removed error after implementing RFID technology.

4.3 MODEL VERIFICATION

Verification means building the model right; hence, to make sure that the computerized model is an accurate representation of the conceptual model. To ensure that the model was built correctly, the input parameters were thoroughly revised; common sense and animation have been extensively used throughout the model translation stage to ensure that the developed model is working as intended. After building the model, through animated runs several errors were detected such as the following:

- Entities got stuck at a queue for certain activities. It was found that wrong processing time was entered for this activity.
- Errors during running the model. It was found that wrong routings were set for certain products.
- Some equations give wrong outputs. It was found that wrong formulae were structured.
- Some of Resource Pool Release blocks released resources more than its capacity. It was found that wrong resource assignment was made.
- Errors in resource assignment which is due to gathering similar resources in one resource pool.
- Routing errors which is due to re-entrant of some entities to certain activities.

Moreover, the model was revised periodically and updated modifications were held from time to time.

4.4 MODEL VALIDATION

Validation is concerned with building the right model; hence, to make sure that the model is an accurate representation of the real system. After the completion of the model, many runs have been carried out for the base model, in order to check the model validity. Using the same inputs of real system in the model must yield an output which is almost equal to that of real system.

The average number of products leaving the system is 1,586 units per year which is more or less the average actual number of units produced from the real system which is 1,594 units based on the actual sales in 2009; where, these results will be showed in details in the next chapter.

Chapter Five

5 EXPERIMENTATIONS, RESULTS, AND ANALYSIS

In this chapter, performance measures used in this study will be defined and explained, simulation setup and parameters will be set, and runs and results of the two models will be represented and analyzed by comparing between the results of both models in order to evaluate the impact of the implementation of the radio frequency identification technology in the selected manufacturing system on the performance measures. Finally, a cost analysis will be conducted to calculate the outcome of radio frequency identification technology implementation on the operating costs of the manufacturing system and the investments required for this implementation.

5.1 PERFORMANCE MEASURES

The performance measures that are evaluated in this study are the output, TH (Throughput), CT (Cycle Time), WIP (Work In Process), resources utilization, and average waiting time in queues. These measures are defined as follows:

- *Output*: the number of finished products that leave the system.
- *TH*: the average number of items produced per unit time.
- *CT*: the time elapsed between the beginning of routing for a certain item until it reaches the end of the routing.
- *WIP*: the number of semi-finished items between the start and end points of the production system.
- *Resources Utilization*: the percentage of working time of a certain resource to the total available time; where resources generally refers to all labour on the shop floor.
- *Average Waiting Time in Queues*: the average time an item spent in a queue waiting for processing.

Improvements in these measures should aim at increasing the output, TH, and resources utilization and; on the other hand, it should also aim at decreasing the CT, WIP and average waiting time in queues.

5.2 SIMULATION SETUP

At this stage, it is necessary to define length of each simulation run, the warm-up period, and the number of replications.

5.2.1 Run Length

Production run length is set to be ten working years; where ten working years = 10 year × 52 weeks/year × 6 days/week × 10 hours/day × 60 min/hr = 1,872,000 minutes

5.2.2 Warm Up Period

Warm up period ensures that the system is working at a steady state and all the outputs are reliable outcomes. Warm up period is assumed to be one working year which is 187,200 minutes at simulation runs of 1,872,000 minutes (10 working years) as shown in Figure 5-1.

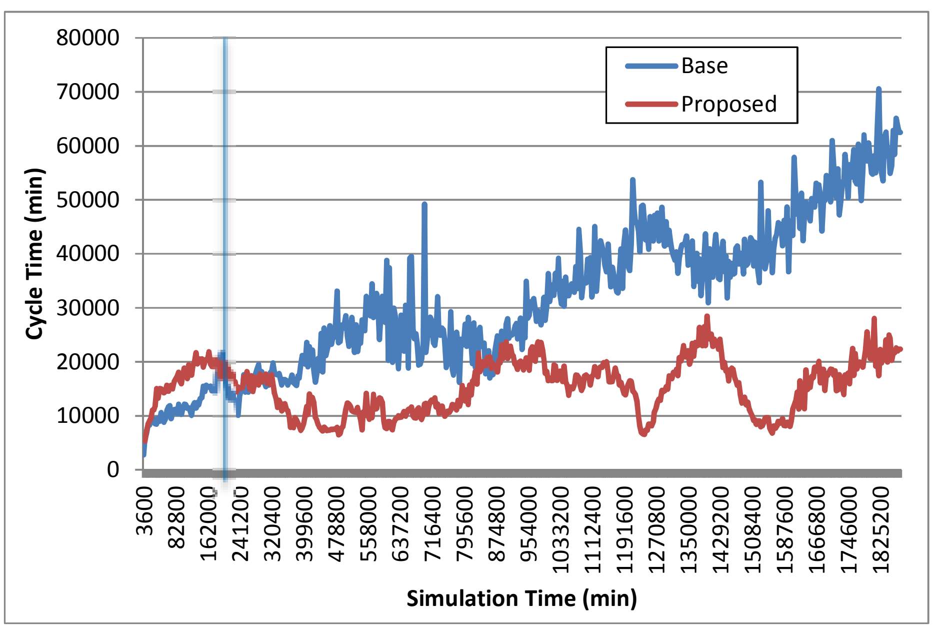


Figure 5-1: Warm up period.

5.2.3 Number of Replications

The number of replications has been set as 20 replications for each model or scenario. Figure 5-2 shows the simulation setup dialogue box with all these settings.

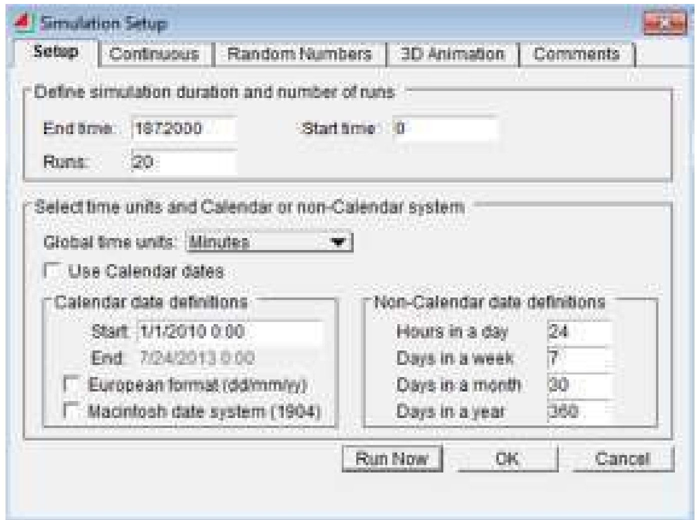


Figure 5-2: Simulation setup.

5.3 SIMULATION RUNS AND ANALYSIS

The previous chapter presented the development of a *base model*, which uses aluminium and bronze tags for the purpose of identification and tracking of products, and a *proposed model* that uses RFID for this purpose. Simulation runs of these models are carried out using the simulation parameters presented in the previous section in order to assess the impact that RFID will have on the selected performance measures. Results of these runs are reported and analyzed in this section.

5.3.1 Output

Output is the number of units produced or released from the model, which is almost the same for the two models. The total number of units produced from the base model is 15,860 over the whole ten years with an average of 1,586 units per year. While in the proposed model output is 15,840 in ten years with an average of 1,584 units per year.

It should be noted that output of the model is counted by the Exit block, which counts the units leaving the system and that output is the only performance measure reported without calculating mean and variance. It is observed that the first item is released from the system after 7,200 minutes and that the model reaches the weekly TH after an average of two weeks meaning that it will have negligible effect on the reported values after averaging ten years.

Hence, the Clear Statistics block was not used to reset the Exit and Information blocks as done for the Activities, Mean and Variance, Resources, and Queues blocks because clearing these blocks will affect the calculation of the TH, CT, and WIP.

5.3.2 Throughput, Cycle Time, and Work In Process

Figure 5-3 illustrates the comparison between the TH in the two models for a single replication. It is observed that the TH is fluctuating around almost the same values for the two models. This is due to the fact that the bottleneck processes, which control the throughput of the models, are the same in the two models and that the bottleneck processes are not affected by the implementation of the RFID system.

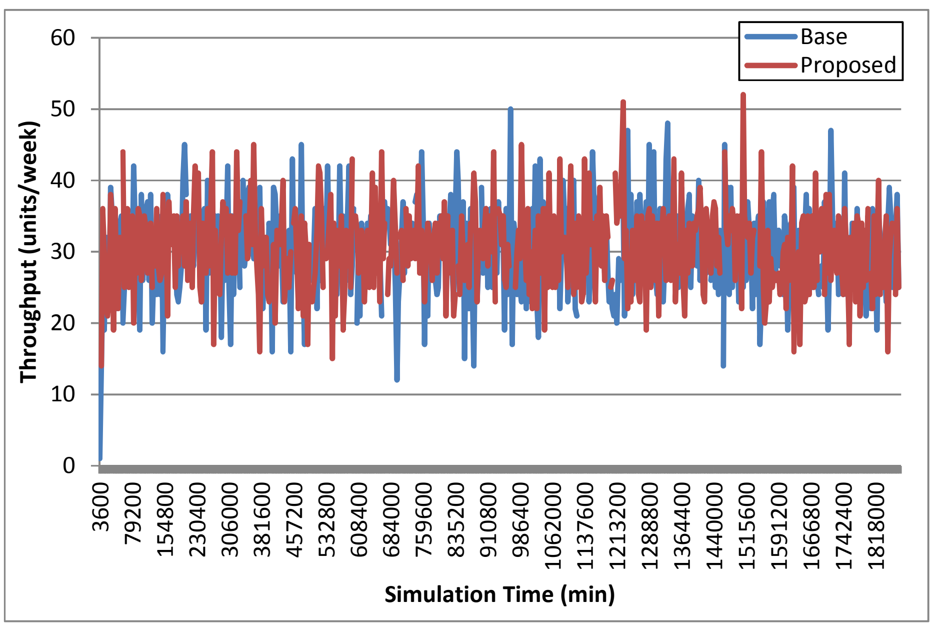


Figure 5-3: TH of the base and proposed models.

On the other hand, the CT significantly decreased in the proposed model as compared to the base model. This decrease is because switching to RFID technology results in eliminating some processes that are related to the current identification system such as the repeated tag attach and release in different parts of the model. Figure 5-4 presents a comparison between the CT in the two models based on a single replication that clearly shows that the CT has decreased.

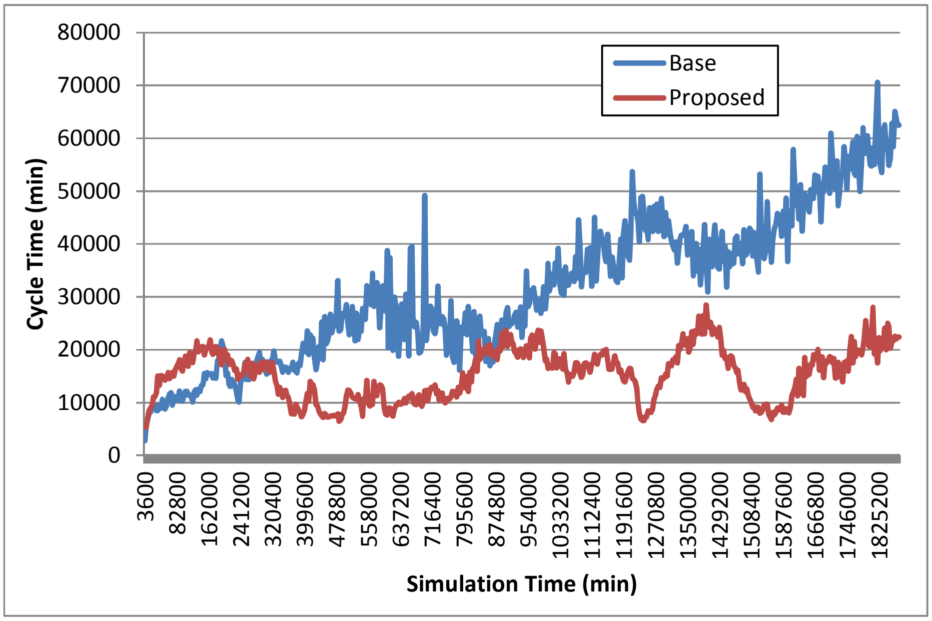


Figure 5-4: CT of the base and proposed models.

Based on Little's Law, the relation between TH, CT, and WIP is as follows:

$$WIP = TH \times CT$$

Referring to this relationship, since TH is on average equal in the two models and since CT has decreased in the proposed model; therefore, the average WIP level in the proposed model decreases too. The average WIP in the base model is 156 units while in the proposed model is 132 units. Average values for weekly TH, weekly CT, and current WIP level for both models are reported in Table 5-1; where, reported values are based on 10 years simulation run, one year warm-up period, and 20 replications. It is clear from these values that the coefficient of variation (CV) lies in the low variability region with minimal variation between the base and the proposed models.

Table 5-1: Comparison of TH, CT, and WIP for the base and proposed models.

Performance Measure	Base Model			Proposed Model		
	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation
Weekly TH	30.54	6.196	0.203	30.49	5.67	0.186
Weekly CT	18,680	5,684	0.304	15,860	5,194	0.327
Current WIP	156	47.67	0.306	131.8	43.56	0.331

5.3.3 Resources Utilization

Due to the large number of resources in the model, resources are classified into three categories and comparisons between the two models are made around these categories. Comparison between the resources utilization of the base model and the proposed model for painting A department; painting B and brass departments; and sanding department and other additional resources; are shown in Figure 5-5, Figure 5-6, and Figure 5-7; respectively. Also, Figure 5-8 shows that the average resources utilization for all resources in the base model is 28%; while, in the proposed model is 26%.

This reduction is due to the fact that RFID implementation reduces the time required for tracking and identification and omits some of the processes that are done in the base model. This directly affects the total time in use for the resources responsible for these processes and results in the reduction in utilization that is clear in Figure 5-7.

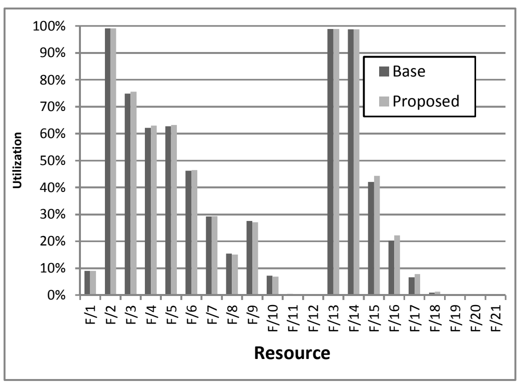


Figure 5-5: Resources utilization of painting department (A).

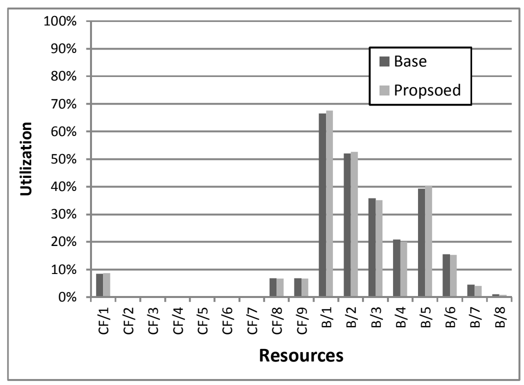


Figure 5-6: Resources utilization of painting department (B) and brass department.

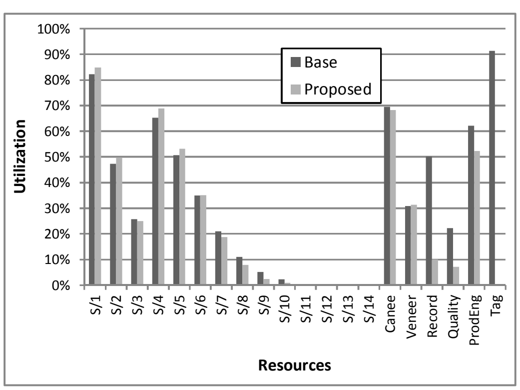


Figure 5-7: Resources utilization of sanding department and other additional resources.

