2016

A framework to generate a smart manufacturing system configurations using agents and optimization

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A FRAMEWORK TO GENERATE SMART MANUFACTURING SYSTEM CONFIGURATIONS USING AGENTS AND OPTIMIZATION

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Spring Term
2016

Major Professor: Luis C. Rabelo

ABSTRACT

Manufacturing is a crucial element in the global economy. During the last decade, the national manufacturing sector loses nearly 30% of its workforce and investments. Consequently, the quality of the domestic goods, global share, and manufacturing capabilities has been declined. Therefore, innovative ways to optimize the usage of the Smart Manufacturing Systems (SMS) are required to form a new manufacturing era. This research is presenting a framework to optimize the design of SMS. This includes the determination of the suitable machines that can perform the job efficiently, the quantity of those machines, and the potential messaging system required for sharing information.

Multiple reviews are used to form the framework. Expert machine selection matrix identifies the required machines and machine parameter matrix defines the specifications of those machines. While business process modeling and notation (BPMN) captures the process plan in object-oriented fashion. In addition, to agent unified modeling language (AUML) that guides the application of message sequence diagram and statecharts. Finally, the configuration is obtained from a hybrid simulation model. Agent based-modeling is used to capture the behavior of the machines where discrete event simulation mimics the process flow. A case study of a manufacturing system is used to verify the study. As a result, the framework shows positive outcomes in supporting upper management in the planning phase of establishing a SMS or evaluating an existing one.

ACKNOWLEDGMENTS

First and foremost, I thank Allah for giving me the health and strength to overcome all difficulties during my PhD journey.

I would like to express my appreciation and thanks to my advisor Dr.Luis Rabelo, you have been a great educator and mentor. Thank you for your endless encouragement, patience, and guidance throughout my research. I am extremely grateful to my committee members: Dr.Ahamd Elshennawy, Dr.Gene Lee, and Dr.Ali Ahmad for their valuable advices. Much appreciation to Mr. Omar Silk and Mr. Christopher Rose Petrilli, for their support and assistance to accomplish this work.

I would also extend my thanks to all faculty and staff in the Department of Industrial Engineering and Management Systems at the University of Central Florida who directly and indirectly contributed to my doctoral study.

Special thanks to my parents, family, friends, and colleagues. Words cannot express how grateful I am for all of the sacrifices that you've made on my behalf. Your prayer for me was what sustained me thus far.

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CHAPTER 1 INTRODUCTION

1.1 Background

Today, consumers are driving the market by setting their expectations in terms of higher quality, lower prices, and minimal lead-time. The conventional manufacturing system is inefficient to achieve customers' expectations. Traditional centralized and sequential manufacturing processes are ineffective toward the rapid change in the market requirements (Shen and Norrie 1999). This forces the manufacturers to seek better ways to satisfy the market (Bülbül, Ömürbek et al. 2013). Apparently, innovative processes and products have to be introduced to close the gap between consumers' expectations and producers' outcomes. Hence, the adoption of the unconventional manufacturing system is crucial.

The timeline of the manufacturing system goes back to the industrial revolution that started in Europe with a steam-engine in the middle of the 18th century. Then, Ford introduced the mass production system in the 19th century, while the introduction of the automation systems (flexible manufacturing system) happened in the 20th century. Today a new era of manufacturing system is introduced and is called: Smart Manufacturing System (SMS) or forth industrial revolution (Kang, Lee et al. 2016).

"Smart" is the new word that is applied to many areas (i.e. smart cities, smart devices, smart cars, smart manufacturing, etc.). For the last decade "smart" has been an area of interest in academia and industries. The focus of this research is to explore opportunities for improvements in the Smart Manufacturing Systems (SMS). According to McKewen (2015) smart manufacturing is the combination of real-time data and technology. It offers the right information to the right people and machines at the right time with the needed format. The key is to obtain data form resources and allow their communication to exchange it.

Different terms are used for SMS including: factory of things, a real-time factory, or an intelligent factory of the future. Scholars denote a smart factory as a technology, an approach, or a paradigm (Radziwon, Bilberg et al. 2014). In Germany it is called the Industry 4.0. It was announced in 2011 at the “Hannover Messe”, Germany. The vision of industry 4.0 is a collaborative work between private, government, and academic sectors. A final report recommends the use of the communication networks based on Cyber Physical System (CPS), Internet-of-Things (IoT) and IoS (Internet of Services) to resolve SMS obstacles (Kang, Lee et al. 2016).

Two leading non-profit organizations in the nation define it differently. The National Institute of Standards and Technology (NIST) is a federal agency within the U.S. Department of Commerce. NIST's mission is to support U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology to enhance the quality of the living standards. The second organization is the Smart Manufacturing Leadership Coalition (SMLC). It is known for its leadership in Smart Manufacturing, as it supports the manufacturers and their integrated supply chain with an advanced technology that no company can built or design by it self. SMLC is building the first national open source manufacturing platform.

According to (NIST) SMS systems are “fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.”

The SMLC defines it as, "the ability to solve existing and future problems via an open infrastructure that allows solutions to be implemented at the speed of business while creating advantaged value." The SMLC is comprised of twenty five large global companies, eight manufacturing groups, six universities, one government lab and four high performance computing centers (Davis, Edgar et al. 2012). SMLC defines goals and objectives for SMS where no company can accomplish by its own (Davis, Edgar et al. 2012):

- Enhance the manufacturing supply chain by integrating customers, partners, and public
- Create an infrastructure that integrates factories and supply chain
- Develop new performance measures for cross factory and supply chain. Other than the traditional indicators
- Encourage workforce innovation
- Breakthrough results in cost reduction of information technology infrastructure
- Deploy the use of modeling and simulation
- Enhance workforce capabilities
- Identify the required research and development that is needed to achieve the vision

Another definition is stated by Rockwell Automation: "Smart Manufacturing is a highly connected, knowledge-enabled industrial enterprise where all business and operating actions are optimized to achieve substantially enhanced productivity, sustainability and economic performance".

Coalition (2011) reports the effect of manufacturing intelligence over a ten-year time horizon:

- Enhancements: Reduce safety incidents by 25%, enhance energy efficiency by 25%, enhance operating efficiency by 10%, and reduce cycle times by 40%

- Product reliability – trace products throughout the supply chain; locate product recalls
- Lead time – ten times improvements in time to market
- Innovation – 25% increase in revenue for products and services, increase number of small and medium enterprises, and more skilled jobs

In fact, leading manufacturing countries such as United States, Germany, and South Korea are focusing on similar key technologies to advance SMS including: Cyber-Physical Systems (CPS), Internet of Things (IoT), big data, cloud computing, sensor, and smart energy.

- Internet of Things: attach smart sensors and electronic devices to resources that are able to collect real-time data as well as exchange it with other resources for better decision-making.
- Big Data and Data Analytics: big data refers to data set that can't be analyzed by conventional analysis tools. This is due its complexity and volume. Hence, new ways and algorithms are developed to deal with this type of data.
- Cyber-Physical Systems (CPS): are systems of virtual networking entities that are also connected to the environment physically and with its operational processes, nevertheless data are shared, exchanged and analyzed via the internet.
- Sensor: is the most basic technology in SMS that enable sharing, exchanging, and controlling data.
- Cloud manufacturing (CM): according to Wu, Rosen et al. (2015) "Cloud Manufacturing is a customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary and reconfigurable production lines that enhance efficiency, reduce product lifecycle costs,

and allow for optimal resource loading in response to variable-demand customer generated tasking”

- Energy Saving: developed procedures to monitor and analyze the consumption of the energy

According to the president’s council of advisors on science and technology, advanced manufacturing technology (AMT) also called SMS is the utilization of the amalgamation between information technology and automation to strike innovative ways to manufacture existing products or produce new ones (States 2012). AMT and SMS AMT is a vital element that contributes to the nation economy as depicted in figure 1.1. Manufacturing has more value per dollar spent than any other sector (States 2012).

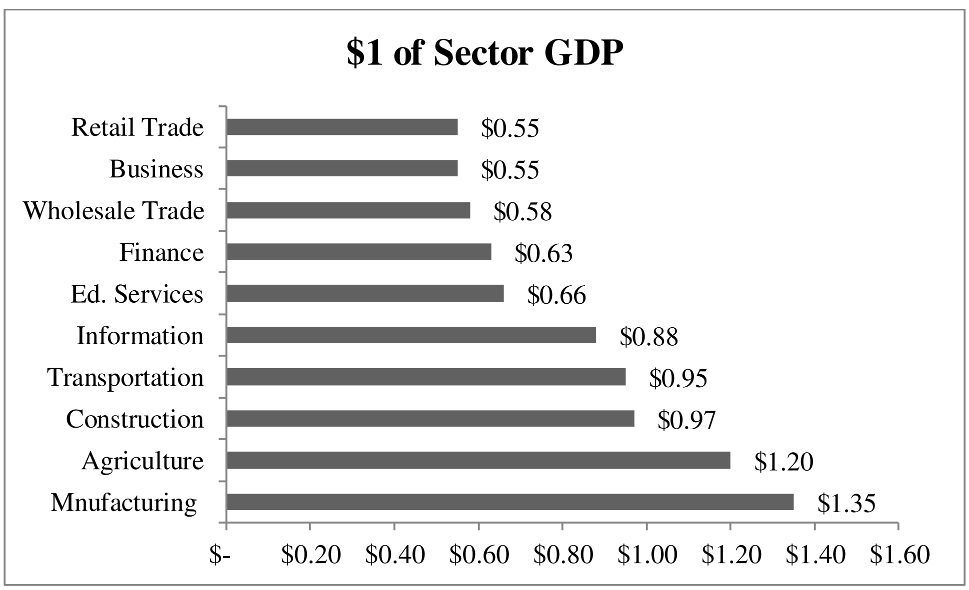


Figure 1-1 Economic Activity Generated by $1 of Sector Output, adapted from report capturing domestic competitive advantage in advanced Manufacturing- the Executive Office of the President of The United States (2012)

However, the contribution of manufacturing in employment as well as in the U.S. gross domestic product has been declining as shown in figure 1.2.