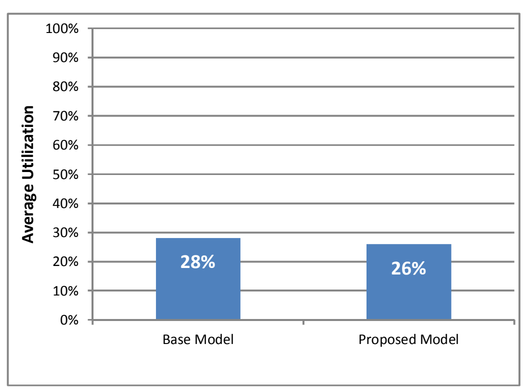


Figure 5-8: Average resource utilization in base model and proposed model.

5.3.4 Average Waiting Time in Queues

Again, queues are classified into three categories and comparisons between the two models are made around these categories. Comparison between the average waiting time in queues of the base model and the proposed model for painting A/B departments; brass, sanding, and veneer departments; other additional queues; are shown in Figure 5-9, Figure 5-10, and Figure 5-11; respectively. Also, Figure 5-12 shows that the average waiting time for all queues in the base model is 278 minutes; while, in the proposed model is 276.5 minutes, which is almost the same.

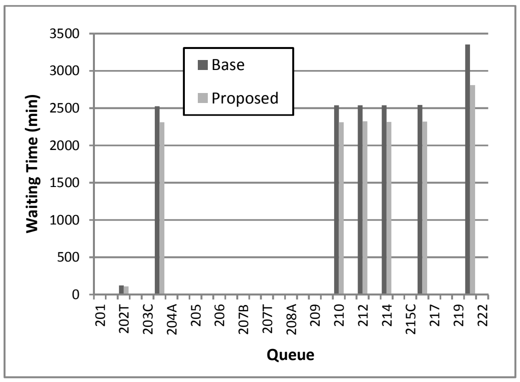


Figure 5-9: Average waiting time in queues of painting departments (A and B).

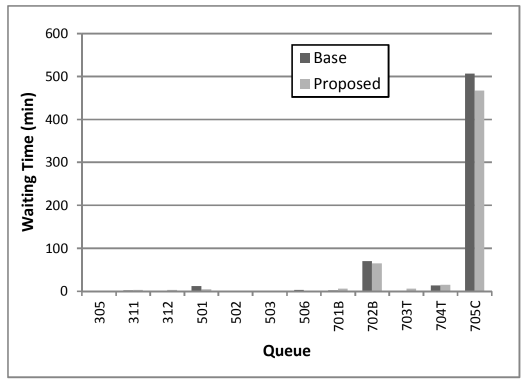


Figure 5-10: Average waiting time in queues for brass, sanding, and veneer departments.

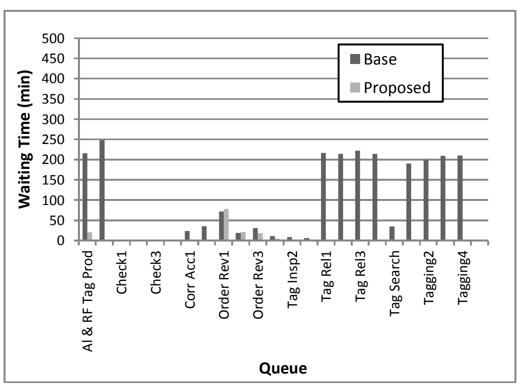


Figure 5-11: Average waiting time in queues for other additional queues.

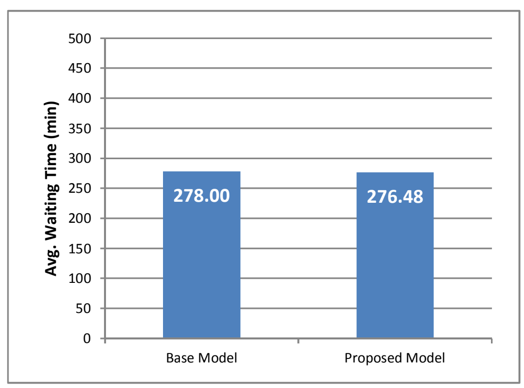


Figure 5-12: Average waiting time for all queues in base model and proposed model.

Average waiting time in all queues remained almost the same for the base and proposed model because of the bottlenecks that exist in the system; where, processes such as 204, 210, 212, 214, and 216 which are spraying operations, are responsible for the greatest portion of waiting time (as shown in Figure 5-9) and these are not affected by the replacement of the aluminium and bronze tags with RF tags. These processes are bottlenecks because they are all done inside the same spray room and using the same two resources which are F13 and F14 (almost 100% utilization as shown in Figure 5-5).

5.3.5 Summary of Results

In this section, a comparison between all the performance measures reported from the base model and the proposed one is conducted. An improvement index is calculated to determine whether the performance measure is improved or not after switching from the base model that represents the current tracking and identification of products to the proposed model that represents the use of an RFID system for tracking and identification.

For output, throughput, and resource utilization (objective is to increase the values of these measures); the improvement index is calculated by subtracting the old value of the performance measure from the new one, then dividing the calculated value by the old value of the performance measure and multiplying it by 100 to change it into percentage as shown in the following equation.

$$\text{Improvement Index} = \frac{\text{New} - \text{Old}}{\text{Old}} \times 100\%$$

On the other hand, for cycle time, WIP, and average waiting time in queues (objective is to decrease the values of these measures); the improvement index is calculated using the following equation:

$$\text{Improvement Index} = \frac{Old - New}{Old} \times 100\%$$

The improvement index shows that the output, TH, and average waiting time in queues are almost similar in the two models and did not improve due to the new RFID technology implementation; while, the CT and WIP are improved by about 15% for each after introducing the new technology. However, the resources utilization has decreased and thus its performance decreased by 7.6%.

Table 5-2 summarizes the performance measures values for the two models and the improvement index for each measure.

Table 5-2: Summary of results of the base and proposed models.

Measure	Base	Proposed	Percentage Improvement
Output	15,860	15,840	-0.13%
Throughput	30.54	30.49	-0.16%
Cycle Time	18,680	15,860	15.10%
WIP	156.0	131.8	15.51%
Resources Utilization	28.15%	26.01%	-7.59%
Waiting Time in Queues	278.00	276.48	0.55%

Figure 5-13 illustrates the improvement index from the base model to the proposed model.

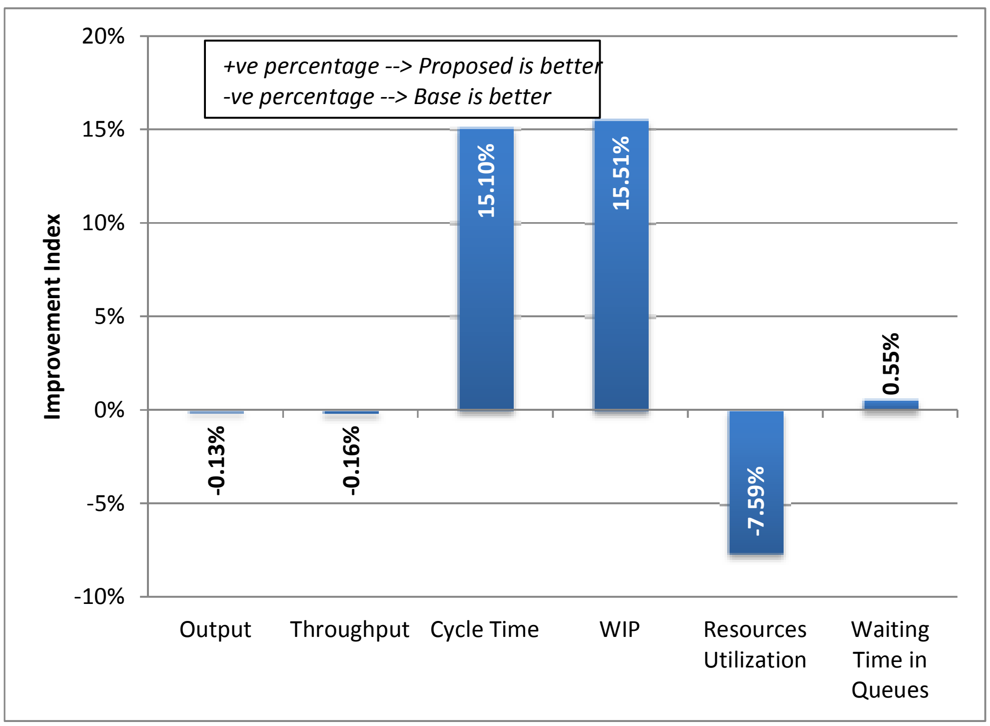


Figure 5-13: Calculated improvement indices for the performance measures.

5.4 MORE RUNS

Results of the previous runs revealed that there a number of resources that are almost idle, which affects the resources utilization. Thus, another model is proposed (scenario 2), which is basically the same as the proposed model presented earlier (scenario 1); however, a number of resources have been removed. This would result in a reduction of operating expenses; yet, the output, TH, CT, WIP, resources utilization, average waiting time in queues must be re-evaluated.

The resources that have been removed are the *tag resource*, one *recording employee*, and *one quality assurance employee*.

Therefore, a comparison is made between the base model and scenario 2 model.

5.4.1 Output

The output of the base model is 15,860 in the total length of the run which is ten years, which means that the output of the base model in one year is on the average 1,586 units. While in the proposed scenario 2, the total output in the ten years is 15,850 units, which means that the output of the proposed scenario 2 in one year is on the average 1,585 units.

5.4.2 Throughput, Cycle Time, and Work In Process

It is observed that the TH is almost constant in even after removing some resources. The proposed scenario 2 leads to the same TH. Figure 5-14 illustrates the comparison between the TH in the base model and the proposed scenario 2 for single replication.

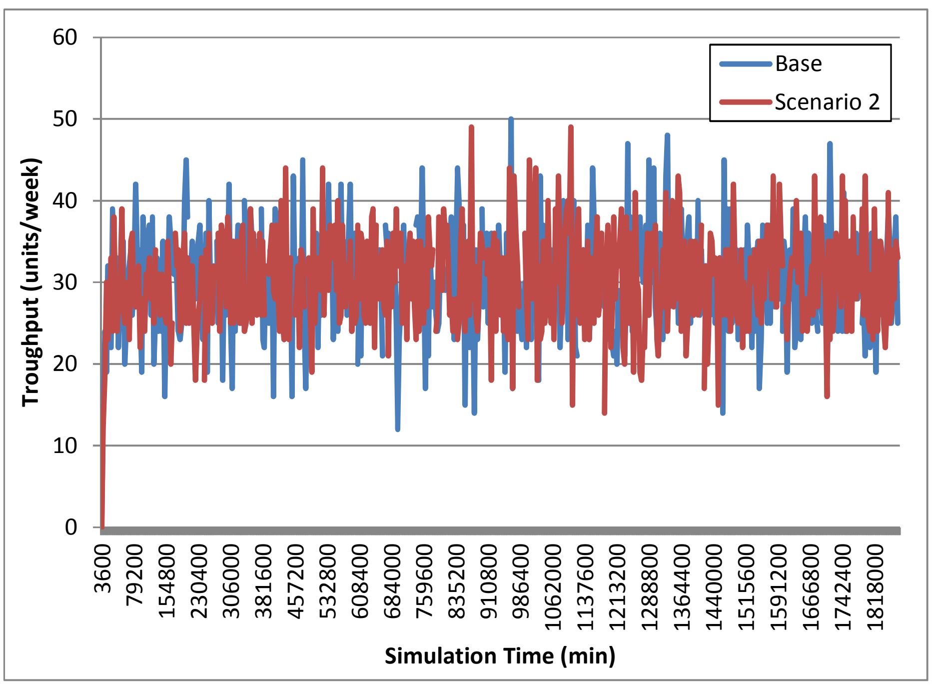


Figure 5-14: TH of the base model and proposed scenario 2.

The CT decreased in the proposed scenario 2 as in the base model but not like the decrease of the proposed scenario 1. This is because the effect of the reduction of some resources such as *quality assurance employee* and *recording employee*. Figure 5-15 shows the comparison between the CT in the base model and proposed scenario 2 for single replication.

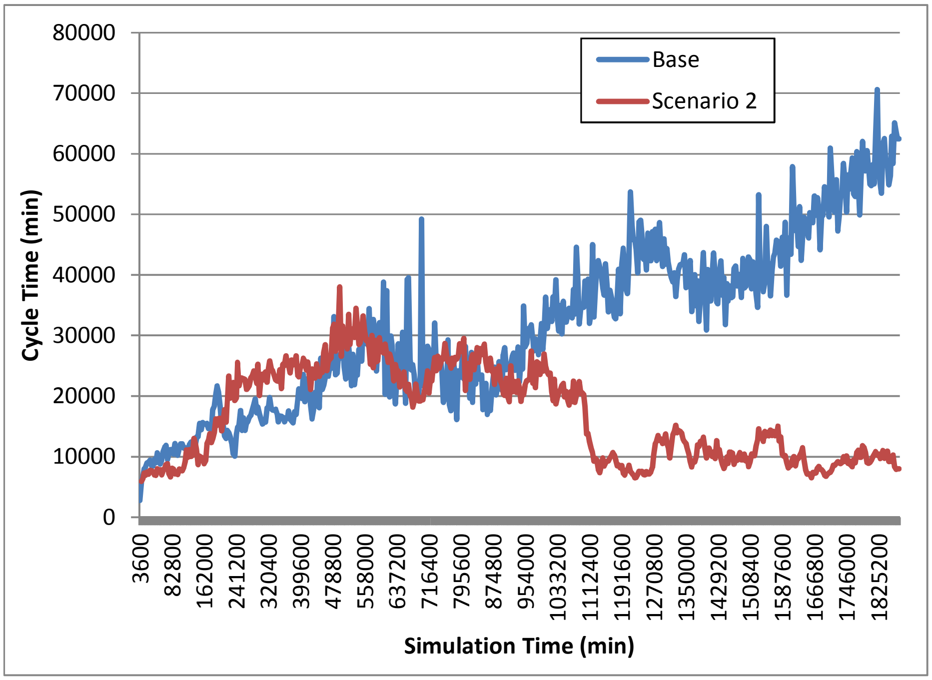


Figure 5-15: CT of the base model and proposed scenario 2.

Referring to the relationship stated before between TH, CT, and WIP, the average TH remains the same, average CT decreased in proposed scenario 2; thus, the average WIP in the proposed scenario 2 is decreased also. The average WIP in the base model is 156 units while in the proposed scenario 2 is 138.4 units. Comparison between weekly TH, weekly CT, and current WIP level for the base model and proposed scenario 2 are reported in Table 5-3. Coefficient of variation is still in the low variability region.

Table 5-3: Comparison of TH, CT, and WIP for the base model and proposed scenario 2.

Performance Measure	Base Model			Proposed Scenario 2		
	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation
Weekly TH	30.54	6.196	0.203	30.5	5.778	0.189
Weekly CT	18,680	5,684	0.304	16,650	5,027	0.302
Current WIP	156	47.67	0.306	138.4	41.86	0.302

5.4.3 Resources Utilization

The resources utilization was definitely affected by the changes in the resources in the proposed scenario 2. Comparison between the resources utilization of the base model and the proposed scenario 2 for painting A department; painting B and brass departments; and sanding department and other additional resources; are shown in Figure 5-16, Figure 5-17, and Figure 5-18, respectively.

Also, Figure 5-19 shows that the average resources utilization for all resources in the base model is 28%, in the proposed scenario 1 is 26%, and in the proposed scenario 2 is 38%. The increase of the average utilization of resources in the proposed scenario 2 is due to the removal of some resources that have a very small utilization, which leads to the usage of the remaining resources more than before.