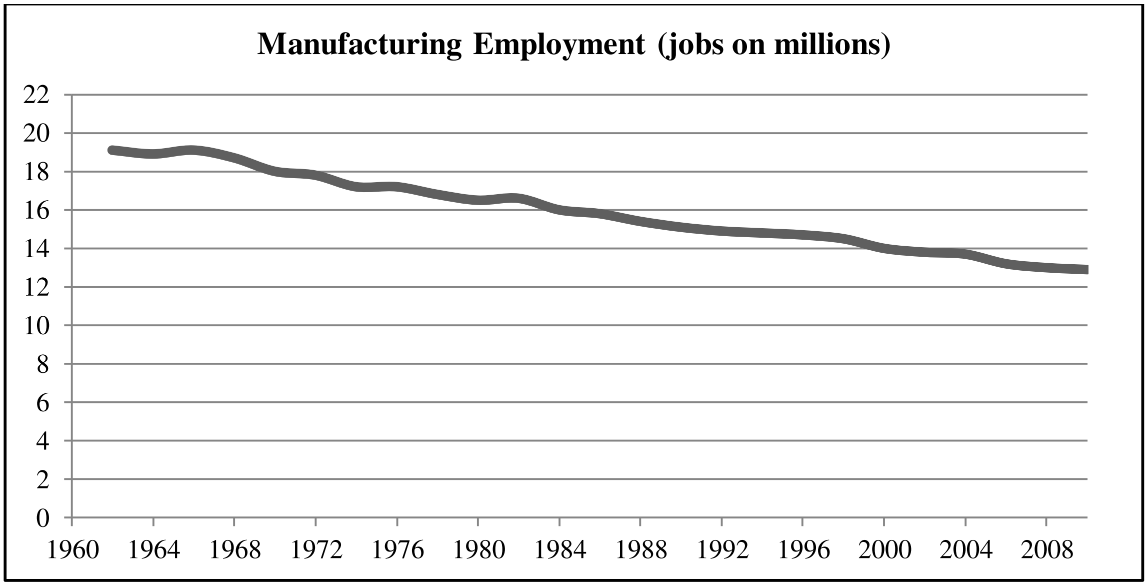


Figure 1-2: Employment trends 1962-2010, adapted from report capturing domestic competitive advantage in advanced Manufacturing- the Executive Office of the President of The United States (2012)

AMT is an umbrella that covers many technologies including: computer-aided design (CAD), robotics, group technology (GT), flexible manufacturing systems (FMS), automated material handling systems, automated storage and retrieval systems (AS/RS), computer numerically controlled machine tools (CNC), and bar-coding or other automated identification techniques (Percival and Cozzarin 2010).

1.1.1 Computer Aided Design (CAD)

CAD is the process of constructing a product through the usage of computer systems and software. The computer will aid the designer to manipulate different inputs such as type of materials, dimensions, and tolerances to optimize the outcome (Davies and Cormican 2013).

1.1.2 Industrial Robots

According to Shivanand (2006), industrial robot is a reprogrammable controlled machine designed to do a wide variety of functions automatically.

1.1.3 Group Technology (GT)

GT is the process of distributing the manufacturing system to subsystems called machine cells. Each machine cell consists of number of parts (Kusiak 1987).

1.1.4 Flexible Manufacturing Systems (FMS)

According to Shivanand (2006), FMS is a collection of integrated machines that can produce different part types and quantities based on market requirements. Machines are connected through material handling and automated storage systems. A central computer controls the whole system. In FMS, *resource* is the name of a workstation or machine center that processes a work piece. Also, the work piece is called a *job*. The *process plan* defines the sequence of a job visiting resources and the processing time required at each resource. FMS allows jobs to visit resources at any sequence based on the requirements dissimilar from transfer line where all jobs have to follow the same sequence (Vinod and Solberg 1985). In addition, the system can alternate jobs' sequences in case of any sudden incident such as machine breakdown (Arbel and Seidmann 1984). Within the many AMT technologies, this research will focus on FMSs.

1.1.5 Automated material handling systems

Chiwoon and Egbelu (2005) describe the material handling as the process of retrieving the requested material with the respect of time, location, sequence and cost.

1.1.6 Automated Storage and retrieval systems (AS/RS)

In high volume of material handling, AS/RSs are used to control the operations. The system consists of several parts that are controlled by a central computer. Parts including storage racks in multiple aisles, storage/retrieval machines (S/R) that retrieve and store items from the storage racks to/from the input/output points (Manzini, Gamberi et al. 2006).

1.1.7 Computer Numerically Control (CNC) machine

CNC usually controls workstations in FMS to perform machining operation on families of parts without a dedicated operator.

1.2 Flexible Manufacturing Systems (FMS)

In the middle of 1960s, market competition has increased and from that time to (Dallery and Frein 1988)1970 cost was the primary concern. Afterward, quality became the priority. Then, shorter lead-time became something that customers ask for. Therefore, manufacturers tend to be agiler by applying FMS (Shivanand 2006). By means, respond faster to the market, operate with the lowest cost, and offer standards that will delight customers.

FMS is a set of interacted computer numerical machines that are integrated and connected through automated transportation system to form an automated production system. A large computer network controls the operation of the system without the need for a dedicated operator close to each machine. FMS can provide different product characteristics simultaneously. Since the operations are fully automated, setup times between operations are negligible. Unfinished work-pieces are stored between operations in buffers. Buffering is known to be a temporary storage space between one process, and another (Johnstone and Kurtzhaltz 1984).

The importance of installing FMS is the fact that it can produce a variety of products simultaneously with different volumes in short lead-times (Stam and Kuula 1991). Also, FMS increases machines' utilization and work in capital productivity while reducing work-in-process, number of machines, labor cost, footprint, and set up cost (Spano, O'Grady et al. 1993). Therefore, the utilization of FMS can achieve 80% - 90%, comparing to 50% or less in conventional manufacturing systems (Shang and Sueyoshi 1995).

However, the growth of FMS did not meet the expectations. Failures in implementing FMSs are due to the difficulty of designing those systems that require strong commitment from skilled manpower in the design phase to integrate complex manufacturing components. In addition, to the high capital investment required for installments. The classifications of the FMS, as well as decisions for its long and short term planning, are discussed below.

1.2.1 Classification of FMS

Based on MacCarthy and Jiyin (1993) FMS is classified as following:

- Flexible Machining Modules (FMM): this is considered to be the smallest automated system. It consists of a CNC machine that has a work-piece exchange mechanism. This will allow the system to perform different operations with minimum time required to exchange tools for the work-piece. Due to the limitation in the buffer space, FMM needs continuous feeding supplies.

- Flexible Machining Cells (FMC): a group of FMMs, setup station, the buffer area, and an automated transportation system.
- Flexible Machining System (FMS): consists of several identical or different FMMs connected together to have a process or product configuration. The process configuration can work on one process for a particular product range. The product configuration consists of different FMMs to work on different products simultaneously.
- *Flexible Transfer Line:* consists of a number of different CNC machines. The flow of the material is fixed based on predefined sequence by the transport mechanism.
-

1.2.2 Flexibility in FMS

According to Sethi and Sethi (1990) there are different flexibility aspects of the FMS. Starting with machine flexibility, which is the ability of the machine to shift from an operation to another. Material handling flexibility is the ability of the system to convey and transport work-pieces. Operation flexibility is the ability of the system to process the work-piece with different sequence to balance the workload. Expansion flexibility is the ability of the FMS to be expanded under certain circumstances. Production flexibility concerns the ability of the system to change the machines setups without investment to meet customers' requirements. Process flexibility is the ability of the machine to work on different work-pieces without main setup times that will delay the production. Routing flexibility is the ability of the system to give work-pieces different route to follow when there are a number of identical machines.

1.2.3 Long-Term Planning

Because companies usually invest between \$5- \$100 million in FMS, planning is a crucial process. Apparently, long term planning is part of the company's structure. Management might envision their future position in the market and decide to invest in new manufacturing technologies to be a head of their rivals. The objective behind pursuing such an investment could rely on many reasons. It could be seeking flexibility in production to produce high volumes with short lead times, low labor cost, higher product quality, and higher productivity through better utilization of resources.

There are different lifecycle phases of FMS including: planning, initial design, detailed design, installation, production planning, scheduling, operation, and ongoing improvement. Yet some important decision variables need to be considered (Suri 1985). This will include decisions related to the final product (types, production volume, sequence/route of operations) and/or decision variables include the components of the FMS (buffer areas, type and quantity of: CNC machines, setup stations, transportation systems, storage systems, tools, and pallets and fixtures).

1.2.4 Short-term Planning of FMS

Short term planning ensures managing the operation of an existing FMS. Production planner for FMS has different perspective than one who manages the traditional job shop in terms of:

- Setup times are nearly negligible between different operations for a machine
- Due to the finite number of tools that the tools magazine can carry, FMS can produce limited part types simultaneously
- Idleness in the machines might occur due the limitation of a number of pallets a system can carry

- Since the whole system running by a computer network, data collection can be provided to analyze, improve, or control the operation.

According to Tempelmeier and Kuhn (1993), short term planning in FMS has two phases: Pre-release planning and scheduling. In the former one, production orders are released by the central control system. Order information includes a quantity, availability of raw materials, and the order due date. Two planning stages are known as batching and system setup planning. Batching is the process of grouping orders for common and simultaneous processing in FMS. System setup planning is the process of deciding the route and machines that will process the assigned batches.

Scheduling is the process of assigning resources to tasks. In FMS number of different or identical machines and routes are available to produce different products (Lee and DiCesare 1994). This will lead the decision maker to face some problems including but not limited to the following (Stecke 1985):

- The optimal sequence of parts to enter the system and interval time between them: the concern is deciding the sequence of orders according to many factors such as order due date and availability of the raw material. Also, due to the constraint of the production rate, sequence input rate should be considered.
- Scheduling approach: scheduling methods can range from simple dispatching rules to sophisticated algorithms
- The way to prioritize parts entering the same machine tool: Within the system if more than one part arrived at the same time to the machine tool, deciding which part to process first is a common problem. Determine the optimal sequence in this event is an important rule.

1.3 Problem Statement

This research recognizes the difficulties and challenges facing top management in their decisions while establishing new SMS. One of those decisions is the configuration of the SMS that will lead to the minimization of the operational cost and lead time as well as utilizing the machines efficiently. The configuration includes the required machines, their quantities, and the required messaging system. Upon deciding the establishment of the system, a market study will be submitted to show the forecasted demand, engineers design or recommend the specifications of the components, and top management then selects the configuration to perform the task and satisfy the requirements from the engineers.

According to Samvedi, Jain et al. (2012) failing to select the suitable machines to perform the job will negatively affect the company's productivity, flexibility, and responsiveness.

1.4 Research Objectives

This objective of this research is to develop a framework to generate the configuration of a SMS. The developed framework provides integrated components that will allow the selection of a particular configuration. In addition, the framework will evaluate the system prior implementation to achieve the organizational strategy efficiently.

The research aims to explore and develop simple hybrid simulation model to augment the design phase in the SMS and hence, optimize the configuration selection. In addition, it will provide guidance of the messaging protocols to be used. This is very important to implement the Internet of Things.

1.5 Research Questions

There is an absence in the literature of system architecture that can assist top management in deciding system configurations required to perform the task. The questions then are:

- How to model the communication between manufacturing resources to share and exchange data for a better decision making?
- How to address the effect of communication on systems' components individually and holistically?
- What are the suitable components of a framework that will lead to optimize the configuration of a SMS?

1.6 Contribution

This research potentially improves the process through a framework that serves as guideline to optimize the planning phase in designing SMS, and in turn, improves the decision-making process.

1.7 Organization of the Reminder of this Document

The remainder of this document is organized as follows. Chapter 2 gives an overview about the previous work in the literature including: SMS, design of FMS and machine tool selection, queueing, analytical hierarchy process, agent based modeling in manufacturing, FMS configuration, manufacturing optimization. Chapter 3 discusses the research methodology where in Chapter 4 the proposed framework is introduced and a case study is implemented in Chapter 5. This work is concluded in Chapter 6 with a summary of the accomplishments and directions of future research.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The previous chapter highlighted the importance of SMS and the urgency to advance the research in this arena. In particular, this chapter discusses the definitions and technical aspects that are necessary for developing a framework to generate a system configuration. The literature review focuses on presenting the scope and approaches behind the usage of hybrid model and optimization. This chapter covers the following topics:

Smart manufacturing systems. Investigate previous studies in this area and understands the current stage of the research.

Design of flexible manufacturing systems. Investigate techniques used to model and evaluate FMSs. Models such as physical models, analytical models, discrete simulation models, and knowledge-based simulation systems. The design will take into account: FMS configuration, machine tool selection, FMS layout selection, transportation selection, buffering area, inspection facility selection, computing system design, economics considerations, and social and human aspects (Chan, Jiang et al. 2000). Deficiency in understanding the different aspect of the system is a major cause in the failure of the technology (Borenstein 1998). Particularly, the focus is on the decision of FMS configuration.

Agent based-systems in manufacturing. Agent technology has become one of the most efficient technologies in designing manufacturing systems. Agent technology is used in manufacturing enterprise integration, enterprise collaboration, manufacturing process planning and scheduling, and shop floor control (Shen, Hao et al. 2006).

Agent based Simulation models. Optimizing the manufacturing system is difficult using solely analytical or mathematical methods (Hao and Shen 2008) . Researchers tend to utilize new technologies to optimize the design of manufacturing facilities (Shen, Hao et al. 2006). Therefore, a simulation model will be used to assess decision makers in their configuration design among number of alternatives to obtain their needs and hence, achieve their goals. By using a simulation model different configurations, system parameters, and operating policies can be tested and verified without doing any physical implementation (Aytug¯and Dog¯an 1998). Agent simulation will allow each machine to act as an independent entity. This will enable the model to enhance and control the interaction, communication, collaboration, and task allocation between agents (Smith, Sahin et al. 2009).

Multi criteria decision making using genetic algorithms. Based on the FMS objectives, the decision support system then will control the overall framework to achieve the optimum design that will satisfy the requirements.

2.2 Smart Manufacturing Systems

Definition of SMS according to Kang, Lee et al. (2016) “It is a collection and a paradigm of various technologies that can promote a strategic innovation of the existing manufacturing industry through the convergence of humans, technology, and information”.

However, Radziwon, Bilberg et al. (2014) there is no consensus about a clear definition of smart manufacturing facility. The authors survey the literature to develop a uniform definition. “A Smart Factory: is a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labor and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization".

Zuehlke (2010) presented a joint project between industries and academia in Germany to illustrate the benefits of smart manufacturing. The facility has a production of colored liquid soap. The product is mixed, filled into dispenser bottles, individually labeled, and then delivered by customer order. The concern is on the use of innovative information and communication technologies and to address the challenges resulted from system design. There are no physical connections between the components of the system. Bluetooth, ZigBee, UWB, NFC and RFID systems are installed between the components. The study shows that it is fairly simple to modify the production process since the components are not physically connected. The wireless communication assures the reduction in the planning effort. Moreover, this will enable new, mobile and flexible systems for the operation, maintenance, and diagnostics of the production facility. The author positively recommends the approach for other facilities. Based on the authors perspective using technology is what makes it smart.

Davis, Edgar et al. (2012) draw some remarks about smart manufacturing systems based on their research on information technology that fundamentally change the existing health care model. Use of data collection to create a database full of history, state, quality and characteristics of each product. This can happen by recording detailed data of each product in each stage in the facility and across the supply chain. Also, this can help in building new key performance measures. For example, build the carbon footprint of each product. Another example, it is required by the Secretary of Health and Human Services to create a national food tracing system in order to discover the source of contamination in the food supply chain in a minimal timeframe. Hence, smart manufacturing system can use data to trace product form the early stages until it is a finish good. Manufacturing should also be information driven base. Performance matrices such as customization, flexibility, responsiveness, energy efficiency, and environmental effectiveness should take place the traditional ones.

Elghoneimy and Gruver (2012), attempt to use agent-based support and simulation model in a wood manufacturing facility. The problem is the difficulties in forecasting orders' scheduling due to vagueness in product characteristics. Currently, there is no scheduling solution where processing times are unknown. The objectives are to develop: decision support system to aid in scheduling and material selection, flexibility to adjust orders and congested machines, distributed system that is able to perform in different locations, flexible to complement with new machines, and flexible to integrate with the enterprise level and monitor the entire supply chain. The goal is to provide the facility with a cost savings of lumber and reduce the waste of natural resources. Two main decisions are included in the system: material selection and scheduling.

A decision support and simulation system for the facility was developed based on a multi-agent model. The model was applied to two production lines using a negotiation protocol. The model has agents (ripsaw, conveyor, and chop-saw) and two decision support agents (Jag Selection and Cut-list Recommend). Different systems were used to provide the simulation model with the historical data.

The advantages of an agent-based design for decision support and simulation of the facility are modeling: agents are working autonomously without a centralized control unit for the machines. That makes more realistically. Communication: through messages, agents can communicate easily. Integration: it is possible to add agents to the same environment where they interact efficiently. On the other hand, the disadvantage of the model relies on the details of the design. As in centralized model, following the flow of entities can reflect the behavior of the system. In contrast, agents are decentralized; each agent is designed separately.

Another research is done by Skobelev, Kolbova et al. (2013). The purpose is to build a multi-agent system to increase factory productivity and efficiency. As the data is fed in real-time, the authors called it a Smart Factory. Including: automated scheduling, forecasting and controlling the manufacturing process.

Under their design, some events were used to change the behavior of the system: new order is coming, equipment failure, changes in priorities, emerging of new urgent tasks, delay in materials. In the process of building the model the following results are expected: increase machines' productivity by 10-15%, increase efficiency of overall resources by 15%, reduce time wasted in tasks allocation, scheduling, overseeing running, reduce response time to unexpected events by 2-3 times, and increase number of orders that are completed within expected lead-time by 15-30%.

In the description about internet of things, Zhang, Zhang et al. (2014) mention that modern developments in networking technologies such as radio frequency identification – RFID or Auto-ID, Bluetooth, Wi- Fi, GSM and infrared have created a new age of the internet of things (IoT). It refers to uniquely identifiable objects (things) and their virtual representations in an Internet-alike structure. They claim that the Internet of Things (IoT) can dramatically improves manufacturing decisions through real-time data.

Due to the lack of real-time data in manufacturing resources, IoT can dramatically improves manufacturing decisions. IoT can capture many forms of data and provide important production information for decision making.

The contributions of the authors are based on: 1) a framework of IoT along with its key components. It can capture real-time manufacturing data, integrate it with the enterprise information system, and make optimal decisions. 2) exchange information between various information systems and the manufacturing operational level, 3) track and trace manufacturing resources.

Bi, Da Xu et al. (2014) illustrate the capabilities of enterprise systems in SMS that include: acquiring static and dynamic data from different devices, analyzing data through advance programming models, processing data to with the purpose of planning and controlling as well as optimizing the performance of the system. The paper distinguishes between data acquisition at the device level and data communication. The former one is how to collect data by sensors and the second one is how this data is exchanged and communicated among different devices (i.e. wire cables and wireless networks).

In Liraviasl, ElMaraghy et al. (2015) the objective of this research is to optimize the re-configurability problem in the manufacturing systems. Reconfiguration of systems hardware and software modules needs to be completed in quick and reliable manner in order to produce new products with new/ different features according to customer requirements without replacing the entire existing system. Goal of re-configurable manufacturing system is to provide required functionality and capacity for system as and when needed. Markets are characterized by high demand fluctuation and shorter lead time. Therefore, the ability of the manufacturing system to reconfigure is a high priority to succeed in the business. Authors describe a framework developed using hybrid simulation consisting of discrete event simulation and agent-based simulation which addresses problem at hand. They used an existence manufacturing facility as a case study to examine the framework. The framework shows advantages of utilizing state charts to construct different agent types. This enables the factory for the better management of the product variety. The framework is modeled in the Anylogic software. The examined system has seven agents: automated storage/retrieval systems, quality inspection, manual assembly, robotic assembly, and three different terminations. Each agent has input/output parameters and variables, control provided using UML state charts, and mechanism developed with the help of Anylogic library to implement the interaction among agents. Authors also evaluate the framework as a high-medium in terms of complexity in case of using a larger case study. Table 2-1 summarizes this section.

SMS and Internet of Things (IoT)

According to Based on Ashton (2009) IoT is the connection of machines, devices, "things" wirelessly. Bi, Da Xu et al. (2014) discuss the existing manufacturing situation to embrace internet of things on manufacturing enterprise level including:

1. IT infrastructure is unable to handle this change
2. Incapability in systems' hardware
3. Collaboration restrictions on the enterprise level

Modeling and Simulation through ABM can amplify the usage of IoT in the SMS. Connecting each machine with its supplier can reduce the possibility of the failure rate.

Table 2-1: SMS literature

No.	Author	Title	Year	Journal
1	(Zuehlke 2010)	Smart Factory—Towards a factory-of-things	2010	Annual Reviews in Control

No.	Author	Title	Year	Journal
2	(Davis, Edgar et al. 2012)	Smart manufacturing, manufacturing intelligence and demand-dynamic performance.	2012	Computers & Chemical Engineering
3	(Elghoneimy and Gruver 2012)	Agent-Based Decision Support and Simulation for Wood Products Manufacturing	2012	IEEE
4	(Skobelev, Kolbova et al. 2013)	Multi-Agent System Smart Factory for Real-Time Workshop Management in Aircraft Jet Engines Production.	2013	Intelligent Manufacturing Systems
5	(Radziwon, Bilberg et al. 2014)	The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions	2014	Procedia Engineering
6	(Zhang, Zhang et al. 2014)	Real-time information capturing and integration framework of the internet of manufacturing things	2014	International Journal of Computer Integrated Manufacturing
7	(Jung, Morris et al. 2015)	Mapping Strategic Goals and Operational Performance Metrics for Smart Manufacturing Systems.	2015	Procedia Computer Science

2.3 Design of FMS and Machine Tool Selection

In early 1960, David Williamson proposes a research named "System 24" in the research and development of London-based Mollins. The purpose is to produce a wide diversity of sophisticated products with the expectations of short lead time, improved quality, and reducing cost (Chen and Chen 2010). Vinod and Solberg (1985) identify that FMS performance measures include: Throughput, queue length, distribution, utilization, and mean waiting.

Two major critical resources are considered in modeling FMS. The investment that mainly depends on the cost of the machines and equipment, and the amount of time each machine can run on an annual basis (Stam and Kuula 1991). Therefore, in optimizing the design of FMS, two main questions appear: 1) How many identical machines are required at each workstation? 2) What is the expected work-in-process level? (Kouvelis 1992) (Vinod and Solberg 1985).