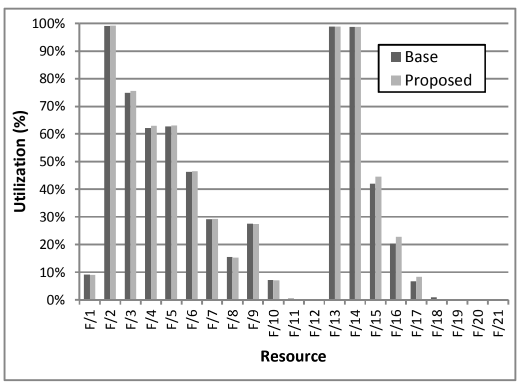


Figure 5-16: Resources utilization of painting department (A).

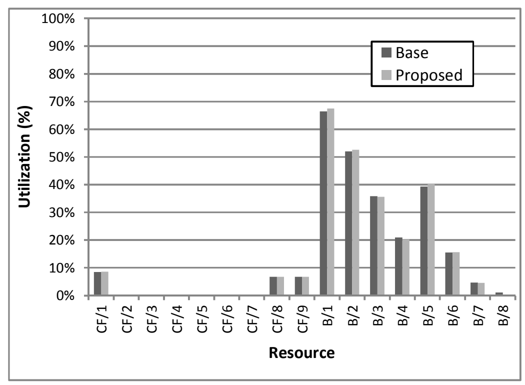


Figure 5-17: Resources utilization of painting department (B) and brass department.

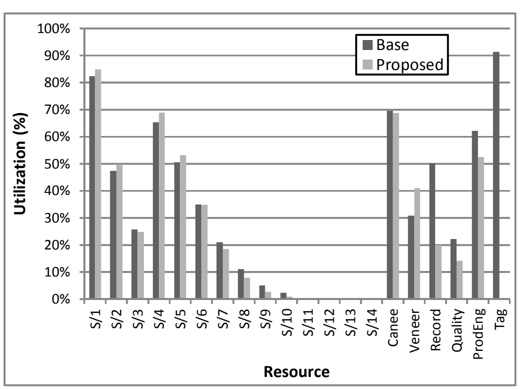


Figure 5-18: Resources utilization of sanding department and other additional resources.

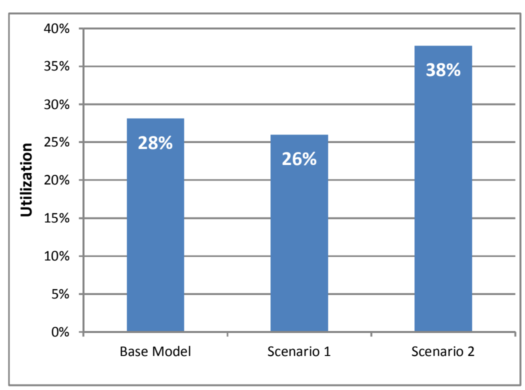


Figure 5-19: Average resource utilization in base model and proposed models.

5.4.4 Average Waiting Time in Queues

The average waiting time in queues was affected also by the changes made in the resources in the proposed scenario 2. Comparison between the average waiting time in queues of the base model and the proposed scenario 2 for painting A/B departments; brass, sanding, and veneer departments; other additional queues; are shown in Figure 5-20, Figure 5-21, and Figure 5-22, respectively.

Also, Figure 5-23 shows that the average waiting time for all queues in the base model is 278 minutes, in the proposed scenario 1 is 276.5 minutes, and in the proposed scenario 2 is 286.3. It was observed that it increases slightly in the proposed scenario 2; due to the reduction of resources.

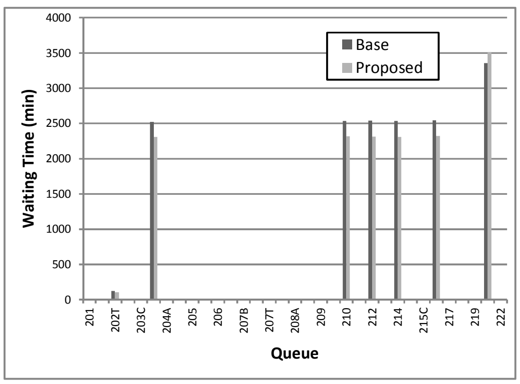


Figure 5-20: Average waiting time in queues of painting departments (A and B).

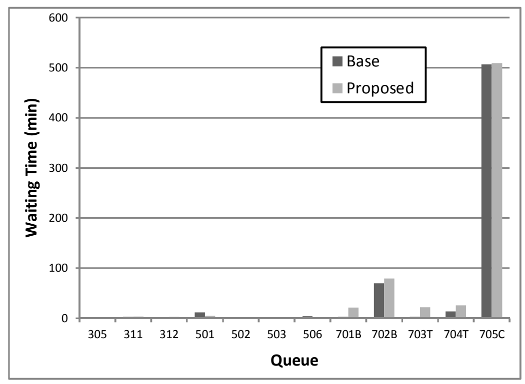


Figure 5-21: Average waiting time in queues for brass, sanding, and veneer departments.

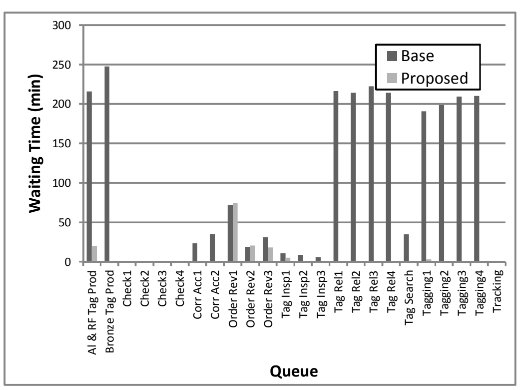


Figure 5-22: Average waiting time in queues for other additional queues.

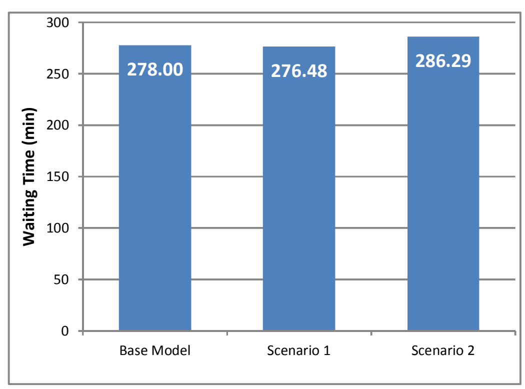


Figure 5-23: Average waiting time for all queues in base model and proposed model.

5.4.5 Summary of Results

All performance measures reported from the base model and the two proposed scenarios are now compared. The improvement index is calculated again to determine whether the performance measure is improved. Table 5-4 summarizes the performance measures values for the base and the two proposed scenarios and the improvement index for each measure.

Table 5-4: Summary of results of the base model and proposed scenario 2.

Measure	Base	Proposed Scenario 1	Proposed Scenario 2	Scenario 1 %age Imp.	Scenario 2 %age Imp.
Output	15,860	15,840	15,850	-0.13%	-0.06%
Throughput	30.54	30.49	30.5	-0.16%	-0.13%
Cycle Time	18,680	15,860	16,650	15.10%	10.87%
WIP	156.0	131.8	138.4	15.51%	11.28%
Resources Utilization	28.15%	26.01%	37.75%	-7.59%	34.13%
Waiting Time in Queues	278.00	276.48	286.29	0.55%	-2.98%

Figure 5-24 illustrates the improvement indices calculated for the two proposed scenarios compared to the base model.

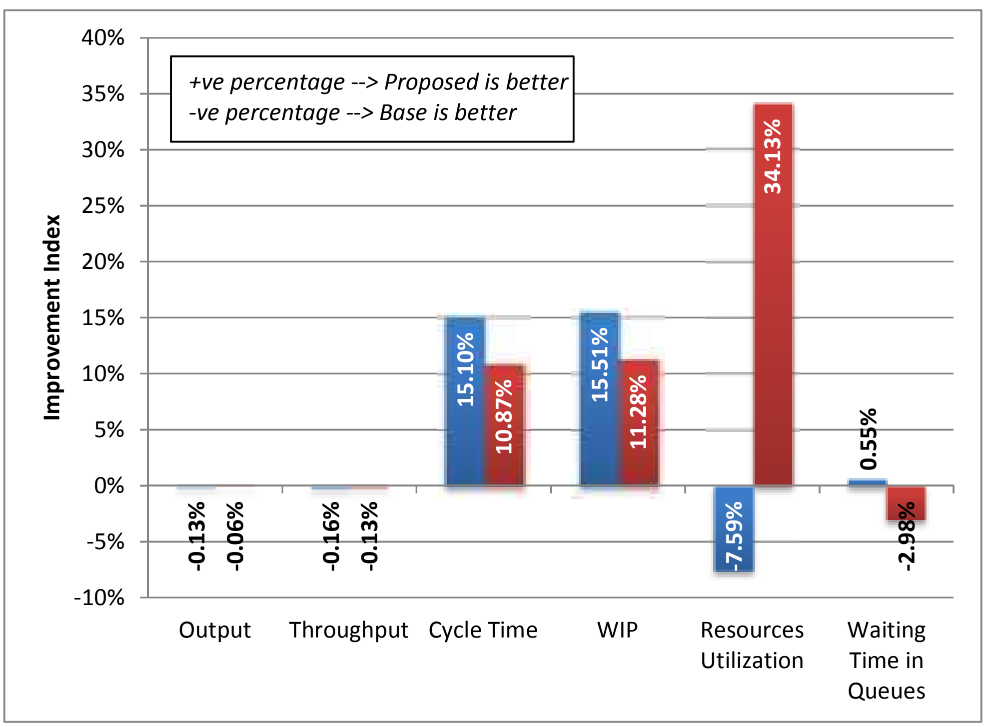


Figure 5-24: Calculated improvement indices for the performance measures of the two scenarios.

Compared to the base model, cycle time improved by almost 11%, WIP also improved by almost 11%, and resources utilization improved by 34%. However, waiting times in queues increased and resulted in poorer performance by almost 3%. Outputs and throughput remained almost unchanged.

Compared to scenario 1 model, resource utilization is much better; however, reducing the resources resulted in higher cycle times, higher WIP levels, and higher waiting time in queues. Outputs and throughput remained almost the same.

To conclude, there is a trade-off between utilization of resources and the remaining measures, which are cycle time, WIP level, and average waiting time in queues. Thus, another factor should be considered, which is the cost of that trade-off. This presented in more details in the next section.

5.5 RFID BENEFITS

After examining several scenarios and analyzing results, cost analysis was used to determine the economical feasibility of the RFID technology and if it has influence on the reduction of the operating expenses.

5.5.1 RFID System Investment Cost

A local vendor has been contacted and is capable to supply the system with the RFID technology configuration requires. The general manager of the company identified his requirements by four RFID portable readers, passive RF tags, software application, training, and start-up before the implementation.

The RF tags cost is not considered as an investment but it is considered as operating costs such as the cost of the current aluminium and bronze tags while the training and start-up costs are offered for free by the vendor given the purchase of the tags and the readers. The annual maintenance cost is 1,000 LE. The other requirements costs are calculated based on an exchange rate of one USD equivalent to six LE. Table 5-5 shows the capital investments of the proposed scenarios. All the previous costs are determined according to an existing vendor in Egypt and can offer all of these requirements.

Table 5-5: Capital investment details of the RFID system in the proposed scenarios.

		Proposed Scenario 1		Proposed Scenario 2	
Item	**Price (LE)**	**Qty**	**Total (LE)**	**Qty**	**Total (LE)**
Readers	6,000	4	24,000	2	12,000
Software Application	2,000	1	2,000	1	2,000
Capital Investment			**26,000**		**14,000**

5.5.2 Resources, Materials, and Inventory Costs

This technology is expected to reduce the operating costs in three different ways which are classified into three categories; resources, materials, and inventory; which are explained next.

First the resources; where, a single resource is eliminated from proposed scenario 1 which is the *tag resource* who makes the tagging processes; this resource is working mainly in the carpentry department but is assigned to do these tasks that take about 25% from his working hours; therefore, his annual salary is considered as 25% from his actual salary.

While in proposed scenario 2, in addition to the *tag resource*, other resources were eliminated which are; one *recording employee* who tracks the items and a *quality assurance employee* who assures the quality of the products. This leads to reducing the readers from four to two. Table 5-6 shows the annual salaries of all employees included in the identification process.

Table 5-6: Resources annual salaries.

Resource Name	Annual Salary (LE)	Qty	Total (LE)
Tag Resource	1,500	1	1,500
Recording Employee	7,200	2	14,400
Quality Assurance Employee	9,000	2	18,000
Production Engineer	10,800	1	10,800

Second, the materials costs those are required for the production of the aluminium and bronze tags in the current identification system. These costs will be eliminated completely after the implementation of the RFID technology, while radio frequency tags will be used. Table 5-7 shows all tag types costs and their estimated quantities.

Table 5-7: Tag types costs and their estimated quantities.

Tag Type	Tag Cost (LE)	Qty	Total (LE)
Aluminium Tag	0.5	1,600	800
Bronze Tag	8	1,600	12,800
RF Tag	6	1,600	9,600

Finally, the inventory costs that consist of three main categories, which are raw materials, work in process, and finished goods inventories. The work in process (WIP) inventory is decreased in proposed scenarios. The WIP cost is concerned with materials, labour, holding, interest, and indirect costs that are added to the cost centre of the product. The cost of a single unit in the WIP was estimated to be on the average 500 LE. The current WIP level is 156 units which costs 78,000 LE. This WIP level is reduced in the proposed scenarios; this leads to a reduction in the inventory costs.

5.5.3 RFID System Operating Costs

The total cost of the identification system is calculated before and after introducing the RFID technology, also for the two proposed scenarios. Mathematical formulae were structured to calculate the total cost. The total cost consists of two types of costs which are fixed cost and variable cost.

Fixed Costs

The fixed cost equals the resources salaries and the maintenance cost. The annual fixed cost is calculated as follows:

$$FC = \left(\sum_{i=1}^{m} W_i \times n_i \right) + MC$$

Where;

- FC: is the annual fixed cost
- i: represents the resource type
- m: number of resource types used
- W: is the resource annual salary
- n: is the number of resources
- MC: is the annual maintenance cost

Table 5-8 shows the annual fixed cost of the base model and the proposed scenarios.

Table 5-8: Annual fixed cost of the base model and the proposed scenarios.

Resource Name	Base			Scenario 1			Scenario 2		
	W	***n***	**Total**	***W***	***n***	**Total**	***W***	***n***	**Total**
Tag Resource	1,500	1	1,500	1,500	0	0	1,500	0	0
Recording Employee	7,200	2	14,400	7,200	2	14,400	7,200	1	7,200
Quality Assurance Employee	9,000	2	18,000	9,000	2	18,000	9,000	1	9,000
Production Engineer	10,800	1	10,800	10,800	1	10,800	10,800	1	10,800
Maintenance Cost			0			1,000			1,000
Fixed Cost			**44,700**			**44,200**			**28,000**

Figure 5-25 shows the annual fixed cost of the base model and the proposed scenarios.

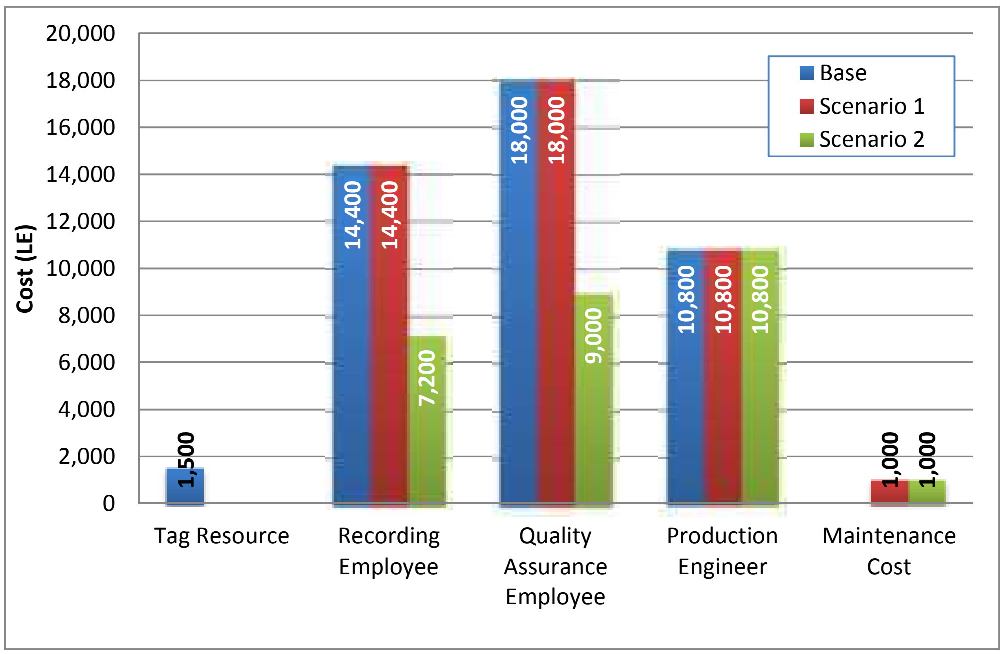


Figure 5-25: Comparison of annual fixed cost for all models.

Variable Costs

The variable cost equals the materials cost and the inventory cost. The variable cost is calculated as follows:

$$VC = \sum_{j=1}^{k} (C_j \times Q_j) + h \times I$$

Where;

- VC: is the variable cost
- j: represents the tag type
- k: number of tag types used
- C: is the cost of a tag
- Q: is the quantity of tags used in the identification system
- h: is the average cost of inventory units
- I: is the average number of work-in-process inventory

Table 5-9 shows the variable cost of the base model and the proposed scenarios.

Table 5-9: Variable cost of the base model and proposed scenarios.

	Base			Scenario 1			Scenario 2		
Tag Type	***C***	***Q***	**Total**	***C***	***Q***	**Total**	***C***	***Q***	**Total**
Aluminium	0.5	1,586	793	0.5	0	0	0.5	0	0
Bronze	8	1,586	12,688	8	0	0	8	0	0
Radio Frequency	6	0	0	6	1,584	9,504	6	1,585	9,510
Inventory	***h***	***I***		***h***	***I***		***h***	***I***	
Work In Process	500	156	78,000	500	132	66,000	500	139	69,500
Variable Cost			**91,481**			**75,504**			**79,010**

Figure 5-26 shows the variable cost of the base model and the proposed scenarios.

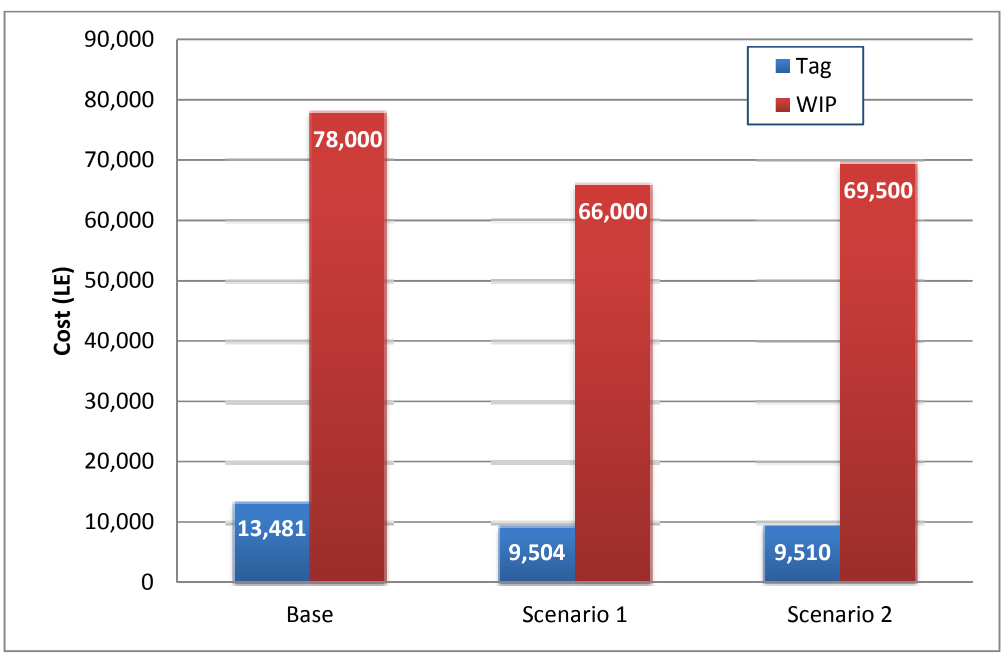


Figure 5-26: Comparison of variable cost for all models.

Figure 5-27 shows the total cost of the base model and the proposed scenarios.

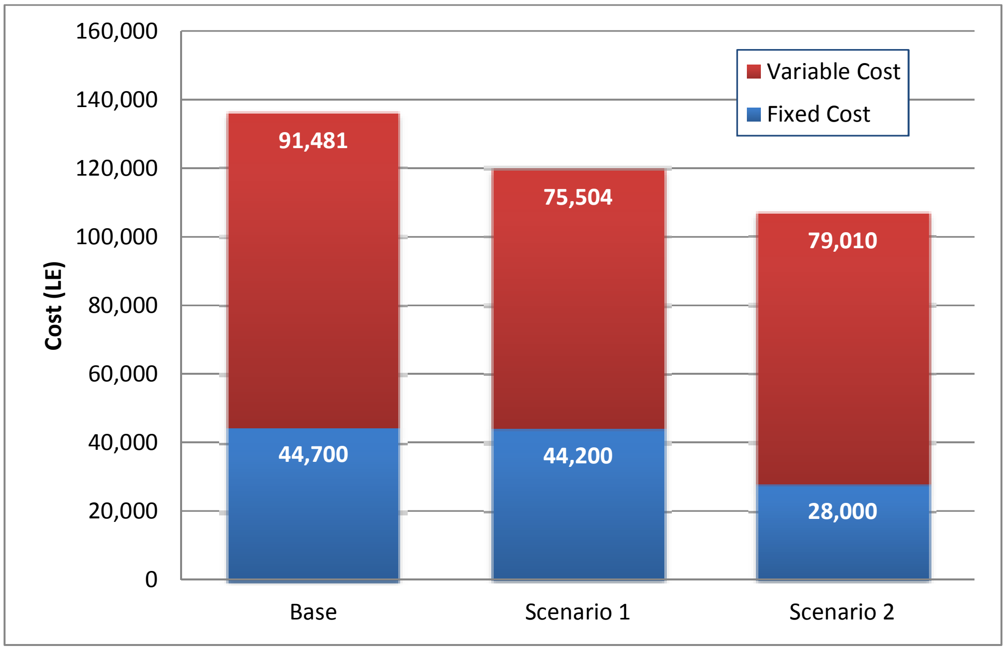


Figure 5-27: Comparison of total cost for all scenarios.

5.5.4 RFID System Savings and Returns

The annual savings equals the difference between the total cost before and after introducing RFID technology. Return on investment (ROI) and payback period (PBP) are calculated to assess the ability of the factory to refund the proposed investments.

ROI equals the annual saving divided by the capital investment, while PBP is calculated by dividing the capital investment by the annual saving. Table 5-10 shows the summary of the costs, savings, investments, ROI, and PBP for the base model and the proposed scenarios.

Table 5-10: Comparison of ROI and PBP between all models.

Item	Base	Scenario 1	Scenario 2	Units
Fixed Cost	44,700	44,200	28,000	LE
Variable Cost	91,481	75,504	79,010	LE
Total Cost	136,181	119,704	107,010	LE
Annual Saving		16,477	29,171	LE
Capital Investment		26,000	14,000	LE
Return On Investment		63%	208%	Percentage
Payback Period		1.58	0.48	Years
Payback Period		19	6	Months

Figure 5-28 shows the annual saving and the capital investment.

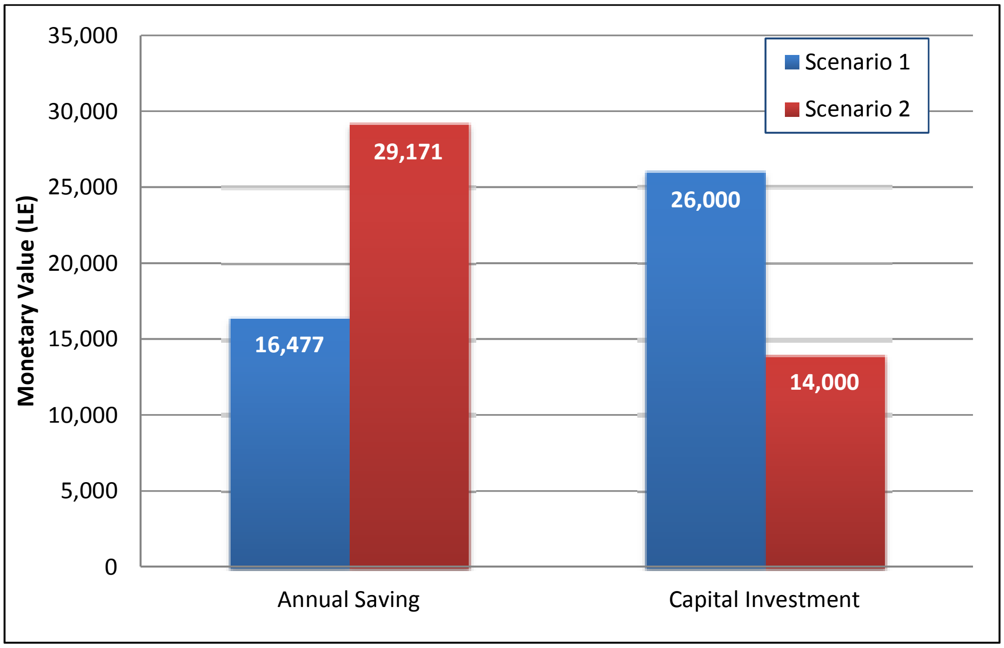


Figure 5-28: Comparing Scenarios 1 and 2 annual saving and capital investment.

Figure 5-29 shows the return on investment and the payback period.

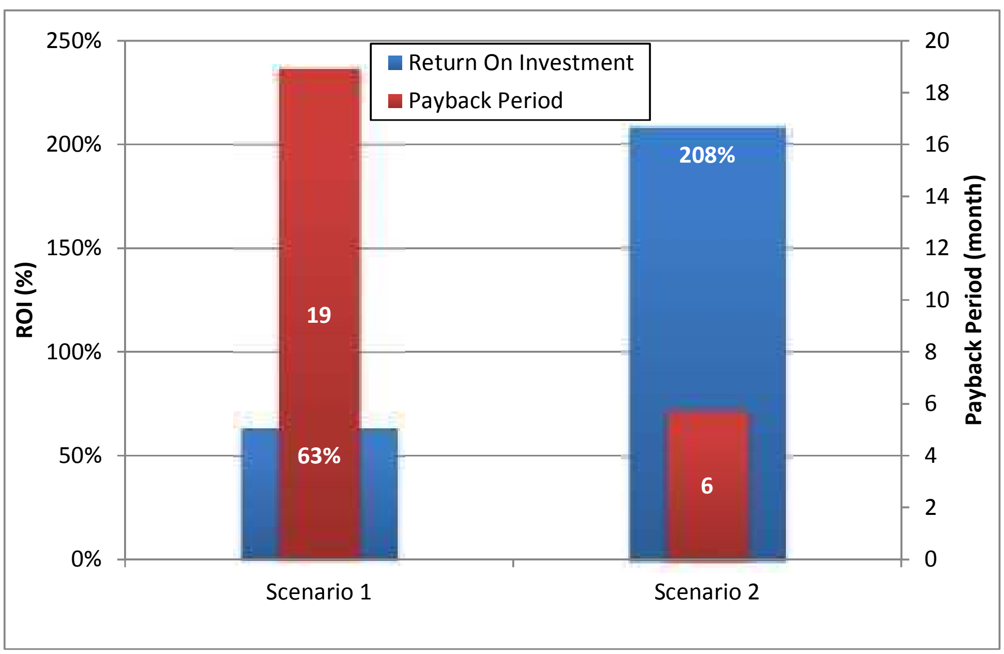


Figure 5-29: Comparing Scenarios 1 and 2 ROI and PBP.

It is clear that the company's expected payback period is 19 months in proposed scenario 1 and six months in the proposed scenario 2, which are considered as small periods of time compared to the benefits that should be achieved due to the implementation of the RFID technology as an identification system.

In addition, other costs are not taken in consideration such as the management and costing department estimations of the loss such as:

- 50% from the accounting department salaries because of the lack of information available from the current system during 10 months.
- 10 - 15% from the accounting department salaries in two months that includes the physical count.
- 20 - 30% of the annual profit of the company is lost due to the unavailability of the financial statements.

Finally, it must be noted that the purpose of this economical study is to show whether or not the RFID system implementation will represent an additional cost to the manufacturer.

To conclude, implementation of the RFID system will help in improving some of the performance measures of the system under study; in addition, other qualitative benefits are gained as well such elimination of tracking and identification errors, improving customer service... etc. The RFID system cost is justifiable and can be recovered within a short period of time. Therefore, it is recommended to implement the RFID system.

Chapter Six

6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This work has investigated the effectiveness of implementing the radio frequency identification technology for products tracking and identification in job shop production systems. This investigation has been made by analyzing a case study in a furniture manufacturing shop floor that suffers in the tracking and identification of its items inside the facility. This type of industry is considered as a job shop manufacturing system in which processes are based on the labour force and their skills. This leads to a high variability in the processing times, a lot of human errors, and tough tracking process.

After system analysis and data collection, a simulation model has been built in order to represent the current situation of the items flowing on the shop floor and the current identification system that is used by the management of this company, which is a manual identification and using handmade labels or tags made from aluminium. This method leads to extra time before production process starts, a lot of errors in the labels or tags production, and difficult identification process.

The simulation model is used to evaluate the items flow after introducing the new proposed technology and its impact on certain performance measures related to the flow, resources, and costs which are; output, throughput, cycle time, work in process, resources utilization, and average waiting time in queues.

Three models are developed, which are: base, first proposed, and second proposed. Runs and experiments with these models have been conducted to compare and analyze their results for the selected performance measures. Finally, a cost analysis is made in order to estimate the economical feasibility of the adoption of the RFID technology on the system.

This chapter reports the most important findings and conclusions of this work accompanied by recommendations and directions for future work.

6.1 CONCLUSIONS

Conclusions drawn from this work are:

1. *Using radio frequency identification technology.*

- RFID technology was primarily invented for automatic data capture and is often referred as a tracking and tracing technology. Leading companies from a variety of industries have adopted RFID to enhance better visibility across their operations.
- The RFID technology is one of the most important and booming technologies in the coming years.
- The RFID technology has a significant influence on the improvement of the tracking and identification processes in all applications particularly retail and manufacturing.
- Literature reviewed didn't show enough evidence of application of RFID in job shop manufacturing systems, which is very complicated and unorganized due to its dependency on labour mainly.

2. *Results of simulation run of the proposed scenario 1.*

- Scenario 1 model reflects the implementation of a basic RFID system for tracking and identification of products.
- Compared to the base model, proposed scenario 1 performed better on cycle time, work in process which have decreased by 15%; however, resources utilization has decreased by 7.5% which could be considered as a good indication because resources should be reduced and hence reduces the cost, while almost the same on output, throughput, and average waiting time in queues.
- Implementation of the RFID system cannot improve the manufacturing processes (throughput cannot be improved); however, it can help in providing a better flow of materials through the shop floor as indicated by the improvement of cycle time and work-in-process levels.
- A clear bottleneck on the shop floor has been identified by its high waiting time in queue and high resource utilization, which is the spray room operation. This

should be considered for further analysis; for example adding more resources to perform this process or, providing extra space for another spray room.

3. *Results of simulation run of the proposed scenario 2.*

- Scenario 2 model reflects the implementation of a basic RFID system for tracking and identification of products; however, this model is run with fewer numbers of resources.
- Compared to the base model, cycle time improved by almost 11%, WIP also improved by almost 11%, and resources utilization improved by 34%. However, waiting times in queues increased and resulted in poorer performance by almost 3%. Outputs and throughput remained almost unchanged.
- Compared to scenario 1 model, resource utilization is much better; however, reducing the resources resulted in higher cycle times, higher WIP levels, and higher waiting time in queues. Outputs and throughput remained almost the same.
- Although this model has been run with fewer resources; yet, CT and WIP are still performing better than the base model. In addition, the model resulted in better performance relative to resource utilization. This gives an indication that resource allocations should be revised.