According to Borenstein (1998) and Chan, Jiang et al. (2000), the difficulty of these questions and the complexity of the design task rely on two essential characteristics:

1. The ample number of alternative system control strategies and configurations available to the designer.
2. FMS design includes a wide variety of criteria to choose from for example system performance, financial parameters, initial capital outlay, flexibility, and quality.

Once the company decides to invest in the manufacturing technology the pre-design stage will take a place. In which the company will determine the part types. Also the company at this stage will determine for example the types of workstations, pallets, and material handling system that are required to produce the chosen products. Then in the design stage, numbers of alternative process plans are known and the management will select the best suitable design (Solot and van

Vliet 1994). According to Spano, O'Grady et al. (1993) the design process for FMS encompasses the following phases: Design of facility, design of material handling system, and design of control system.

Doumeingts, Vallespir et al. (1987) identify the lifecycle of the advance manufacturing system. It consists of five phases: 1) Analysis phase: study the current condition, set goals, and identify constraints. 2) Design specification phase: determine the functional specifications and the framework of the AMS. 3) Development phase: according to the design specification different components in the system will be selected such as: machines, transport system, quality control equipment. In many cases this phase require development software tool. 4) Implementation phase: in this phase the actual component installation will be done, data input, tests, and training. 5) Operational phase: run the facility aiming to achieve the objectives, control the system, and provide feedback to react against any negative changes.

On other hand, machine tool selection is an important decision-making process for many manufacturing companies. Improperly selected machines can negatively affect the overall performance of a production system. The speed, quality and cost of manufacturing strongly depend on the type of the machine tool used. Since the selection of new machines is a time-consuming and difficult process requiring advanced knowledge and experience, it may cause several problems for the engineers, managers and also for the machine manufacturer (Budak 2004) and (Stam and Kuula 1991).

In reviewing the literature numbers of models were found including: queuing, analytical hierarchy process, digraph and matrix models that are used to select the best FMS among numerous alternatives. Although the focus of the research is on agent simulation, the research is highlighting the main techniques used in the context of FMS.

2.4 <u>Queuing</u>

According to Solot and van Vliet (1994), discrete-event simulation model was the only tool used to evaluate and improve the performance of the FMS until the introduction of the queuing models in the late seventies. The introduction of queuing network models allow manufacturer to evaluate the throughput, work in process, and lead times. In fact, Solberg (1977) introduces the CAN-Q model as a starting point of the use of queuing network models for FMS performance evaluation. Two types of queuing networks are used to evaluate and improve FMS: open and closed queuing networks (Solot and van Vliet 1994).

Vinod and Solberg (1985) attempted to reduce the operational cost of a manufacturing facility. Given the required specification of the work in process, they develop a mathematical model based on a closed queuing network to determine the configuration of the system (a configuration is defined by the number of resources of each machine type). Then, solve the bottleneck problem that occurs between resources and examine the workflow in the system. However, Dallery and Frein (1988) discover a disadvantage in the model. The initial solution depends on subjective starting point and as number of stations increase time required for calculations increase.

Dallery and Frein (1988) model the FMS as a closed queuing network to determine the optimal configuration of the system. In order to overcome the disadvantages from Vinod and Solberg (1985), they introduce three steps: 1) Determine a lower configuration, 2) Develop a heuristic solution, and 3) Find the optimal solution. Also, Dallery and E. (1990) use the closed queuing network to optimize the configuration of the FMS. However, they divided each network to a sub network. Then, they optimize each sub-network to achieve the highest overall throughput. According to Kouvelis (1992) the method of Vinod and Solberg (1985) is more sophisticated way in determining the initial solution while Dallery and E. (1990) use much more better efficient way. Buzacott and Shanthikumar (1992) illustrate previous work on single and multiple stage queuing systems to optimize manufacturing systems.

2.5 Analytic Hierarchy Process (AHP)

AHP is a tool developed to solve complex problems involving multiple criteria (Saaty 1977). It can be utilized to judge subjective issues (i.e. feelings, ideas, and emotions). The result of the AHP indicates the overall preference for each decision alternative. There are three stages in AHP to solve problems: decomposition, comparative judgments, and synthesis of priorities. The decomposition principle calls for constructing a hierarchy. The objective will be at the top of the hierarchy, then the criteria, sub-criteria, and alternatives are placed downward, respectively. In the comparative judgment, a comparison matrix at each level will be set then, comparing pairs of criteria, or pairs of alternatives at the lowest level. In the synthesis, preferences derived from a criteria or sub-criteria matrix are used to find the composite weight for each alternative. The option/alternative with the highest rating is the final solution (Shang and Sueyoshi 1995).

Arbel and Seidmann (1984) present an AHP model to evaluate the performance and select FMS in a real application. As mentioned in their study the FMS acquisition problem consists of: 1) technical data for preliminary design (performance analysis, production time study, group technology, and define machines and tools), 2) FMS concept validation, 3) capacity planning design through request for proposal (RFP), 4) evaluation of the vendor’s proposal.

Stam and Kuula (1991) develop a decision support framework to assist top-level management in selecting the most suitable FMS from various configurations during the planning phase. The framework has two phases; each phase has a separate user interface that will allow top management to deal with the model. The purpose of the first phase is narrow down the different FMS designs and configurations to three or four different configurations. The “Expert Choice” software package is used in this phase. The software is based on AHP. Expert choice will eliminate the least desirable configurations and leave a small group of attractive ones. In the second phase detailed quantitative information is needed for further comparisons. Due to the distinctive specification for each FMS, the analysis in this phase requires formulating each FMS separately. The problem is then formulated using a multi-objective mathematical programming model. Since the Expert Choice doesn’t have the capability to deal with multi-objective models, the Visual Interactive Goal (VIG) programming software package is used. The operational decision variables are the quantity of each part to be produced and the batch size of each part. While the boundaries of the system include the amount of time available on each machine.

Stam and Kuula (1991) use a case study to test their model. Thirty FMS configurations were used in the framework. Six major criteria were used: investment cost, capacity, flexibility, utilizations rate, unit cost, and economic risk. Under each criterion there are several components. However, they recommended using their model with other support analysis such as feasibility study and the future consequences on the organizational level (i.e. organizational structure and training workers).

Later, Shang and Sueyoshi (1995) tackle the same problem of selecting the most suitable FMS through a unified framework. The proposed framework has three modules: 1) AHP: evaluate long-term effects and qualitative benefits at a strategic level, 2) Simulation module: evaluates tactical impact of the system, 3) Accounting procedure: determine the cost and resources that are required to implement the system and benefit from it. An efficiency measurement method called Data Envelopment Analysis (DEA) unified the framework. The DEA is used to evaluate the different alternatives. The DEA is capable of converting all inputs in the framework to a single efficiency score. According to the authors, no one has integrated the three modules in one framework.

Rao (2007) applies the AHP model in a Turkish tractor manufacturing plant to decide whether to invest in implementing FMS or not. In addition to a sensitivity analysis that shows the stability of the outcome. The tractor manufacturing company had invested nearly $1 billion in FMS in seven flexible manufacturing production lines. Yet the management is facing some difficulties to go further in their investments. In order to reach the decision, the management (quality manager, production manager, operation manager, purchasing manager, sales manager, and plant manager) contributes in identifying the attributes/criteria required for the AHP model. Initially the management found 39 criteria and then narrows it to 28. These criteria fall under four major criteria: advantages, opportunities, risks, and disadvantages. As a result, the analysis from the model concluded that the company should invest in FMS.

Mohanty and Venkataraman (1993) assist Indian manufacturing company facing problems in: 1) A delay in the release of the drawings from the design department, 2) Expanding the products range without additional resources, 3) High material cost due to: inventory, wastage during material handling, and rework. Different automated manufacturing systems are proposed. An AHP model is used to examine three alternatives (Computer aided design (CAD), Computer aided design-computer aided manufacturing (CAD-CAM), Computer aided design-flexible manufacturing modules (CAD-FMM)). The company considers the strategic, technological, and social impact as the main factors/criteria. Consequently, the analysis recommends the CAD-FMM for the company.

Borenstein (1998) develops a framework to select the most suitable FMS. The framework links the strategic, tactical and financial aspects in one integrated systematic decision support system. The following figure 2.1 illustrates the framework. A software package is introduced to select the most appropriate configuration from different alternatives. The methodology is focused on: 1) Selecting equipment and logic control features from a strategic perspective, 2) Adopting to the tactical decisions as needed.

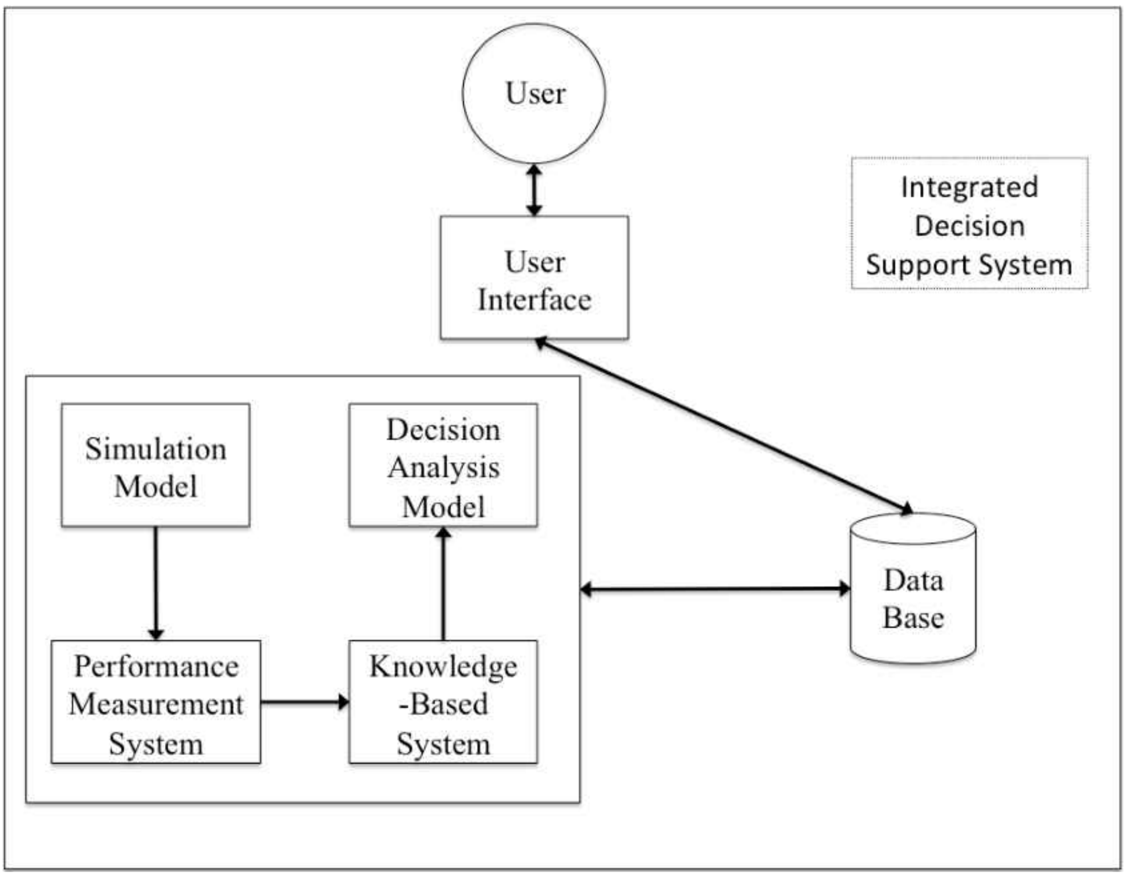


Figure 2-1: A framework to select the appropriate FMS configuration adapted from Borenstein (1998)

In addition, Chan, Jiang et al. (2000) developed another model to aid the design of FMS through simulation and multi-criteria decision-making (MCDM) techniques. The simulation model and the expert system are used to constructing and test alternative designs. Then, AHP is used to select the most suitable design from the simulation output. Also, intelligent tools such as expert systems, fuzzy systems and neural networks are developed to support the design of the FMS. Figure 2.2 illustrates the framework. In developing the framework Chan, Jiang et al. (2000) use ARENA a software to develop a simulation model and the expert system is developed in CAPPA.