4. *Cost analysis*

- The RFID technology has a relatively high investment cost but it leads to several benefits and eliminates different errors that costs a lot.
- It is feasible to introduce the RFID technology in such a system and the return on investment will be very promising in both proposed scenarios.
- Proposed scenario 1 has an extra resources and small cycle time which leads to less work in process but a high cost of resources.
- In proposed scenario 2, resources are reduced which leads to reduction in the cost of resources but the cycle time and the work in process increased. Therefore, total cost has to be calculated to compare between tradeoffs that have conflicting objectives.

5. RFID system implementation

- RFID system will result in a better operational performance than the current products' identification and tracking system.
- RFID system costs will be recovered at a relatively short period of time; in fact, it is expected that it will provide annual savings as well.
- Other benefits are associated with the implementation of the RFID system, which have motivated the management to select the RFID system as a solution for the tracking and identification of their products.
- Finally, based on these results and analysis, it is recommended to implement the RFID system for the furniture manufacturer.

6.2 RECOMMENDATIONS FOR FUTURE WORK

It is recommended that further research be undertaken in the following areas:

- The RFID technology adoption could be applied to other locations in the system under study such as storage of raw materials, warehouse of semi-finished products, and warehouse of finished products which will requires fixed readers on each gate of these warehouses and passive RF tags to identify the items inside each warehouse.
- Assessing the applicability of this model on other furniture manufacturing systems or larger furniture firms.
- Comparing different RFID solutions with respect to their impact on the system performance and on the overall cost such as fixed readers.

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APPENDICES

A p p e n d i x A

PUBLICATION ARISING FROM THIS WORK

This appendix shows the publication arising from this work, submitted and accepted by the Flexible Automation and Intelligent Manufacturing 20th Annual conference that was held on July 12 to 14, 2010 California, USA.

Analytical Hierarchy Process for Selection of RFID System: An Application in Retail Supply Chains

Aly M. Owida, Khaled S. El-Kilany, and Aziz E. El-Sayed

Department of Industrial and Management Engineering
College of Engineering and Technology
Arab Academy for Science, Technology, and Maritime Transport
Abou Keer Campus, P.O. Box1029, Alexandria, Egypt

Abstract

Radio frequency identification (RFID) technology is assumed to be a key technology for the retail sector and logistic operations. Mandatory RFID tagging decrees by Wal-Mart and other European companies such as Metro and Tesco, has lead to rapid development of RFID and caused similar companies to consider adopting the technology. Selection of the most suitable RFID system rapidly and correctly before implementation is a major issue due to the various selection criteria and factors involved; where, a typical RFID system consists of radio frequency tags, readers, application software, computing hardware, and middleware. This system structure is determined according to factors such as required quantity of tags, conditions in the area of application, memory, range, and capabilities of the system; in addition to, cost, policy, and security factors. To complicate matters further, a number of vendors, supplying complete or partial RFID solutions, are available to choose from. Therefore, there is a need to select the most appropriate system that match the application according to a predetermined set of criteria. This paper presents a multi criteria decision making approach for selecting the most suitable RFID system using analytical hierarchy process approach (AHP) in order to reach the highest possible benefits from the implementation of this system in retail supply chains.

1. Introduction

Radio frequency identification (RFID) is one of the Automatic Identification and Data Capture (AIDC) systems which are used in order to identify and track an item by scanning it using radio waves through the use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum. RFID is not a new technology, but it is being applied in new ways supported by other new technologies [1]. RFID has become a hot topic in the fields of manufacturing and logistics. It has emerged as part of a new form of inter-organizational system that aims to improve the efficiency of the processes in the supply chain. Cumulative sales of RFID tags for the 60 years up to the beginning of 2006 reached 2.4 billion [2].

Furthermore, RFID has been identified as one of the ten greatest contributory technologies of the twenty-first century. This technology has found a rapidly growing market, with global sales expected to top $7 billion by year 2008. Companies lined up to use RFID and employ experts to improve the efficiency of their operations to gain competitive advantages over time [3]. According to two marketing reports, the revenues of the RFID industry will surge from $188 million in 1996 to $3.5 billion in 2004; in addition, investments in RFID infrastructure that will exceed $1.1 billion by 2007 [4]. Furthermore, labor cost could be reduced up to 40%, depending on the number of handling points and the degree of technology deployment, due to RFID capabilities in automating most of the operations of a distribution center [5].

The aim of this paper is to prepare a set of criteria for selection of RFID solution for retail supply chain concerning the owner's goals which are required to be achieved after the implementation of the RFID system and a set of solutions that are offered by the RFID vendors in order to achieve these goals, which will give the owner the ability to select the best alternative that suits the real case.

The paper starts by defining the RFID solutions for retail supply chains including the importance of the RFID technology to this industry and the RFID system components. Then, analytical hierarchy process (AHP) will be explained as a multi-criteria decision making tool and how it could be used in the selection process of RFID vendors. Followed by, presenting a set of criteria for selecting the most suitable RFID solution and group of factors

*Corresponding Author; E-mail id-alyowida@aast.edu

that affect each criterion with their descriptions will be clarified, in addition to classifying these criteria and factors into two classifications according to the required implementation phases. Finally, conclusions of this work are pointed out.

2. RFID SOLUTIONS FOR RETAIL SUPPLY CHAIN

The retail sector has been among the early adopters of RFID technologies, both internally and within their shared supply chains. Many are already seeing benefits, and are prepared to share their insights regarding those benefits and the implementation issues they needed to address before achieving them. This is generally attributed to the fact that retail supply chains have a large variety of products which increase its complexity. Large hypermarkets can carry upwards of 8,000 different SKU's which creates a lot of work to be done such as order placement, order reception, payment, inventory management, and promotion planning, all of these processes must be performed efficiently and accurately [7].

The retail and manufacturing sectors are the key sectors investing in RFID technology. The revenue in the RFID retail market was $400.2 million in 2004, and expected to grow to $4,169 million by 2011. In addition, 9% of participating retailers have an RFID implementation timeline. During the past two decades rapid progress in the development and applications of information and communication technology has both facilitated and driven retail marketing strategies. The advent of RFID systems is a result of mandate compliance requirements and continuous expansion of item level RFID tagging in a number of major retailers such as Wal-Mart and Target in the US and Marks and Spencer in the UK [8-11].

2.1. IMPORTANCE OF RFID TO RETAIL SUPPLY CHAINS

Based on statistics published in 2005 [12], RFID technology is implemented in the retail industry to the extent that spending on this implementation in the retail supply chain alone has been estimated at $91.5 million. The retail industry implement RFID systems in reaction to the losses of around $180 to $300 billion annually because of poor supply chain visibility and inability to track the location of products throughout the distribution process.

A recent study showed that inventory records were wrong for over 70% of SKU's in a store belonging to a leading US retailer with more than $1 billion in annual sales. RFID technology offers better supply chain management, higher efficiency, less product shrinkage, and more convenience to the consumer through satisfaction and faster check-outs [7].

The manual labor in the retail supply chain could not differentiate between several units of the same SKU, which is very essential for the products that have short shelf life such as dairy products that may have less than 14 days to be expired when arrive to the retail store. So the bottle of milk with a bar code that has just arrived in the retail store is identical to one that arrived four days ago and still sits on the shelf. While RFID enabled retail stores are able to differentiate between these two items and therefore they reduce the price for the one closer to its expiry date to ensure that it was sold on time[7].

2.2. RFID SYSTEMS

The components of an RFID system are illustrated in Figure 1 and are described as follows [2]:

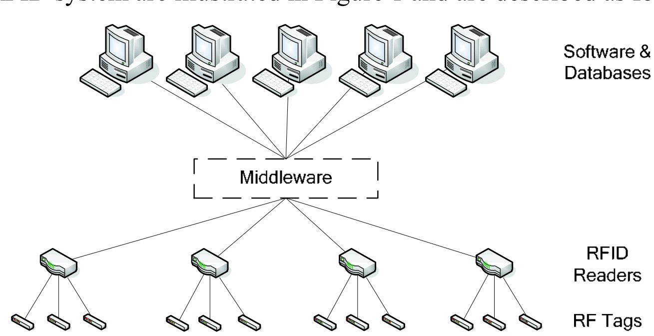

Figure 1: RFID System

- *Radio frequency tag*: which is a memory chip and an antenna that is applied to the desired item and it receives the radio signal via the antenna from the reader then responds by transmitting the data stored in the chip to the reader.
- *Reader*: which captures the returned data from the tag via its antenna and decodes it, then transfers the data to the middleware using a cable or a wireless connection.
- *Computing hardware and software*: converts the data sent by middleware into useful information for the user in order to monitor the desired objects.
- *Middleware*: is responsible for gathering, filtering, and aggregating statistics tag information from the reader and sending them to the backend database for further application usages.

3. AHP AS A DECISION MAKING TOOL

Analytical Hierarchy Process (AHP) is a multi-criteria decision making tool which has been used for the selection of RFID vendors [13-17]. This is mainly due to the large number of factors involved and due to the hierarchical nature of this decision making process, the analytical hierarchy process (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 decision maker is only asked to give judgments about either the relative importance of one criterion against another or its preference of one candidate on one criterion against another. The preferences of criteria against another is also called pairwise comparisons, so when the number of candidates or number of criteria increases the pairwise comparisons increases and the risk of generating inconsistencies increases, for this reason the AHP suits applications with large hierarchy decision trees. However, AHP can measure such inconsistencies and can determine whether these inconsistencies are acceptable or not. As a result, AHP is capable to handle such uncertainty and imprecision issues in the decision making process.

In the AHP approach, the decision problem of selecting the RFID system vendor can be structured hierarchically at different levels with each level consisting of a finite number of decision elements. The upper level of the hierarchy represents the overall goal of the process, which is the decision to be taken; while, the lower level consists of all factors affecting the decision. One or more intermediate levels embody the decision criteria and sub-criteria.

Firstly, the weights of the criteria and the scores of the factors are determined and are considered as decision elements in the second step of the decision process in which the decision maker is required to provide his preferences of vendor by pair-wise comparisons, with respect to the weights and scores. The values of the weights and scores are drawn from these comparisons and represented in a decision table. The last step of the AHP is to determine the weighted sum (score) for each vendor and selecting the highest one.

The next section shows the factors that affect the RFID selection for retail supply chains. Also, it provides a classification of these factors; where, different groups of factors form the main criteria upon which this decision is made.

4. CRITERIA FOR SELECTING RFID SOLUTIONS

Although implementing a complete RFID system in a retail supply chain can have several advantages; yet, selection of the most suitable system that fits the needs and requirements of a company adopting this technology is not a simple task. This is due to the wide range of varieties in each of the RFID system components mentioned before. In addition, to complicate matters further, several vendors are now available to provide either part of or the whole RFID system. For example, RFID tags have two main types which are passive and active tags. Passive RFID tag has no internal power supply, so it gets its energy from the reader. Active RFID tag has an internal power supply, so it gets its energy from a battery. Furthermore, there are other minor types of RFID tags such as semi-passive and semi-active, but they are classified under the main types; passive and active. Usually active tags have larger range and higher cost than the passive tags.

This issue has attracted the attention of several researchers who have addressed the main concerns and issues that should be considered when selecting an RFID system [4, 5, 17-29]. These concerns and issues have been used as the main input for developing the multi-criteria decision making model which is presented in this section. However, these concerns and issues have been tailored specifically for retail supply chains. Two classifications were constructed in order to be used in the AHP model in order to facilitate the multi-criteria decision making process.

4.1. Classification One

The first classification is useful for retailers aiming to implement a partial/complete RFID system in their stores for the first time; therefore they need to know the selection criteria for RFID systems of retail supply chains. This classification is illustrated in **Error! Reference source not found.**.

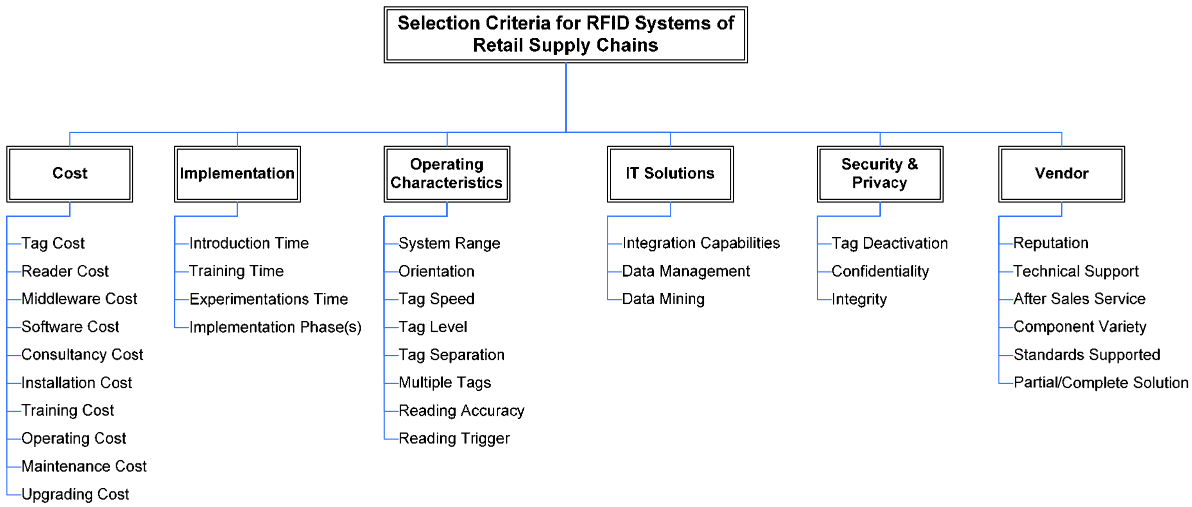

Figure 2: Classification of the Vendor Selection Criteria

Description of the main criteria is shown next and the factors affecting each of these criteria are listed in Table 1.

- *Cost:* The cost criteria involve the total cost required for investment, operations, and maintenance.
- *Implementation:* The implementation criterion involves the time required and desired phases of applying this technology.
- *Operating Characteristics:* The operating characteristics criteria involve all the features and specifications of the RFID system, which identified in retail supply chain.
- *IT Solutions:* The IT solutions criteria involve available capabilities and desired options in the software used in the RFID system in a retail supply chain.
- *Security and Privacy:* The security and privacy criteria involve issues concerning security of the data of the tagged items and privacy of the customers who purchase these tagged items.
- *Vendor:* The vendor criteria involve the required information about the vendor that illustrates what is offered.

Table 1: Classification one factors listing.

Criteria	**Factors**	**Description**
Cost	Tag cost	The cost of a single RF tag
	Reader Cost	The cost of a single reader
	Middleware Cost	The cost of the required middleware to link the data captured by the reader(s) with the existing/new software
	Software Cost	The cost of the software, if not available at the retail store before technology implementation
	Consultancy Cost	The cost of consulting an expert to contribute in the planning and implementation phases

Criteria	Factors	Description
		of the system in the retail store
	Installation Cost	The cost of installing the partial/complete system in the retail store
	Training Cost	The cost of required training for the labor that will deal with the new technology implemented in the retail store
	Operating Cost	The cost of electricity required to operate the components of the whole system
	Maintenance Cost	The cost of preventive/corrective actions that would be taken in order to maintain the system performance as expected
	Upgrading Cost	The expected cost of upgrading the system due to the new emerging technologies in the future, in order to keep the system up to date and able to compete with competitors
Implementation	Introduction Time	The time required for introducing a new technology in the retail store and for the employees
	Training Time	The required time to train the labor force on the new technology which will deal with the new technology
	Experimentations Time	The required time for experimentations to make sure that the system installation is done rightly, the system is performing as expected, and delivering the desired benefits/outcomes
	Implementation Phase(s)	The adoption of the technology in the whole store or at certain phase(s)
Operating Characteristics	System Range	The frequency of the wireless communications between the tags and the readers
	Orientation	The ability of the tag to be read at different orientations with respect to the reader antenna
	Tag Speed	The maximum allowable speed of the tag movements without affecting the system performance
	Tag Level	The decision of the retailer either tagging items or pallets, this criteria is depending on the size and value of the commodity, where item-level tagging is better for high-priced items, while pallet-level tagging is better for inexpensive everyday items
	Tag Separation	The minimum distance required at which two tags could be positioned next to each other without their performance being affected
	Multiple Tags	The maximum number of operational tags that could be present within the transmitting antenna capture zone without the system performance being affected
	Reading Accuracy	The degree of accuracy of the reader and the percentage of its errors such as reading ghost tags or not reading a tag within the capture zone
	Reading Trigger	The ability of using external sensors to detect the movement of tagged items in the reader capture zone in order to switch the reader on
IT Solutions	Integration Capabilities	The capability of the software to consolidate the large amount of data captured by the reader(s) and link these data to the existing supply chain management software
	Data Management	The data required by the retailer from the implementation of such a technology in data management issues and its objectives that are expected to be delivered
	Data Mining	Data needed by any department in the organization and the ability to find it
Security and Privacy	Tag Deactivation	The ability to deactivate the tags after the sale of the tagged item in order to avoid the violation of the consumer privacy
	Confidentiality	The kill functionality and limiting the read range of tags inside the retail store to prevent personal information from being used illegally
	Integrity	The ability to encrypt the data memorized on the tag to prevent anyone from accessing these data
Vendor	Reputation	The number of successful projects that were implemented by the vendor to similar customers working in the retail sector and the feedbacks from these retailers
	Technical Support	The technical support which is offered by the vendor
	After Sales Service	The options and services which are offered by the vendor for his customers after sales and the degree of the customer care
	Component Variety	The different types of components offered by the vendor for example most vendors would supply different sizes, shapes, and memory capacity of RF tags.
	Standards Supported	The interoperability of the hardware offered by the vendor with RFID systems offered by other vendors
	Partial/Complete Solution	The ability of the vendor to offer his customers either a partial solution or a complete solution for the RFID system

4.2. CLASSIFICATION TWO

The second classification is useful for retailers that already applied the RFID technology in their retail store and want to expand the implementation phase(s) or change the desired objectives of the existing system, which may require some changes in the system. This classification is illustrated in Figure 3.

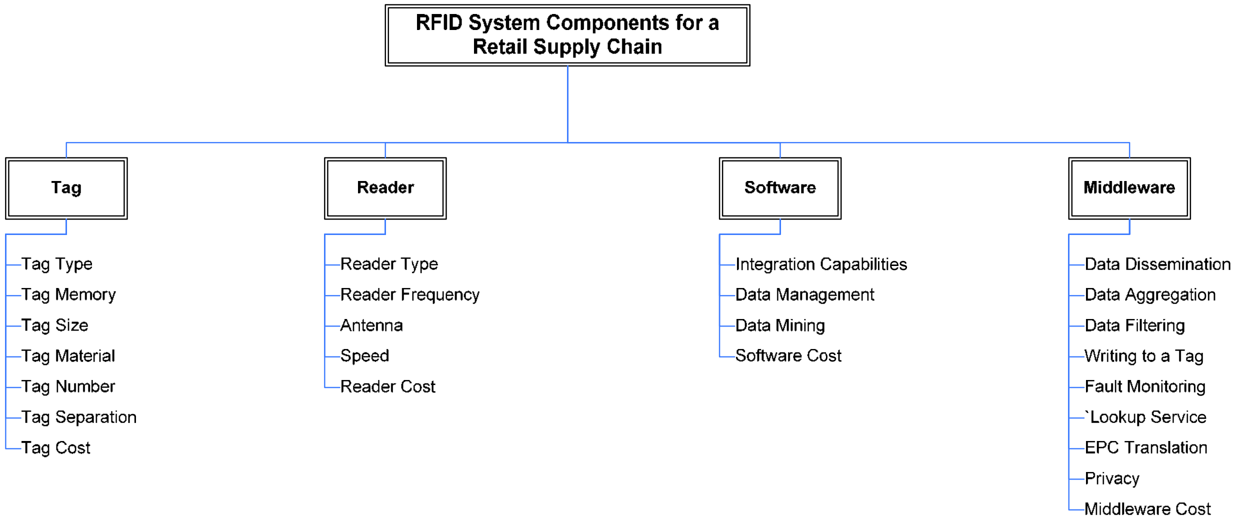

Figure 3: Classification of RFID System Components

The criteria for selection based on the second classification are equivalent to the components of the RFID system that was described in section 2.1, which include the tag, reader, middleware, and software. The factors considered within each of these criteria are listed and described in Table 2.

Table 2: Classification two factors listing.

Criteria	Factors	Description
Tag	Tag Type	The type of the RF tag whether passive or active
	Tag Memory	The required memory of the RF tag depending on the amount and type of the data that will be memorized
	Tag Size	The size of the RF tag which is depending on the tagged item size, because the cost of the RF tag increases as the RF tag size decreases, therefore it is recommended to use the largest possible RF tag size to minimize the tags' cost
	Tag Material	The type of the material used in the production of the RF tag which is depending on the type of material of the tagged item because there are some commodities such as clothes that requires a certain material of the RF tags to be used
	Tag Number	The number of RF tags required by the retailer to implement the RFID technology and the phase(s) of this implementation
	Tag Separation	The minimum distance required at which two tags could be positioned next to each other without their performance being affected
	Tag cost	The cost of a single RF tag
Reader	Reader Type	The type of the reader whether fixed or portable which is depending on the desired tracking and identification by the retailer, and the implementation phase(s) whether warehouse, receiving area, check-out cashiers, or shelf
	Reader Frequency	The frequency of the RFID system which is depending on the required read range by the retailer and the implementation phase(s)
	Antenna	The angle of the antenna of the reader and its position that depends on the required orientation of the RF tags inside the retail store
	Speed	Maximum allowable speed of the tag movements without affecting the system performance
	Reader Cost	The cost of a single reader

Criteria	Factors	Description
Software	Integration Capabilities	The capability of the software to consolidate the large amount of data captured by the reader(s) and link these data to the existing supply chain management software
	Data Management	The data required by the retailer from the implementation of such a technology in data management issues and its objectives that are expected to be delivered
	Data Mining	The data which might be needed by any department in the organization and the ability to find it
	Software Cost	The cost of the software, if not available at the retail store before technology implementation
Middleware	Data Dissemination	The data captured by the reader could be transferred to several applications across the company and its business partners in the retail supply chain
	Data Aggregation	RFID systems generate a significant amount of data that can be aggregated in a number of different ways
	Data Filtering	The data captured by the reader could be filtered before sending it to the users
	Writing to a Tag	Tags have memory for identifier plus another memory for additional data where the middleware could write to and read from
	Fault Monitoring	Monitoring the health of RFID readers and accessing their configuration remotely which result in integrating these readers into IT service management
	Lookup Service	The ability to locate the databases of different parties that store read events and other related data for tagged items
	EPC Translation	RFID allows for the unique identification of objects through the identifier stored in the memory on the RFID tag in addition to tag identifier translation mechanism
	Privacy	The kill functionality and limiting the read range of tags inside the retail store to prevent personal information from being used illegally
	Middleware Cost	The cost of the middleware required to link the data captured by the reader(s) to the existing/new software

5. CONCLUSIONS

The RFID is a fast-growing technology in the retail supply chains and has a significant influence on this industry especially in the last 5 years because of the recent technological developments and mandatory RFID tagging decrees by Wal-Mart and other European companies such as Metro and Tesco. However, the expected benefit of RFID system can only be achieved if the most appropriate system is selected according to the requirements of company. However, the number of factors and criteria upon which such a decision is made is vast; leading to inaccuracies and inconsistencies in the decision made. Hence, RFID system selection decision is a multi-criteria decision making problem having strategic importance to companies.

This research aimed at presenting a multi-criteria decision making approach for selecting the most suitable RFID system using analytical hierarchy process approach (AHP) in order to achieve the highest possible benefits from the implementation of this system in retail supply chains.

The factors that should be considered in this decision making process had to be defined; where, two classifications have been proposed that would suit a company seeking an RFID solution for its retail supply chain. Determining and defining these factors and criteria were the main objective of this paper. Two classifications for the criteria and their factors were suggested. The first classification was for the selection criteria for RFID systems vendor of retail supply chains, and the second classification was for the RFID system components for RFID systems of retail supply chains. The number of factors that are reported in this work (in both classifications) clearly shows the complexity of the decision making process.