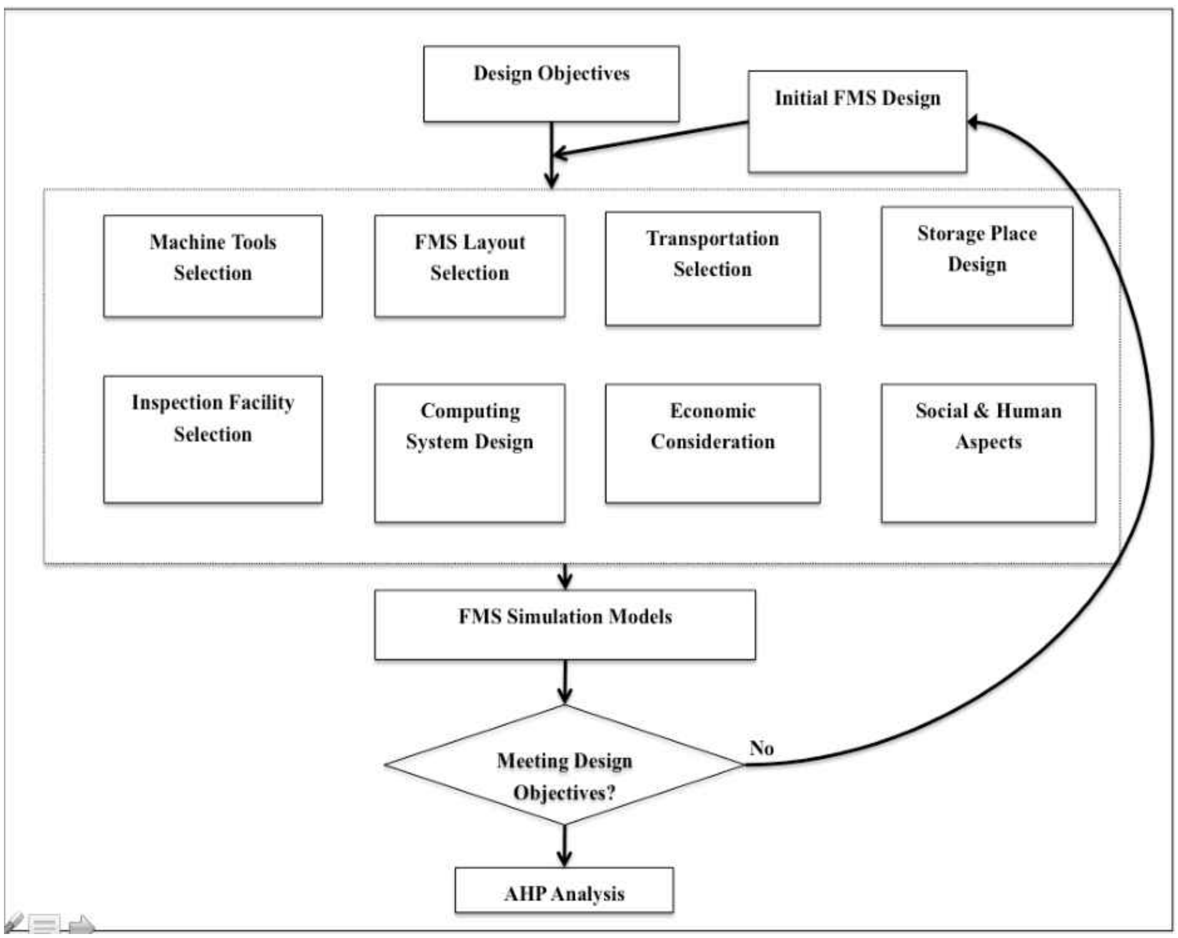


Figure 2-2 A framework to select the best FMS configuration adapted from Chan, Jiang et al. (2000)

AHP is used to evaluate the FMS from the simulation models. Figure 2.3 is illustrating the AHP. The top of the hierarchical structure represents the goal of the AHP model that is choosing the best FMS. The criteria are finance, productivity, flexibility, building time and risk. The sub-criteria of finance are the installation cost and the operational cost. The sub-criteria of productivity are production rate, total production, lead-time, inventory, and machine utility. The sub-criteria of flexibility is flexibility of part type, machine, process, product, routing, expansion, operation and transfer. The sub-criteria of building time are planning time and implementing time. The sub-criteria for the risk are technological and operational.

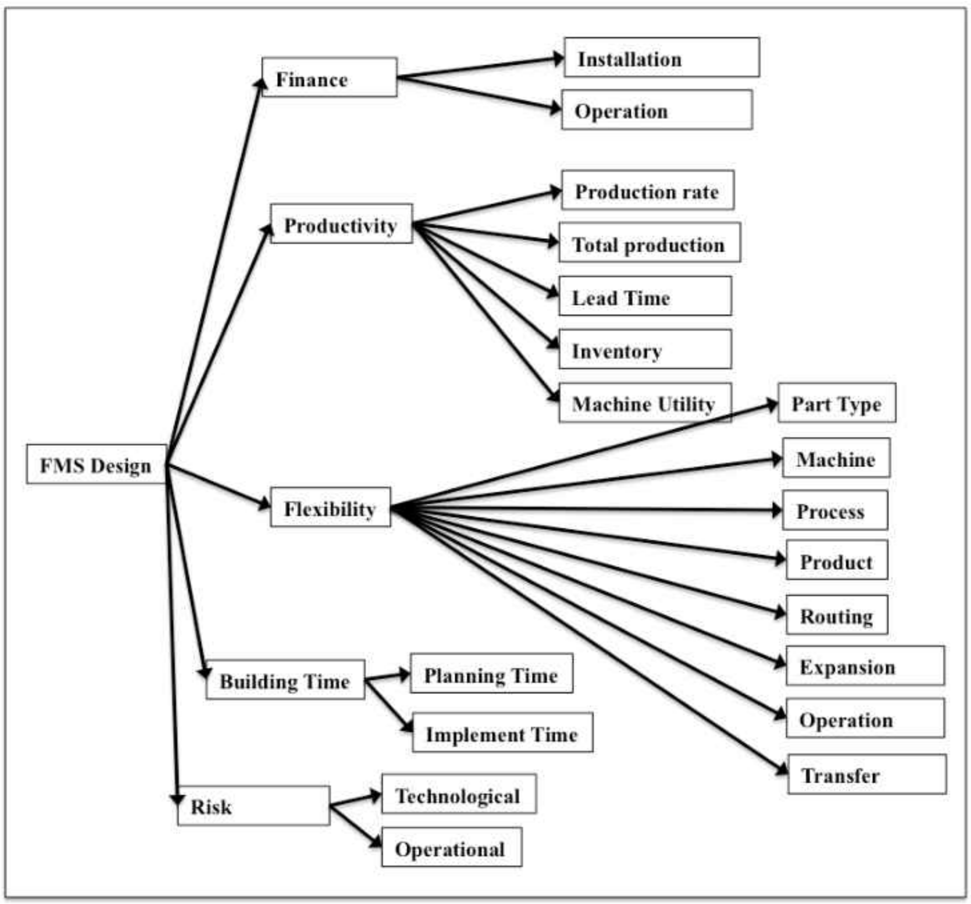


Figure 2-3: AHP Model adapted from Chan, Jiang et al. (2000)

Rao (2009) claims proposed an FMS Selection Index' (FMS-SI) that evaluates and ranks FMSs for a given selection problem. The author used a compromise ranking method in conjunction with

AHP. Later, Maniya and Bhatt (2011) propose a model based on the preference selection index (PSI) method.

Karande and Chakraborty (2013) apply the measure of attractiveness by a categorical–based evaluation technique to solve FMS selection problems. Four different FMS alternatives are considered while six criteria are taking into consideration: annual depreciation and maintenance costs, quality of results, ease of use, competitiveness, adaptability, and expandability.

2.6 Other Models

Generally, there are two ways to analyze the performance of FMS: 1) simulation models, and 2) analytical models (Stam and Kuula 1991). Borenstein (1998) states that simulation is the most powerful tool to evaluate FMS. The fact that FMS/automated systems are complex makes it difficult to be modeled mathematically

According to Chan, Jiang et al. (2000), in using simulation the performance measures are mainly encompass: total production, average waiting time in a queue, maximum time waiting in queue, maximum number of parts that were at any time waiting in the queue, average and maximum process time of parts, and the utilization of machines. Borenstein (1998) uses simulation model to evaluate FMS based on lead time, equipment utilization, and bottleneck identification. Also, the simulation model is used to perform sensitivity analysis of critical input parameters such as batch sizes. The simulation module is an object-oriented simulation model programmed in C++.

Sarkis (1997) evaluates FMS by applying data envelopment analysis (DEA) modeling. The model is to find whether to invest or not considering conventional factors such as cost and nonconventional factors such as flexibility. In addition to Wang and Chin (2009) who utilize the DEA in machine-tool selection considering best and worse efficiencies while choosing the tools.

However, Rao and Parnichkun (2009) say that DEA requires more computation and if the number of attributes that the decision maker wants to consider is very large and the alternatives are small, then DEA may not be the best way to tackle the problem. Talluri, Whiteside et al. (2000) develop a framework based on the combined application of DEA and nonparametric statistical procedures, for the selection of different FMS alternatives. The framework considers criteria including work-in-process (WIP), percentage of tardy jobs, and yield. Yield is defined as throughput excluding scrap and rework.

In addition, Young (1991) presents a cost model to estimate the total cost in designing AMS including: productivity cost (labor, material, depreciation, machine, tool, floor space, computer software), quality cost (prevention and failure), flexibility cost (setup, waiting, idle, inventory). Also, Rao (2009) presents a decision-making model for FMS selection through digraph and matrix methods. The method does not show proof for consistency in the judgments of relative importance of attributes.