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Appendix B

PRODUCTS SELECTION CLASSIFICATION

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
1	25	BUFFET	721	11	13,475	148,228	6.92%	6.92%	0.4%
2	23	DINING TABLE	662	11	10,683	117,511	5.48%	12.40%	0.8%
3	25	BUFFET	254010	7	11,209	78,462	3.66%	16.06%	1.2%
4	29	CHAIR	294015	74	950	70,266	3.28%	19.34%	1.6%
5	23	DINING TABLE	234016	7	8,844	61,910	2.89%	22.23%	2.0%
6	25	BUFFET	718	6	9,324	55,943	2.61%	24.84%	2.4%
7	29	CHAIR	294036	42	1,018	42,737	1.99%	26.83%	2.8%
8	25	BUFFET	736	4	9,523	38,091	1.78%	28.61%	3.2%
9	25	BUFFET	252696	3	11,677	35,032	1.63%	30.25%	3.6%
10	38	BAHU-VTRN	511	4	7,951	31,802	1.48%	31.73%	4.0%
11	29	CHAIR	792	38	812	30,870	1.44%	33.17%	4.4%
12	23	DINING TABLE	657	3	9,301	27,902	1.30%	34.47%	4.8%
13	23	DINING TABLE	678	4	6,664	26,656	1.24%	35.72%	5.2%
14	29	CHAIR	778	30	813	24,375	1.14%	36.85%	5.6%
15	27	MIRROR	951	6	4,002	24,013	1.12%	37.98%	6.0%
16	25	BUFFET	254013	2	11,230	22,460	1.05%	39.02%	6.4%
17	10	TABLE	107	11	1,973	21,706	1.01%	40.04%	6.8%
18	23	DINING TABLE	234017	3	6,979	20,938	0.98%	41.01%	7.2%
19	29	CHAIR	292022	20	1,017	20,341	0.95%	41.96%	7.6%
20	60	PLCRDS	608006	4	4,863	19,450	0.91%	42.87%	8.0%
21	23	DINING TABLE	648	2	9,525	19,050	0.89%	43.76%	8.4%
22	60	PLCRDS	604006	1	18,900	18,900	0.88%	44.64%	8.8%
23	26	BUFFET	264017	2	9,378	18,755	0.88%	45.52%	9.2%
24	23	DINING TABLE	234014	2	9,270	18,540	0.87%	46.38%	9.6%
25	21	COMMODE	212011	5	3,504	17,518	0.82%	47.20%	10.0%
26	23	DINING TABLE	681	3	5,788	17,365	0.81%	48.01%	10.4%
27	10	TABLE	113	9	1,897	17,073	0.80%	48.81%	10.8%
28	29	CHAIR	294029	18	910	16,380	0.76%	49.57%	11.2%
29	38	BAHU-VTRN	385695	1	16,380	16,380	0.76%	50.33%	11.6%
30	29	CHAIR	776	18	903	16,260	0.76%	51.09%	12.0%
31	60	PLCRDS	604005	1	16,200	16,200	0.76%	51.85%	12.4%
32	29	CHAIR	294794	16	877	14,024	0.65%	52.50%	12.7%
33	25	BUFFET	695	1	13,450	13,450	0.63%	53.13%	13.1%
34	26	BUFFET	739	2	6,646	13,293	0.62%	53.75%	13.5%
35	60	PLCRDS	608005	4	3,213	12,850	0.60%	54.35%	13.9%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
36	21	COMMODE	212015	2	5,958	11,915	0.56%	54.91%	14.3%
37	16	VANITY	388	4	2,978	11,912	0.56%	55.46%	14.7%
38	19	CONSOLE	437	5	2,337	11,687	0.55%	56.01%	15.1%
39	26	BUFFET	266011	2	5,750	11,500	0.54%	56.55%	15.5%
40	21	COMMODE	212525	3	3,426	10,279	0.48%	57.03%	15.9%
41	10	TABLE	102186	3	3,281	9,844	0.46%	57.48%	16.3%
42	10	TABLE	102094	4	2,394	9,578	0.45%	57.93%	16.7%
43	29	CHAIR	298023	10	950	9,500	0.44%	58.37%	17.1%
44	10	TABLE	106014	3	3,049	9,148	0.43%	58.80%	17.5%
45	22	DESK	636	2	4,522	9,044	0.42%	59.22%	17.9%
46	17	BED	172027	1	9,000	9,000	0.42%	59.64%	18.3%
47	60	PLCRDS	608003	2	4,488	8,975	0.42%	60.06%	18.7%
48	25	BUFFET	252011	1	8,970	8,970	0.42%	60.48%	19.1%
49	13	VETRINE	239	2	4,318	8,635	0.40%	60.88%	19.5%
50	10	TABLE	6	5	1,724	8,618	0.40%	61.29%	19.9%
51	10	TABLE	97	4	2,135	8,539	0.40%	61.68%	20.3%
52	23	DINING TABLE	234030	1	8,525	8,525	0.40%	62.08%	20.7%
53	34	BOOKCASE	347010	1	8,500	8,500	0.40%	62.48%	21.1%
54	31	ARM CHAIR	312015	7	1,211	8,475	0.40%	62.87%	21.5%
55	30	SOFA	903	2	4,236	8,472	0.40%	63.27%	21.9%
56	31	ARM CHAIR	903.1	4	2,118	8,471	0.40%	63.67%	22.3%
57	29	CHAIR	294026	8	1,050	8,400	0.39%	64.06%	22.7%
58	29	CHAIR	292025	8	1,035	8,276	0.39%	64.44%	23.1%
59	19	CONSOLE	194021	2	4,135	8,270	0.39%	64.83%	23.5%
60	38	BAHU-VTRN	382010	1	8,238	8,238	0.38%	65.21%	23.9%
61	23	DINING TABLE	238013	1	8,125	8,125	0.38%	65.59%	24.3%
62	30	SOFA	302030	2	4,023	8,045	0.38%	65.97%	24.7%
63	26	BUFFET	725	2	4,009	8,018	0.37%	66.34%	25.1%
64	23	DINING TABLE	236681	1	8,000	8,000	0.37%	66.72%	25.5%
65	38	BAHU-VTRN	386010	1	7,900	7,900	0.37%	67.08%	25.9%
66	27	MIRROR	276018	3	2,628	7,885	0.37%	67.45%	26.3%
67	29	CHAIR	299012	8	955	7,640	0.36%	67.81%	26.7%
68	27	MIRROR	274034	2	3,789	7,579	0.35%	68.16%	27.1%
69	21	COMMODE	214022	1	7,500	7,500	0.35%	68.51%	27.5%
70	40	SCREEN	402010	1	7,494	7,494	0.35%	68.86%	27.9%
71	21	COMMODE	212014	2	3,693	7,385	0.34%	69.21%	28.3%
72	21	COMMODE	212050	1	7,250	7,250	0.34%	69.55%	28.7%
73	21	COMMODE	212021	2	3,618	7,235	0.34%	69.88%	29.1%
74	43	CHIFFONIERE	432015	3	2,400	7,200	0.34%	70.22%	29.5%
75	27	MIRROR	274035	2	3,576	7,153	0.33%	70.55%	29.9%
76	27	MIRROR	274027	1	7,150	7,150	0.33%	70.89%	30.3%
77	23	DINING TABLE	232012	1	6,925	6,925	0.32%	71.21%	30.7%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
78	30	SOFA	308020	1	6,800	6,800	0.32%	71.53%	31.1%
79	21	COMMODE	533	2	3,389	6,779	0.32%	71.84%	31.5%
80	17	BED	172022	1	6,500	6,500	0.30%	72.15%	31.9%
81	17	BED	172023	1	6,500	6,500	0.30%	72.45%	32.3%
82	30	SOFA	302033	1	6,500	6,500	0.30%	72.75%	32.7%
83	10	TABLE	102174	2	3,200	6,400	0.30%	73.05%	33.1%
84	60	PLCRDS	608004	4	1,563	6,250	0.29%	73.34%	33.5%
85	10	TABLE	104034	1	6,225	6,225	0.29%	73.63%	33.9%
86	26	BUFFET	264014	1	6,073	6,073	0.28%	73.92%	34.3%
87	30	SOFA	876	1	6,015	6,015	0.28%	74.20%	34.7%
88	31	ARM CHAIR	876.1	2	3,008	6,015	0.28%	74.48%	35.1%
89	31	ARM CHAIR	312044	2	3,000	6,000	0.28%	74.76%	35.5%
90	14	SECRETARY	144010	1	5,910	5,910	0.28%	75.03%	35.9%
91	17	BED	178016	2	2,955	5,910	0.28%	75.31%	36.3%
92	26	BUFFET	262010	1	5,900	5,900	0.28%	75.59%	36.7%
93	10	TABLE	130	5	1,176	5,880	0.27%	75.86%	37.1%
94	10	TABLE	93	5	1,170	5,851	0.27%	76.13%	37.5%
95	10	TABLE	108	5	1,167	5,833	0.27%	76.40%	37.8%
96	34	BOOKCASE	344016	1	5,750	5,750	0.27%	76.67%	38.2%
97	13	VETRINE	243	1	5,700	5,700	0.27%	76.94%	38.6%
98	10	TABLE	23	4	1,396	5,582	0.26%	77.20%	39.0%
99	23	DINING TABLE	234033	1	5,500	5,500	0.26%	77.46%	39.4%
100	30	SOFA	30001	1	5,500	5,500	0.26%	77.71%	39.8%
101	31	ARM CHAIR	864.1	6	917	5,500	0.26%	77.97%	40.2%
102	34	BOOKCASE	344018	1	5,500	5,500	0.26%	78.23%	40.6%
103	27	MIRROR	953	2	2,739	5,478	0.26%	78.48%	41.0%
104	31	ARM CHAIR	314015	4	1,367	5,466	0.26%	78.74%	41.4%
105	10	TABLE	104216	4	1,353	5,413	0.25%	78.99%	41.8%
106	31	ARM CHAIR	314027	4	1,350	5,400	0.25%	79.24%	42.2%
107	30	SOFA	893	1	5,300	5,300	0.25%	79.49%	42.6%
108	31	ARM CHAIR	893.1	2	2,650	5,300	0.25%	79.74%	43.0%
109	19	CONSOLE	194035	1	5,150	5,150	0.24%	79.98%	43.4%
110	19	CONSOLE	194024	1	5,145	5,145	0.24%	80.22%	43.8%
111	20	BAHU	204022	2	2,570	5,140	0.24%	80.46%	44.2%
112	30	SOFA	928	1	5,055	5,055	0.24%	80.69%	44.6%
113	10	TABLE	120	4	1,260	5,041	0.24%	80.93%	45.0%
114	22	DESK	227011	1	4,850	4,850	0.23%	81.15%	45.4%
115	29	CHAIR	294043	8	600	4,800	0.22%	81.38%	45.8%
116	10	TABLE	106	6	791	4,748	0.22%	81.60%	46.2%
117	17	BED	174056	1	4,735	4,735	0.22%	81.82%	46.6%
118	10	TABLE	104013	3	1,559	4,677	0.22%	82.04%	47.0%
119	19	CONSOLE	194020	2	2,335	4,670	0.22%	82.26%	47.4%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
120	10	TABLE	102099	2	2,325	4,650	0.22%	82.47%	47.8%
121	13	VETRINE	224	1	4,531	4,531	0.21%	82.69%	48.2%
122	10	TABLE	104104	1	4,530	4,530	0.21%	82.90%	48.6%
123	21	COMMODE	556	1	4,500	4,500	0.21%	83.11%	49.0%
124	22	DESK	621	1	4,500	4,500	0.21%	83.32%	49.4%
125	25	BUFFET	254021	1	4,500	4,500	0.21%	83.53%	49.8%
126	10	TABLE	103010	5	898	4,490	0.21%	83.74%	50.2%
127	30	SOFA	877	1	4,470	4,470	0.21%	83.94%	50.6%
128	31	ARM CHAIR	877.1	2	2,235	4,470	0.21%	84.15%	51.0%
129	10	TABLE	75	5	891	4,455	0.21%	84.36%	51.4%
130	20	BAHU	206011	1	4,421	4,421	0.21%	84.57%	51.8%
131	10	TABLE	101	4	1,102	4,410	0.21%	84.77%	52.2%
132	17	BED	174060	1	4,400	4,400	0.21%	84.98%	52.6%
133	17	BED	178021	1	4,375	4,375	0.20%	85.18%	53.0%
134	30	SOFA	882	1	4,365	4,365	0.20%	85.39%	53.4%
135	30	SOFA	883	1	4,360	4,360	0.20%	85.59%	53.8%
136	31	ARM CHAIR	883.1	2	2,180	4,360	0.20%	85.79%	54.2%
137	17	BED	174058	1	4,300	4,300	0.20%	85.99%	54.6%
138	30	SOFA	304025	1	4,288	4,288	0.20%	86.19%	55.0%
139	31	ARM CHAIR	314025	2	2,144	4,288	0.20%	86.39%	55.4%
140	30	SOFA	302031	1	4,250	4,250	0.20%	86.59%	55.8%
141	27	MIRROR	437.1	4	1,053	4,213	0.20%	86.79%	56.2%
142	14	SECRETARY	270	1	4,165	4,165	0.19%	86.98%	56.6%
143	19	CONSOLE	449	1	4,113	4,113	0.19%	87.18%	57.0%
144	29	CHAIR	796	6	681	4,084	0.19%	87.37%	57.4%
145	10	TABLE	102197	1	4,061	4,061	0.19%	87.56%	57.8%
146	10	TABLE	9	3	1,332	3,995	0.19%	87.74%	58.2%
147	20	BAHU	204019	1	3,980	3,980	0.19%	87.93%	58.6%
148	10	TABLE	96	2	1,963	3,925	0.18%	88.11%	59.0%
149	31	ARM CHAIR	851.1	2	1,960	3,920	0.18%	88.29%	59.4%
150	31	ARM CHAIR	312042	2	1,960	3,920	0.18%	88.48%	59.8%
151	10	TABLE	102184	1	3,900	3,900	0.18%	88.66%	60.2%
152	31	ARM CHAIR	312046	2	1,950	3,900	0.18%	88.84%	60.6%
153	27	MIRROR	274020	1	3,890	3,890	0.18%	89.02%	61.0%
154	29	CHAIR	292032	5	760	3,800	0.18%	89.20%	61.4%
155	34	BOOKCASE	342012	1	3,795	3,795	0.18%	89.38%	61.8%
156	22	DESK	638	2	1,891	3,783	0.18%	89.55%	62.2%
157	10	TABLE	104211	2	1,890	3,780	0.18%	89.73%	62.5%
158	27	MIRROR	274016	1	3,780	3,780	0.18%	89.91%	62.9%
159	15	COMMODINO	331	2	1,850	3,700	0.17%	90.08%	63.3%
160	19	CONSOLE	192020	2	1,850	3,700	0.17%	90.25%	63.7%
161	19	CONSOLE	194038	1	3,700	3,700	0.17%	90.42%	64.1%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
162	21	COMMODE	212035	1	3,600	3,600	0.17%	90.59%	64.5%
163	10	TABLE	102090	1	3,550	3,550	0.17%	90.76%	64.9%
164	15	COMMODINO	318	4	884	3,537	0.17%	90.92%	65.3%
165	21	COMMODE	559	1	3,500	3,500	0.16%	91.09%	65.7%
166	17	BED	178019	1	3,475	3,475	0.16%	91.25%	66.1%
167	21	COMMODE	524	1	3,454	3,454	0.16%	91.41%	66.5%
168	15	COMMODINO	158021	6	575	3,450	0.16%	91.57%	66.9%
169	21	COMMODE	218015	3	1,142	3,425	0.16%	91.73%	67.3%
170	27	MIRROR	272966	1	3,424	3,424	0.16%	91.89%	67.7%
171	21	COMMODE	212051	1	3,375	3,375	0.16%	92.05%	68.1%
172	16	VANITY	386	1	3,366	3,366	0.16%	92.20%	68.5%
173	27	MIRROR	274029	1	3,363	3,363	0.16%	92.36%	68.9%
174	21	COMMODE	218016	2	1,663	3,325	0.16%	92.52%	69.3%
175	10	TABLE	104036	1	3,320	3,320	0.15%	92.67%	69.7%
176	27	MIRROR	276020	1	3,313	3,313	0.15%	92.83%	70.1%
177	10	TABLE	102	2	1,644	3,288	0.15%	92.98%	70.5%
178	15	COMMODINO	352	2	1,625	3,250	0.15%	93.13%	70.9%
179	17	BED	178022	2	1,625	3,250	0.15%	93.28%	71.3%
180	27	MIRROR	272032	1	3,250	3,250	0.15%	93.43%	71.7%
181	15	COMMODINO	367	2	1,597	3,193	0.15%	93.58%	72.1%
182	10	TABLE	105	3	1,055	3,164	0.15%	93.73%	72.5%
183	20	BAHU	488	1	3,155	3,155	0.15%	93.88%	72.9%
184	19	CONSOLE	194042	1	3,150	3,150	0.15%	94.02%	73.3%
185	13	VETRINE	226	1	3,130	3,130	0.15%	94.17%	73.7%
186	43	CHIFFONIERE	434020	1	3,130	3,130	0.15%	94.32%	74.1%
187	17	BED	178020	1	3,075	3,075	0.14%	94.46%	74.5%
188	21	COMMODE	212058	2	1,520	3,040	0.14%	94.60%	74.9%
189	15	COMMODINO	316	2	1,495	2,990	0.14%	94.74%	75.3%
190	22	DESK	222021	1	2,950	2,950	0.14%	94.88%	75.7%
191	31	ARM CHAIR	315010	2	1,445	2,890	0.13%	95.01%	76.1%
192	30	SOFA	304010	1	2,850	2,850	0.13%	95.15%	76.5%
193	29	CHAIR	844	1	2,775	2,775	0.13%	95.28%	76.9%
194	16	VANITY	403	1	2,750	2,750	0.13%	95.41%	77.3%
195	31	ARM CHAIR	312027	2	1,345	2,690	0.13%	95.53%	77.7%
196	31	ARM CHAIR	314010	2	1,335	2,670	0.12%	95.66%	78.1%
197	31	ARM CHAIR	760	2	1,328	2,655	0.12%	95.78%	78.5%
198	31	ARM CHAIR	319022	2	1,320	2,640	0.12%	95.90%	78.9%
199	30	SOFA	922	1	2,600	2,600	0.12%	96.02%	79.3%
200	31	ARM CHAIR	922.1	2	1,300	2,600	0.12%	96.15%	79.7%
201	10	TABLE	102017	1	2,595	2,595	0.12%	96.27%	80.1%
202	27	MIRROR	274060	1	2,500	2,500	0.12%	96.38%	80.5%
203	10	TABLE	102036	1	2,467	2,467	0.12%	96.50%	80.9%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
204	31	ARM CHAIR	814	2	1,202	2,404	0.11%	96.61%	81.3%
205	10	TABLE	134	1	2,370	2,370	0.11%	96.72%	81.7%
206	27	MIRROR	274064	1	2,370	2,370	0.11%	96.83%	82.1%
207	21	COMMODE	218013	1	2,325	2,325	0.11%	96.94%	82.5%
208	19	CONSOLE	192031	1	2,300	2,300	0.11%	97.05%	82.9%
209	15	COMMODINO	158017	4	563	2,250	0.10%	97.15%	83.3%
210	10	TABLE	102220	1	2,100	2,100	0.10%	97.25%	83.7%
211	19	CONSOLE	194044	1	2,100	2,100	0.10%	97.35%	84.1%
212	21	COMMODE	218014	1	2,075	2,075	0.10%	97.45%	84.5%
213	10	TABLE	102025	1	2,065	2,065	0.10%	97.54%	84.9%
214	10	TABLE	106015	1	2,055	2,055	0.10%	97.64%	85.3%
215	10	TABLE	4	1	2,023	2,023	0.09%	97.73%	85.7%
216	10	TABLE	78	1	1,988	1,988	0.09%	97.82%	86.1%
217	29	CHAIR	292046	1	1,988	1,988	0.09%	97.92%	86.5%
218	29	CHAIR	292037	1	1,900	1,900	0.09%	98.01%	86.9%
219	29	CHAIR	842	1	1,880	1,880	0.09%	98.09%	87.3%
220	10	TABLE	39	1	1,849	1,849	0.09%	98.18%	87.6%
221	29	CHAIR	297027	1	1,800	1,800	0.08%	98.26%	88.0%
222	31	ARM CHAIR	911.1	1	1,740	1,740	0.08%	98.35%	88.4%
223	31	ARM CHAIR	317012	1	1,740	1,740	0.08%	98.43%	88.8%
224	10	TABLE	88	2	854	1,708	0.08%	98.51%	89.2%
225	10	TABLE	102034	1	1,613	1,613	0.08%	98.58%	89.6%
226	10	TABLE	154	1	1,515	1,515	0.07%	98.65%	90.0%
227	16	VANITY	162018	1	1,500	1,500	0.07%	98.72%	90.4%
228	31	ARM CHAIR	312035	1	1,500	1,500	0.07%	98.79%	90.8%
229	15	COMMODINO	158022	2	738	1,475	0.07%	98.86%	91.2%
230	10	TABLE	40	1	1,475	1,475	0.07%	98.93%	91.6%
231	10	TABLE	170	1	1,460	1,460	0.07%	99.00%	92.0%
232	29	CHAIR	292042	1	1,415	1,415	0.07%	99.06%	92.4%
233	27	MIRROR	274059	1	1,375	1,375	0.06%	99.13%	92.8%
234	31	ARM CHAIR	312036	1	1,330	1,330	0.06%	99.19%	93.2%
235	31	ARM CHAIR	757	2	647	1,294	0.06%	99.25%	93.6%
236	47	SPL DÉCOR	472010	1	1,290	1,290	0.06%	99.31%	94.0%
237	31	ARM CHAIR	319027	1	1,250	1,250	0.06%	99.37%	94.4%
238	10	TABLE	14001	1	1,238	1,238	0.06%	99.43%	94.8%
239	27	MIRROR	278030	1	1,125	1,125	0.05%	99.48%	95.2%
240	29	CHAIR	299020	1	1,125	1,125	0.05%	99.53%	95.6%
241	15	COMMODINO	158019	1	1,100	1,100	0.05%	99.58%	96.0%
242	27	MIRROR	274065	1	1,100	1,100	0.05%	99.63%	96.4%
243	29	CHAIR	292053	1	1,075	1,075	0.05%	99.68%	96.8%
244	29	CHAIR	756	1	1,060	1,060	0.05%	99.73%	97.2%
245	29	CHAIR	299019	1	920	920	0.04%	99.78%	97.6%

No.	Category	Type	Item Code	Quantity	Price/unit (LE)	Monetary Value (LE)	% of Monetary Value	Cummulative %	Cummulative #
246	29	CHAIR	292054	1	890	890	0.04%	99.82%	98.0%
247	10	TABLE	73	1	825	825	0.04%	99.86%	98.4%
248	10	TABLE	81	1	791	791	0.04%	99.89%	98.8%
249	10	TABLE	67	1	778	778	0.04%	99.93%	99.2%
250	27	MIRROR	272034	1	750	750	0.03%	99.97%	99.6%
251	29	CHAIR	291011	1	750	750	0.03%	100.00%	100.0%
Total Number of Sold Products Locally				**797**	**Total Value (LE)**	**2,142,950**	**100.00%**		

Appendix C

DATA COLLECTION

Buffet 721	Processing Time (min)																								
Process Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
701B	360	390	330	420	375	340	400	380	300	430															
501	522	230	454	434	553	265	561	392	527	276	474	349	512	315	345	355	190	105	150	235	190	105	240		
502	477	260	537	460	340	430	215	490	135	145	340	155	205	240	270	255	255								
503	22	11	30	11	11	115	20	22	11	30	11	11	115	20	22	11	30								
201	115	170	130	70	67	180	135	65	75	135	25	30	35	75	105										
202	180	150	202	225	160	138	258	235	262	190															
203	30	45	33	25	35	44	32	37	39	31															
204	60	105	93	85	95	104	92	45	55	53															
129A	240	284	269	240	307	229	198	277	255	235															
311	240	255	235	213	284	269	244	307	229	198															
209	210	195	185	167	235	247	129	302	177	249															
305	150	147	135	118	490	245	175	133	170	118															
205	180	165	153	145	225	205	168	245	105	235															
129A	240	284	269	240	307	229	198	277	255	235															
702B	150	118	490	290	175	133	170	118	147	135															
501	522	230	454	434	553	265	561	392	527	276	474	349	512	315	345	355	190	105	150	235	190	105	240		
502	477	260	537	460	340	430	215	490	135	145	340	155	205	240	270	255	255								
221	90	135	127	69	59	47	108	111	96	53															
222	120	98	84	165	131	151	109	70	181	129															
221	90	135	127	69	59	47	108	111	96	53															
207	55	75	75	80	20	107	172	232	347	432															
208	800	440	530	487	470	410	630	405	565	565	550	500	780	540											
210	41	38	33	59	41	35	173	78	98	77	58	58													
211	120	105	185	150	95	67	142	109	169	150															

212	102	59	74	60	75	61	80	78	117	74	75	24	24	39	39										
213	300	255	235	213	284	269	375	340	400	380															
214	60	97	33	127	85	49	55	35	65	105															
312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
129B	120	95	67	142	109	169	150	105	185	150															
221	90	135	127	69	59	47	108	111	96	53															
215	60	30	95	40	180	52	52	27	90	135	115	30	135	123	158	108	108								
216	11	33	30	33	30	21	21	16	16	63	63														
206	420	155	320	507	265	325	526	360	402	450															

Buffet 254010	**Processing Time (min)**																								
Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
701B	360	390	330	420	375	340	400	380	300	430															
501	522	230	454	434	553	265	561	392	527	276	474	349	512	315	345	355	190	105	150	235	190	105	240		
502	477	260	537	460	340	430	215	490	135	145	340	155	205	240	270	255	255								
503	22	11	30	11	11	115	20	22	11	30	11	11	115	20	22	11	30								
201	115	170	130	70	67	180	135	65	75	135	25	30	35	75	105										
202	180	150	202	225	160	137	257	235	262	190															
203	30	45	33	25	35	44	32	37	39	31															
204	60	105	93	85	95	104	92	45	55	53															
311	240	255	235	213	284	269	244	307	229	198															
209	340	186	223	212	205	258	301	223	213	178	315	193	270	201	231	280	271								
305	150	147	135	118	190	245	175	133	170	118															
205	180	165	153	145	225	205	168	245	105	235															
129A	242	240	255	235	213	284	269	307	229	198															
702B	150	118	490	245	175	133	170	118	147	135															
501	522	230	454	434	553	265	561	392	527	276	474	349	512	315	345	355	190	105	150	235	190	105	240		
502	477	260	537	460	340	430	215	490	135	145	340	155	205	240	270	255	255								
221	90	135	121	69	59	47	108	111	96	53															
222	120	98	84	165	131	151	109	70	181	129															
221	90	135	121	69	59	47	108	111	96	53															
207	55	75	75	80	20	107	172	232	347	432															
208	343	265	345	545	271	378	389	261	213	588	211	317	443	396	304	292	353	460	488	290	336	277	234	352	341
210	41	38	33	59	41	35	173	78	98	77	58	58													

211	120	105	185	150	95	67	142	109	169	150															
212	102	59	74	60	75	61	80	78	117	74	75	24	24	39	39										
213	428	332	357	445	248	270	337	467	330	322	405	285	212	248	260										
214	60	97	33	127	85	49	55	35	65	105															
312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
129B	235	180	165	153	145	225	205	168	245	105															
221	90	135	121	69	59	47	108	111	96	53															
215	60	30	95	40	180	52	52	27	90	135	115	30	135	123	158	108	108								
216	11	33	30	33	30	21	21	16	16	63	63														
206	420	455	320	507	285	325	526	360	402	450															

Table 234016	**Processing Time (min)**																								
Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
703T	180	150	202	225	160	137	257	235	262	190															
704T	90	75	45	93	108	97	155	59	65	175															
502	115	150	45	5	15	60	115	240	85	115	255	85	75	135	90	240	85	25	80	80	90	30	30	115	130
503	220	65	100	60	30	30	75	30	220	65	100	60	30	30	75	30	30								
506	120	98	84	165	131	151	109	70	181	129															
201	42	32	135	42	15	65	40	55	70	110															
202	60	55	39	67	140	100	105	120	126	45															
203	40	50	60	55	175	230	245	245	50	55															
204	15	32	35	12	20	27	45	39	60	44															
311	210	255	235	213	284	269	244	127	229	198															
305	120	105	185	150	95	67	142	109	169	150															
205	30	27	45	32	25	55	49	22	62	44															
222	60	60	73	55	70	75	45	93	125	93															
221	60	55	49	22	62	44	67	142	109	169															
207	33	60	100	160	160	170	170	170	210	210	255	100	135												
208	540	600	585	485	517	475	562	573	557	505															
209	240	255	235	213	284	269	244	307	229	198															
221	60	55	49	22	62	44	67	142	109	169															
210	30	32	35	12	20	27	45	39	60	44															
312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
211	120	105	185	150	95	67	142	109	169	150															

212	18	18	15	12	7	7	15	12	7	7															
213	90	93	108	97	155	59	65	175	75	45															
214	30	27	45	32	25	55	49	22	62	44															
312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
221	60	55	49	22	62	44	67	142	109	169															
215	120	67	142	109	169	75	45	93	125	203															
216	7	7	77	22	7	22	7	7	13	13	13	13													
206	180	150	202	225	160	137	257	235	262	190															

Table 662	**Processing Time (min)**																								
Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
703T	180	150	202	225	160	137	257	235	262	190															
704T	90	75	45	93	108	97	155	59	65	175															
502	115	150	45	5	15	60	115	240	85	115	255	85	75	135	90	240	85	25	80	80	90	30	30	115	130
503	220	65	100	60	30	30	75	30	100	100															
506	120	98	84	165	131	151	109	70	181	129															
201	42	32	135	42	15	65	40	55	70	110															
202	60	75	45	93	125	60	73	55	70	83															
203	15	32	35	12	22	27	45	39	60	44															
204	30	27	45	32	25	55	49	23	62	44															
311	210	255	235	213	284	269	244	127	229	198															
305	120	105	185	150	95	67	142	109	169	150															
205	120	105	185	150	95	61	142	109	169	150															
221	60	55	49	23	62	44	67	142	109	169															
207	33	60	100	160	160	170	170	170	210	210	255	100	135												
208	85	100	105	105	120	145	145	225	85	100															
209	240	255	235	213	284	269	244	307	229	198															
221	60	55	49	23	62	44	67	142	109	169															
210	30	32	35	12	23	27	45	39	60	44															
312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
211	120	105	185	150	95	67	142	109	169	150															
212	18	18	15	12	7	7	15	12	7	7															
213	90	93	108	97	155	59	65	175	75	45															
214	30	27	45	32	25	55	49	22	62	44															

312	320	280	302	480	390	168	220	271	152	258	135	230	200	250	455	271	152								
221	60	55	49	23	62	44	67	142	109	169															
215	120	67	143	109	169	75	45	93	125	203															
216	7	7	77	22	7	22	7	7	13	13	13	13													
206	180	150	203	225	160	137	257	235	262	190															

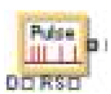
Chair 294015	**Processing Time (min)**																								
Process	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
705C	150	147	135	118	130	245	175	133	170	118															
502	30	30	30	15	30	30	30	30	30	60	120	295	60	220	60	120	60	120	120	155	230	60	45	95	25
503	220	65	100	65	30	30	75	30	65	100															
311	5	5	5	5	5	14	14	14	14	14															
217	40	40	40	40	60	40	22	40	90	30															
218	22	40	50	22	65	22	57	45	57	35	30	30	30	40											
219	15	15	15	15	15	15	20	25	30	30															
203	90	6	55	22	55	22	120	22	55	22	80	105	105	12	28	52	52	28	43	52	12	13	12	60	60
204A	20	1	1	1	1	13	1	13	13	1	1	1	1	1	1	1	5	5	5	5	2	2	2	2	2
207	135	135	16	80	85	55	85	150	17	170	15	75	135	15	90	15	30	52							
205	25	30	20	15	35	40	32	42	45	27															
208A	35	140	120	120	60	35	90	80	65	220	65	95	35	165	120	75	8	120	65	70	11	65	7	135	60
204B	15	32	35	12	22	27	45	39	24	44															
208B	35	140	120	120	60	35	90	80	65	220	65	95	35	165	120	75	8	120	65	70	11	65	7	135	60
209	7	10	10	60	60	7	10	10	10	114	60	7	10	10	13	45	7	10	10	112	7	10	10	14	45
210	30	20	35	40	32	42	45	27	15	22															
312	145	59	152	116	93	123	57	62	74	102	77	85	71	114	153	86	63	84	100	92	60	83	263	99	160
215	10	10	10	50	10	10	55	10	10	60	10	30	10	50	70	10	60	10	30	10	25	60	30	40	60
216	15	32	35	12	22	27	45	39	60	44															
206	15	17	27	27	27	15	17	15	17	15	17	15	18	15	17	27	27								
706C	450	450	450	450	450	450	450	450	450	450															

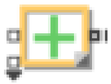
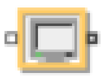
A p p e n d i x   D

EXTENDSIM LIBRARY BLOCKS

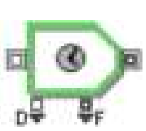
This Appendix provides description of the libraries used in building the different models of the studied manufacturing system.

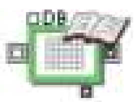
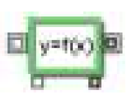
1. VALUE LIBRARY BLOCKS

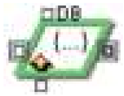
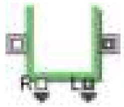
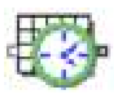
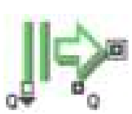
Decisions	**Function**
 *Pulse*	Outputs a true value (1) at specified times, and a false value (0) at all other times. In the dialog, you specify the time between outputting true values (the delay or time out); the dialog value is overridden by the D connector. The R connector resets the block back to the beginning of the delay period.
 *Random Number*	Generates random integers or real numbers based on the selected distribution. You can use the dialog or the three inputs, 1, 2, and 3 to specify arguments for the distributions. You can select the type of distribution or use an Empirical Table. The Empirical distribution uses a table to generate a discrete, stepped, or interpolated distribution.
 *Simulation Variable*	Outputs the value of a simulation variable. It is usually used in conjunction with a decision-type block, for example, to halt a process after current time reaches a certain value. The variables you can use are: current run number, current step, current time, end time, number of runs, number of steps, start time, time step, and random seed.
 *Equation*	Outputs the results of the equations entered in the dialog. You can use ExtendSim's built-in operators, functions, and some or all of the input values as part of the equation. The equations can have any number of inputs and any number of outputs.

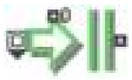
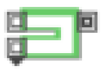
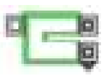
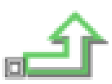
 *Math*	Performs a selected mathematical operation on its inputs and outputs a result.
 *Display Value*	Displays the value at the input connector on each simulation step. This is useful for debugging models and scripts because you can display the value of a block's value output connector at any time.
 *Clear Statistics*	Clears the statistics in various blocks in a model at a specific time or event. Useful in reducing the effects of warm-up in a model.
 *Mean & Variance*	Calculates the mean, variance, and standard deviation of the values input during the simulation.
 *Statistics*	Collects common statistics from blocks in a model into a single table. You can select which types of blocks will have their information collected. The choices are Activity, Mean & Variance, queue, Resource Item, Resource pool, or mixed.

2. ITEM LIBRARY BLOCKS

Decisions	**Function**
 *Activity*	Holds one or more items and passes them out based on the process time and arrival time for each item.

 *Batch*	Allows items from several sources to be joined as a single item. Useful for synchronizing resources and combining various parts of a job (“kitting”).
 *Unbatch*	Produces multiple items from a single input item. This block can be used to disassemble a kit, break a message packet into component messages, route the same message to several places, or distribute copies of invoices.
 *Read(I)*	Reads data from a database when an item arrives. You can define an indefinite number of reads to be made by the block when an item passes through.
 *History*	Views and displays information about the items that pass through it. You specify which properties will be displayed. Properties can be attributes on the item, priority values, or other more obscure values that are available on the item.
 *Information*	Reports statistics about the items that pass through it, such as cycle time and TBI (Time Between Items).
 *Equation(I)*	Calculates equations when an item passes through. The equations can use multiple inputs and properties of the item as variables, and the result(s) of the equations can be assigned to multiple outputs and properties of the item.
 *Get*	Displays and outputs properties from items that are passing through. The property value is shown in the dialog and output at the value output connector. You can specify multiple properties and multiple output connectors.

 *Set*	Sets the properties of items passing through the block from input connectors, values in the dialog, or databases.
 *Queue*	Queues items and releases them based on a user selected queuing algorithm, such as Resource pool queue, Attribute value, First in first out, Last in first out, and Priority. Options include reneging and setting wait time. If you need more advanced control over the queueing algorithm, consider using the Queue Equation block, below.
 *Resource Pool*	This block holds resource pool units to be used in a simulation. These units limit the capacity of a section of a model. For example, this could be used to represent a limited number of tables at a restaurant. The Resource Pool block works with the Queue block in Resource Pool mode and the Resource Pool Release blocks.
 *Resource Pool Release*	Releases a resource back to its resource pool as an item passes through.
 *Shift*	Generates a schedule over time which can be used to change the capacity of other blocks in the model. Multiple Shift blocks can be connected together to create complex shift patterns. For example the typical 40 hour work week can be built with two connected Shift blocks, the first containing the work days, the second contains the work hours.
 *Catch Item*	This block catches items sent by Throw Item blocks without using connection lines. Any number of Throw Item blocks can send items to a Catch Item block.
 *Create*	Provides items or values for a discrete event simulation at specified interarrival times. Choose either a distribution or a schedule for the arrival of items or values into the model.

 *Exit*	Passes items out of the simulation. The total number of items absorbed by this block is reported in its dialog and at the value output connectors.
 *Select Item In*	Selects items from one input to be output based on a decision.
 *Select Item Out*	Selects which output gets items from the input, based on a decision.
 *Throw Item*	This block throws items to a Catch block without using connection lines. Any number of Throw blocks can send items to a single Catch block. You could use the Throw and Catch blocks instead of using Combine blocks, even from inside one hierarchical block to inside another one.
 *Executive*	This block must be placed to the left of all other blocks in discrete event and discrete rate models. It does event scheduling and provides for simulation control, item allocation, attribute management, and other discrete event and discrete rate model settings.

3. UTILITIES LIBRARY BLOCKS

Decisions	**Function**
 *RealTimer*	Shows the duration of a simulation in real time. It should be placed at the far right side of the model worksheet.

4. PLOTTER LIBRARY BLOCKS

Decisions	Function
 *Plotter, Discrete Event*	Gives plots and tables of data for up to four value inputs in discrete event and discrete rate models. Both the value and the time the value was recorded are shown in the data table for each input. In the dialog you can specify whether to plot values only when they change or to plot all values. Use the **Show instantaneous length** option if you attach an input to the **L** connector of a queue-type block and you want it to report on items that arrive and depart on the same time step (these are items that stay in the queue for zero time).