2.7 Machine-tool selection

A machine tool selection is an important decision-making process for many manufacturing companies. Improperly selected machines can negatively affect the overall performance of a production system. The speed, quality and cost of manufacturing strongly depend on the type of the machine tool used. Since the selection of new machines is a time-consuming and difficult process requiring advanced knowledge and experience, it may cause several problems for the engineers, managers and also for the machine manufacturer. (Budak 2004). Generally the performance of the FMS can be evaluated using one of two types of models: analytical or simulation models (Stam and Kuula 1991).

Simulation

The purpose of the simulation is mimicking a real life application in a virtual and controlled environment. Computer based-simulation is used in design, planning, and control of manufacturing facilities and systems. According to In Hughes (1985) there are four levels in applying simulation within manufacturing systems including:

- Facility demand
- Division, shop, or cell control associated with loading, shifting, and system management
- Machine and equipment level: tooling, palletizing, robots
- Operational level: process planning and tool design and manufacturing technology

Traditionally, machine tool selection was based on financial evaluation. Hughes (1985) discussed a simulation technique that is used by several companies to select the most appropriate machine tools. The goal is to optimize the use of capital by selecting the optimum machine tools. Since Hughes (1985) mentions that conventional forecasting methods that are based on management science is not reliable, the Delphi method is used to find the future manufacturing requirements to identify the expected machine load.

Two case studies are illustrated in Hughes (1985)using the proposed model. Marketing department provide the management with a market study that shows the expected demand for the coming five years. Based on the Delphi method range of products will be determined with assigned probability for each sales level. Then bills of material can be calculated and an annual demand for each part can be calculated. By adding the machine routing file the machine load can be determined and hence the capacity needed at each type of operation is determined. Note that each operation is representing a machine tool. As a result, in each case study a particular machine tool is selected.

Decision-Support System

Stam and Kuula (1991) develop a decision support framework to assist top management in selecting the most suitable FMS from various configurations during the planning phase. Then, Myint and Tabucanon (1994) consider the same framework but taking into account two crucial factors the uncertainty of the demand and risk affecting the flexibility. Figure 2.4 shows the flow diagram of the model.

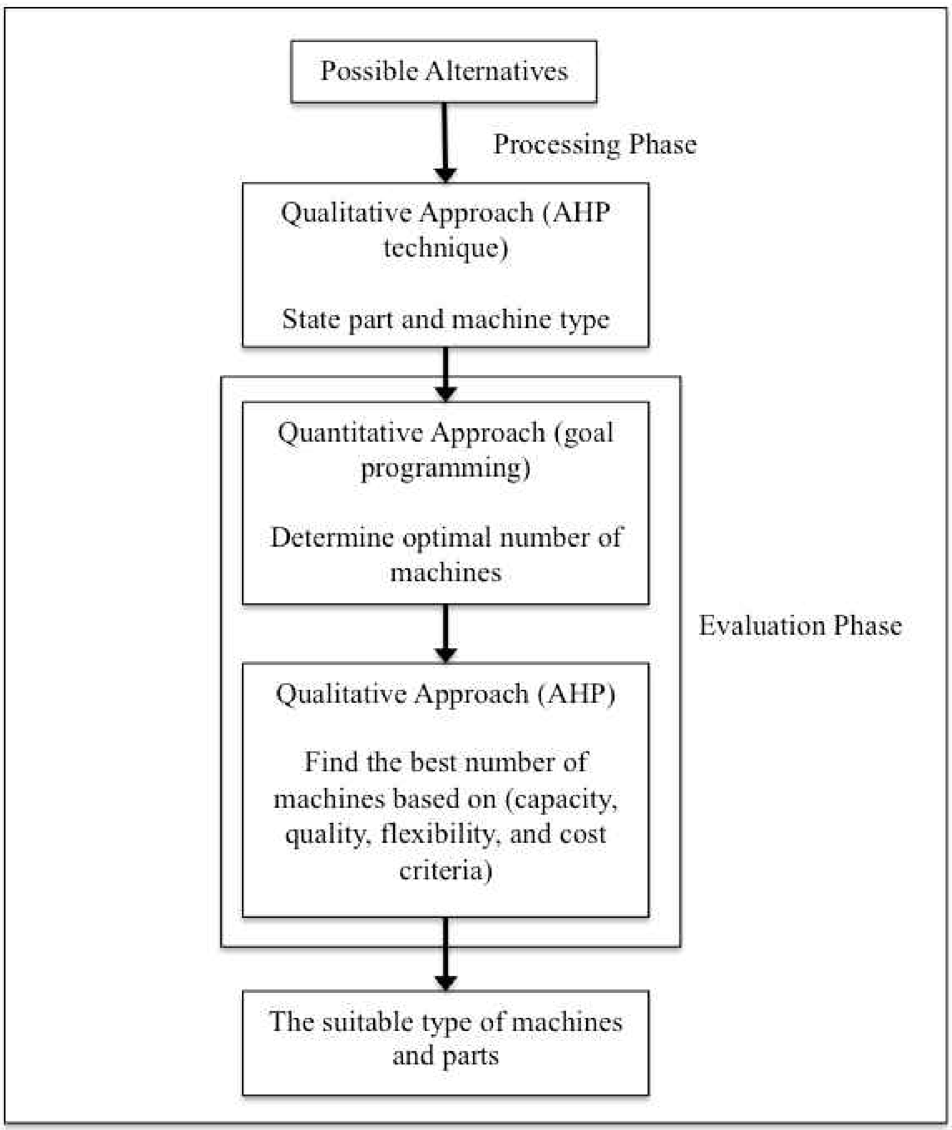


Figure 2-4 Framework for FMS Selection adapted from Myint and Tabucanon (1994)

Tabucanon, Batanov et al. (1994) develop a framework to solve the machine selection problem for FMS. The framework consists two phases: the first phase narrows down the selection to seven or less alternatives. The second phase uses AHP to select the best-required machine as show in figure 2.5.

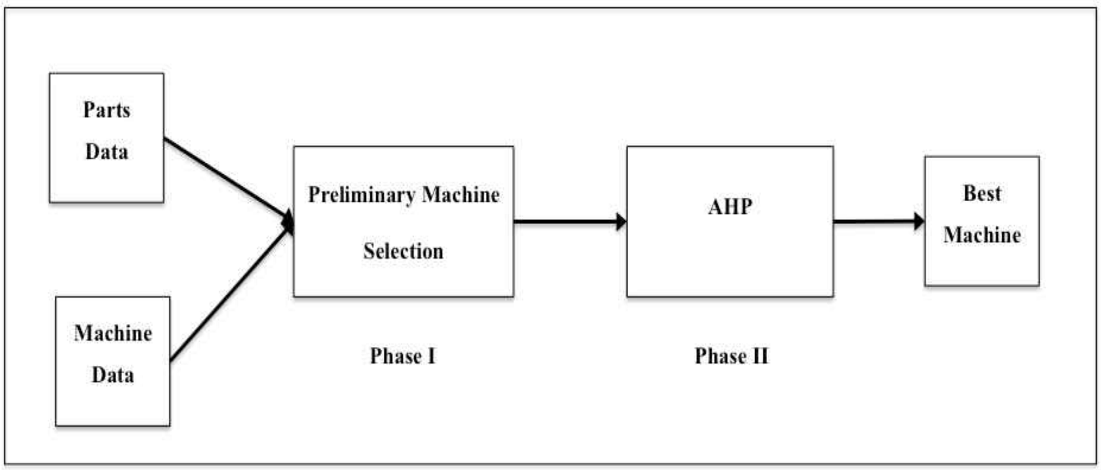


Figure 2-5 Decision framework for machine selection adapted from Tabucanon, Batanov et al. (1994)

The approach uses Expert Choice, Dbase III + DBMS, Expert System shell (EXSYS), and Turbo Pascal. The input of the framework is the database that includes information about parts and machines. Information considered in the parts database includes: material of each part, machining time, set up time, batch size, batch set up time, annual demand of each part, maximum size of the raw material, operations needed for each part with the required cutting tool, and spindle speed required.

Phase one consists of two steps: the first one needs information about parts to determine the machines. The second step is only needed if the first step leads to more than seven alternatives. Numbers of criteria are used in the first step including: cost, operations, accuracy, cutting tools, length, and outer diameter, spindle speed, spindle power, feed rate, floor space, electric power. If the result gives more than seven alternatives a consultation module is available otherwise, the user have the option to directly choose the machine. Criteria in the case of the consultation module are about gearbox (i.e. machine with gear transmission system between the spindle drive unit), types of spindle drive AC or DC motor, machine material structure (steel or welded steel plate, etc), and machine hours available. The result of the first phase (seven or less alternatives) becomes an input in the AHP model (phase 2). Criteria and sub criteria that are considered as shown in table 2.1.

Table 2-2: : AHP criteria for machine selection problem adapted from Tabucanon, Batanov et al. (1994)

Criteria
Flexibility of machine
Adaptability of machine
Total cost of machine
Continues operation of machine
Special feature of machine
Total productivity of machine
Power and space requirements of machine
Sub-criteria
Adaptability of machine to tools
Adaptability of machine to manpower

Reliability of machine
Spares availability of machine
Multi-tool operation of machine
Power consumed by machine
Space occupied by machine

Lin and Yang (1996) apply AHP to assess what type of machine in flexible manufacturing cell, numerical control machine, or conventional machine is most suitable for certain type of parts. Before applying the AHP program, experts are surveyed to build a knowledge foundation for the system.

In Atmani and Lashkari (1998), linear integer programming is used to determine the route of the parts in existing facility. The problem is to find the optimum machine selection for each part to minimize the operational cost and utilize the machines efficiently.

In Yurdakul (2004), machine tools selection as a strategic decision and its implication to the organizational strategy using AHP and analytical network process. Three criteria are selected: quality, cost, and delivery. The quality has sub criteria including: process quality, actual machining time of a typical part, set-up time of an activity, and number of operations that can be performed at the machine tool. The cost criteria include: factory (material, labor, and factory overhead), administrative, and selling costs. The delivery criteria include: time between order and delivery, on time shipments, shipments accuracy. Using DEA, Wang and Chin (2009) develop a model for machine –tool selection considering the best and worse efficiencies of each configuration in FMS.

2.8 Agent based-modeling in manufacturing

2.8.1 Background

In the manufacturing world, it is difficult for a decision maker to manage a facility/facilities that consist of a large number of machines and processes, and assess alternative decisions in a timely manner. The literature introduces different methods to address this problem including constraint satisfaction, genetic algorithms, tabu search and neural networks (Cheeseman, Swann et al. 2005). Although these techniques have shown optimum results, they can be used for static problems. Therefore, scholars are working to improve the performance of FMS dynamically utilizing agents (Chen and Chen 2010). Agent-based modeling is introduced to address the dynamic problems in manufacturing (Anosike and Zhang 2009).

The purpose of modeling and simulation is mimicking the real-life application to a controlled environment in order to conduct experiments for decision support systems (i.e. behavioral or performance prediction and evaluation, evaluation alternatives of engineering design, planning, acquisition), understanding models, and education. It also used for training and entertainment (Barry, Koehler et al. 2009). The concept of agents is considered by researchers in both artificial intelligence (AI) and mainstream computer science; AI is a subfield from the computer science that aims to construct agents that demonstrate intelligent behavior (Wooldridge and Jennings 1995).

Wooldridge and Jennings (1995) highlight the theoretical and practical issues associated with the design and construction of agents. They divide the work into agent theory, architecture, and languages. *The theory* defines agents and how it is represented mathematically. *Agent architectures:* concerning the requirements that will satisfy the initiation of agents in terms of software and hardware. *Agent languages*: programming languages that will support agents to function.

Generally, agents are programmed virtual entities that have the abilities to operate autonomously to solve defined problems. In multi-agent systems (MAS), the system will have more than one agent where agents have the ability to communicate with each other. MAS is an artificial system that includes number of autonomous agents, which communicate with each other to reach common objectives, while at the same time each agent has an individual objectives and constraints (Kouiss, Pierreval et al. 1997). MAS have the advantages of decentralization, autonomy, scalability, and reusability (Bollinger, Benson et al. 1998).

Agents can represent workers, cells, machines, tools, automated guided vehicles, and parts to enhance the workflow in the facility in terms of planning, scheduling and control (Shen and Norrie 1999). A result based on the distributed artificial intelligence specify that the intelligent manufacturing system designed with agent technology is the most potential development direction (Guo and Zhang 2010).

2.8.2 Agent Characteristics

A typical agent has characteristics that shape its behavior (Shen and Norrie 1999) and others call it the agent's flexibility (Jennings and Wooldridge 1998). These characteristics include:

- Autonomous: Upon defining the agent in the program, the agent can work and interact with other agents independently without external interference from the user.
- Proactive: Initiate operations independently to achieve a goal.
- Reactive: Immediate response towards any changes.

2.8.3 Agent Structure

According to Kouiss, Pierreval et al. (1997) agents can be structured based on three layers:

1. The static knowledge layer: also called the social knowledge. The agent must know about itself and the environment surrounding it.
2. The expertise layer: the distinction of the agent through the individual know-how. This can be in different forms (e.g. algorithms, production rules, frames, or logical expressions).
3. The communication layer: describes the communication and networking protocols between the agent and the different entities in the environment.

According to the foundation for intelligent physical agent (FIPA), the environment is divided into six parts: software, agent, agent management system (AMS), directory facilitator (DF), message transport service (MTS), and agent platform (Chen and Chen 2010).

2.8.4 Agent Architectures

According to Komma, Jain et al. (2011), agent architecture is the configuration of the agent that defines its behavior and can be classified into: *logic-based agents*: this type is used when reasoning and logic is required for decision making, *reactive agents, Belief–desire–intention (BDI) agents*: this type of agent is based on data representing beliefs and intentions of the agent, and *layered agents*: decision making is made through various software layers.

2.8.5 Agent Modeling and Frameworks

In Anosike and Zhang (2009), a description of the multi-agent systems' frameworks are illustrated as follow:

- Hierarchical frameworks: Manufacturing systems are structured in a hierarchal manner to control the decisions. The directions of the decisions are coming from the upper level toward the lower one and status reports are following the opposite direction. This framework usually applied in scheduling agents or a process planning agents. However, it is difficult in this framework to adapt to changes and restructure the system by adding or removing resources.
- Heterarchical frameworks: This framework gives each individual the control to make decisions. Hence, resolve the disadvantage of the hierarchical framework to make it easier in adapting changes in the environment. Yet, it is difficult to achieve the global optimum goal since each individual is working to achieve a narrow objective.
- Hybrid frameworks: Combine hierarchy and heterarchy frameworks together to control manufacturing systems. Examples of systems under hybrid frameworks include yet another manufacturing system (YAMS) and holonic manufacturing systems (HMS)

Yet another manufacturing system (YAMS): Jennings and Wooldridge (1998) define YAMS as a system that works to manage different facilities/factories at the same time. A hierarchal manufacturer has a number of work cells, for example: Milling, lathing, grinding, and painting. These work cells are grouped to form FMS. Each will present and provide different functionality such as assembly, paint spraying, buffering of products. Then, a collection FMSs is grouped into a factory and hence a company has multiple factories that YAMS tend to manage. YAMS applies a multi-agent approach. Each factory and factory component is represented as an agent. Each agent has a collection of plans.

2.8.6 Agents in Scheduling and Job-Shop Control

In manufacturing, the problem of scheduling and control resources is a common problem in the shop floor. The problem deals with decisions related to type of machines required for each product, prioritizing customers' orders, inventory management, and scheduling maintenance. These decisions will meet the requirements for producing high-quality goods, with the minimum cost, and at the right time (Van Dyke Parunak, Baker et al. 2001). As mentioned earlier many models and techniques have been developed for static problems. According to Guo and Zhang (2010) the scheduling problem become more complex when dynamic situations are considered.

Van Dyke Parunak, Baker et al. (2001) apply autonomous agents to shop floor scheduling and control. Prior the application they identified seven requirements associated with using agents in the shop floor problem. These requirements are identified through interviewing manufacturing staff at Rock Island Arsenal and at number of manufacturing facilities. Based on Cheeseman, Swann et al. (2005) one of the largest agent-models is the Autonomous Agents for Rock Island Arsenal (AARIA) program. Van Dyke Parunak, Baker et al. (2001) identify the requirements of AARIA a particular manufacturing shop floor scheduling and control problem. They use NeXT operating system to design agent-based system to solve the problem. The design is used in two scheduling applications: for the production of semiconductors and for shipbuilding.

Start by defining the system requirement based on experts' opinions. Initially the requirements are outlined into: external environment and internal operations – table 2.2 summarizes the requirements.

Table 2-3: Summary of System Requirements adapted from (Van Dyke Parunak, Baker et al. 2001)

Requirement	Definition
Least Commitment	The customers' demand are developed interactively (product specification, quantity, price, and delivery time)
Empowerment	Operators, manufacturing engineers, and managers receive the information they need to do their jobs, with interfaces to let them control the system
Frequent change	Frequent response to any demand change
ERP functionality	The aggregate behavior of the agent community subsumes functionality currently provided by ERP systems
Metamorphosis	The system maintains continuity between different entities that represent different stages in a common life cycle
Modality emergence	An entity's factory control modality emerges dynamically from its operation in the context of the rest of the system inference.
Uniformity	An operation at the system boundary interacts with external Suppliers or Customers in the same way that it does with internal ones

Agents are identified as follow:

Operation: Steps required performing the manufacturing job.

Resource: Any device that including machines, material handling devices.

Manager: Plant manager responsible for performance changes, energy consumption, cash flow, and formally chaotic dynamics.

Part: The input (Material) or output (Product).

Customer: The end user from the final outcome.

Supplier: The vendor of the raw material.

As a result, the proposed architecture provides more flexibility and ease of configuration comparing to the conventional scheduling mechanisms in its performance.

Kouiss, Pierreval et al. (1997) Solve a dynamic scheduling problem in a job shop by applying dispatch rules through multi-agent models. Each agent represents a resource of a manufacturing system. Example of dispatch rules include shortest processing time (SPT), smallest critical ratio (SCR), earliest due date (EDD), conditional expedite shortest processing time (CEXSPT), and critical ratio shortest processing time (CR/SPT). A simulation model is used without a real application or implementation. The results show a significant improvement. The authors mention that such model needs further work to include problems such as assembly and machine selection.

In an ongoing research by Goldsmith and Interrante (1998) to describe a multi-agent scheduling system, an architecture of autonomous manufacturing collective is presented. The collective has two agents one representing the parts and the second one representing the machines. The part agent's objective is to maximize the flow of the parts in the system. While the machine agent's objective is to maximize the machine utilization. Also the research of Ouelhadj, Hanach et al. (1998) combined different architectures to propose a new multi-agent architecture based on real time dynamic scheduling and control in manufacturing cells. The major functions of a cell control system include the need to schedule and monitor cell resources, and the ability to react to abnormal conditions or exceptions. The proposed architecture replaces a centralized database and control computer with a network of agents.

For intelligent manufacturing systems Maturana, Shen et al. (1999) introduce an adaptive agent-based mediator-centric architecture for intelligent manufacturing systems. The adaptive agent-based architecture is called MetaMorph. It is proposed to address system adaptation and extended-enterprise issues at four fundamental levels: virtual enterprise, distributed intelligent systems, concurrent engineering, and agent architectures.

Mohanty (2004) solves a multi-objective production-planning problem using agent modeling in a steel manufacturing system. Java Agent Development environment (JADE) is selected as the platform and the program is coded in a C language. The research has four agent roles defined (batch agents (BAs), tool agents (TAs), machine agents (MAs) and control agents (CAs)). In order to evaluate the proposed many simulation models have been tested. Consequently, the proposed model is more flexible, economical and energy efficient.

Srivastava, Choudhary et al. (2008) apply agent modeling to optimize the design of the automated guided vehicle systems (AVGs) in AMS. AGVs are material handling devices used in AMS to transport materials among workstations. Particularly developing agent-based architecture programmed in JAVA for a real-time traffic control of AGV. Nejad, Sugimura et al. (2011) apply multi-agent system to solve the planning and scheduling problem in the shop floor. A mathematical model is developed to assign jobs to machine tools. Six agents and a negotiation protocol are proposed to integrate the whole system. Three different issues are discussed in the paper:

1. Target flexible manufacturing systems: the proposed system requires certain components to form the manufacturing facility including: a set of machine tools, preparation stations, input and output buffers, AGVs, fixtures and cutting tools

2. Multi-agent system for dynamic process planning and scheduling: the architecture is based on the PROSA reference architecture and ADACOR reference architecture. However, some customization and modification has been added to satisfy the requirements of the proposed model (i.e. machining process agents and production engineering agents). Two types of agents are considered physical and information. The physical agents define jobs, manufacturing resources, and machining processes. The information agents represent virtual agents to govern the negotiation protocol. The diagram in figure 2.6 shows the summary of physical agents including their attributes and relationships.

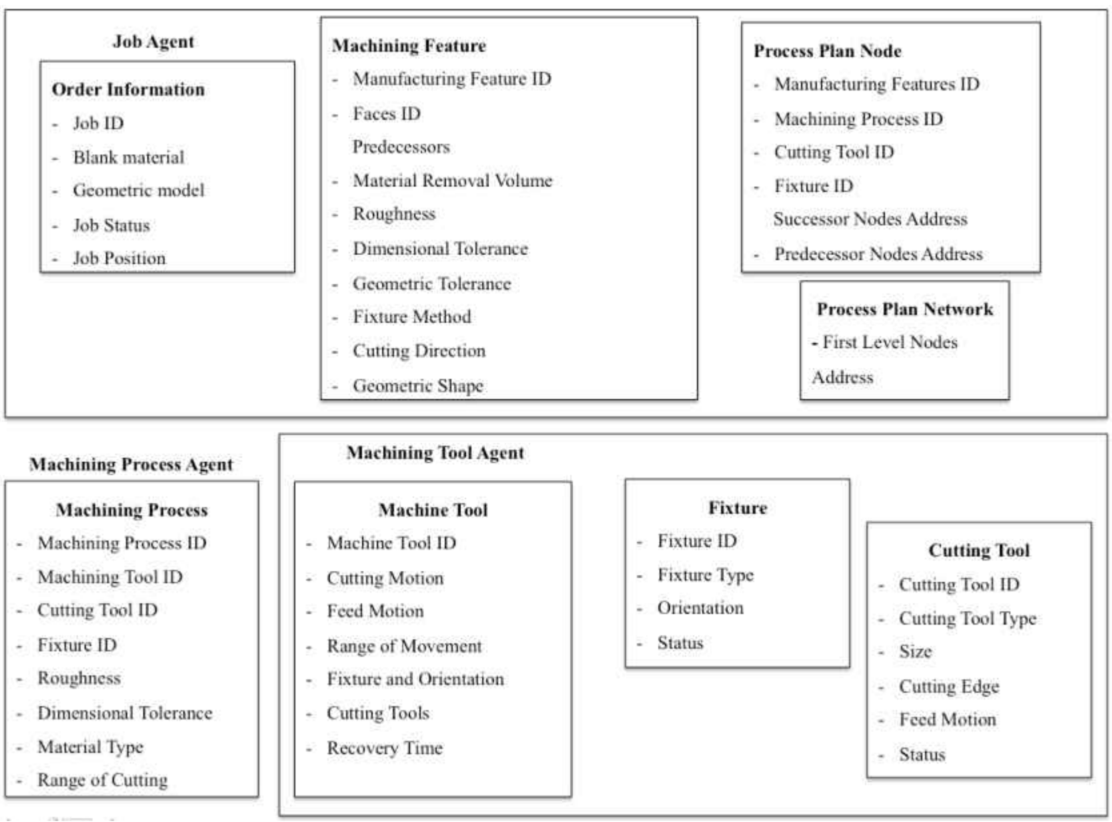


Figure 2-6: Attributes and Relationships of Physical Agents adapted from (Nejad, Sugimura et al. 2011)

A negotiation protocol has been defined in the system due to the importance of the communication between agents for decision-making. The protocol support the following decisions:

(a) Selection of candidate machining processes for individual machining features

(b) Selection of suitable combinations of machine tools, cutting tools and fixtures

(c) Selection of proper machining sequences of machining features

3. Simulation software and experimental results are discussed: the proposed architecture is very efficient for real time application, and robust enough to dynamically generate alternative process plans and schedules.

Guo and Zhang (2010) use agent structure such as in the scheduling optimization system, the composition structure of agent has: 1) Label: an attribute that distinguishes an agent from another; 2) Object: is what an agent intend to pursue and work for; 3. Knowledge: it includes facts and rules stored in the knowledge base of agent; 4) Communication module: a way to exchange data and information between agents; 5) Reasoning module: a decision-making module that allow the agent or multi-agents together to achieve certain objective; 6) Business processing module: defined business processes methods; 7) Learning module: storing the experiences of agents, enhance the current knowledge to improve the capability. In their paper they study the production workshop-scheduling problem. They apply multi-agent system into an intelligent manufacturing in a virtual workshop environment to resolve the unforeseen events.

Agent Unified Modeling Languages

Huget and Odell (2005) introduce the second version of the Agent Unified Modeling Language (AUML) interaction diagrams dedicated to interaction protocols, and based on UML 2.0. Moreover, Mireslami and Far (2013) mention that UML sequence diagrams are the most commonly used techniques for multi agent system verification. Hence, in the sequence diagram is used in the framework to represent the interaction between agents. BPMN serves as the foundation to build the sequence diagram in this case.

2.8.7 Decision-Making and Controls

Agents tend to change the control structure from centralized to decentralized decision making. Because conventional manufacturing systems can not adapt to sudden incidents that interrupt the system such as tool wear, machine breakdown, malfunction of robot or transporter, Park and Tran (2012) propose an autonomous manufacturing system based on swarm of cognitive agents (AMS-SCA). Cognitive agents control work-pieces, machines, robots, and transporters.

Papakostas, Mourtzis et al. (2012) propose a decision making mechanism. Agents represent resources. An agent is capable enough to generate alternatives and select the best among them in case of any incident such as machine breakdown. Also an agent can communicate the incident to other agents in order to act accordingly. They conclude that expertise in the field could never be fully substituted by agents.

Renna (2011) presents a multi-agent architecture for the scheduling of cellular manufacturing systems. The research is base on finding the internal and external indices of a generic manufacturing cell. Then a comparison has been made with an approach based on the workload index in order to provide evidence of the improvements. A simulation package (ARENA) is used to for the comparison. Performance indicators are: throughput time, throughput, work in process (WIP), machines average utilization, and tardiness. As a result the proposed model gives a better outcome. In addition, Chen and Chen (2010) apply multi-agent technology into multi-section FMS to improve the availability of machines, shorten the manufacturing time and increase the capacity. Java application development environment (JADE) is used to adopt the agent system. According to Chen and Chen (2010), the advantage of agent system is that it can prevent the decline of system stability, shorten the development time and increase the operating efficiency.

Ouelhadj, Hanachi et al. (2000), also work on controlling the unexpected failures on the manufacturing systems and apply multi-agent monitoring system. Two types of agents are developed. The first one is the task manager agent who is managing and coordinating the behaviors among agents. The second one is the resource-monitoring agent who is responsible for managing the assigned resources.

2.8.8 Reconfiguration

In Lepuschitz, Zoitl et al. (2011) discuss a reconfiguration model for low-level control system. Each individual manufacturing component represented in an automation agent consist a high-level control (HLC) system and a low-level control (LLC) system. The HLC is responsible for the overall production that coordinates between agents. On the other hand, LLC is responsible for the actions needed from the hardware to satisfy the HLC requirements. The purpose of the reconfiguration is to give the manufacturing system the ability to adapt to any changes in the environment without shutting down the system by reconfigure its components. Anosike and Zhang (2009) discuss the problem of optimizing decisions across planning and control systems in order to adapt to changes in the manufacturing environment as well as reconfiguration and restructuring the resources. In manufacturing where systems are hierarchical, distributed and heterogeneous. To resolve the problem an integrated decision platform for dynamically integrated manufacturing systems (DIMS) is proposed. The platform has a multi-layer hierarchical agent-based modeling and simulation architecture for complex heterogeneous systems.

2.9 Optimization in AMS

Generally, there are standard steps that organizations tend to follow in order to acquire FMS. According to Solot and van Vliet (1994), there are three phases including: 1) Justification where the company decides whether to invest or not, and 2) Predesign: This phase happens when a decision been made to invest. At this stage the pat types, manufacturing requirements including types of workstations, storage, pallets and material handling system are determined, and3) Design phase: here number of decisions will be taken such as:

- Processing capacity concern the number of machines of each type. This is also called machine allocation studies or servers allocation. Along with the number of machines and types, processing rate will take a place.
- Buffer capacity that deals with the storage volume at the system level generally and at each machine specifically.
- Facility layout deals with the above two issues location of the machines and the size of the storage area.
- Pallet quantity deals with the number of pallets needed for the operation
- AGV deals with the type, number of vehicles, and paths for each one.
- Workload allocation deals with the balance load over the facility resources of the FMS.

2.10 FMS configuration

Since FMS require huge amount of investment, designers are asked to seek minimal system configuration cost that satisfies the market need. Generally for highly automated manufacturing system, around 80% of the total budget is for the design stage (Lee 1999).

Lee (1999) propose a general analytical design method that is based on CQN model for FMSs. The proposed method is mainly for the early design stage where number of design alternatives need to be evaluated. Upon the selection of part types the model seek to study the design problem in FMS. The problem includes deciding the number of machine groups, number of machines at each group, the workload allocation among the machine groups, the number of pallets, the number of transporters, and batch transfer size. Also Tetzlaff (1995) introduces a mathematical programming model to aid the designer in selecting the right equipment for a flexible manufacturing system. The objective is to minimize equipment costs and work-in-process inventory cost. Unlike previous models, this one not only allows capacity optimization, but assigning production to different alternative routes.

Shin, Park et al. (1997) use a closed queuing network model and optimization model to find the optimum combination between part types and FMS configuration considering constraints such as production requirement and cost effectiveness. Matta, Tolio et al. (2001) present a stochastic method that is based on a hierarchical decomposition of the system configuration problem into different sub-problems. At each level of the problem the expected present value is computed to estimate the investment.

2.11 Introduction of Genetic Algorithms

A genetic algorithm (GA) is extracted from the natural process of evolution as in biological sciences. It is a heuristic search procedure. Based on the natural behavior the population of genetics will grow and progress in a given environment where the fittest survive and the weakest are destroyed. In the optimization world, at each generation given by a search algorithm, solutions will improve until optimum is reached (Chaudhry and Luo 2005). Briefly, the GA can be described as a problem of finding the optimal solution. At any point of time, the algorithm will generate a possible solution to the problem. The closest population component is evaluated based on a given fitness function. Then, it will have the chance to reproduce another generation. The procedure will continue until a satisfactory point or solution is reached.

In FMS, GA has been used in different areas such machine loading problem, facility layout design, part-type selection, and scheduling. The following review some of the literature in these areas.

2.11.1 Machine Loading Problem

In FMSs machine loading problem is define as the problem of uneven workload distributed between machines. The problem deals with assigning resources such as machines, tools, and pallets to produce different parts. Researches tend to solve this problem to minimize the unbalanced workload in order to maximize the throughput (Tiwari and Vidyarthi 2000).

Tiwari and Vidyarthi (2000) introduce a genetic algorithm to find the part type sequence and the operation machine sequence. Prior to this research, the loading problems were addressed using fixed sequencing rules in order to minimize the unbalanced system and maximize the throughput considering the boundaries of the technological systems. Tiwari and Vidyarthi (2000), also recommended further development of the algorithm to solve the problem, for example, taking into account other objective functions such as minimization of part movement, tool changeovers, and material handling. Yang and Wu (2002) take the model of Tiwari and Vidyarthi (2000) further to consider the technological constraints in their GA-model. Constraints such as the number of available tools, tool magazine capacity, and available machine time.

Kumar, Prakash et al. (2006) and Yogeswaran, Ponnambalam et al. (2009) proposes a constrained-based GA (CBGA) to augment the capabilities of the GA procedure by using specialized operators (initialization, crossover, and mutation). The operators will prevent any premature result or solution, which will lead to a shorter time to reach the optimum result. However, Yogeswaran, Ponnambalam et al. (2007) present a hybrid algorithm between GA and Simulated Annealing (SA) algorithm (GASA algorithm) to solve the machine loading problem.

Recently, Abazari, Solimanpur et al. (2012) present a linear mathematical programming model for part-type selection and machine loading problems. The objective is to maximize the profit and utilization of the system. The mathematical model considers number of constraints while assigning jobs to machines including capacity of machines, batch-sizes, processing time of operations, machine costs, tool requirements, and capacity of tool magazine. Then a GA algorithm is proposed to solve the problem. Another hybrid GA model is proposed by Basnet (2012) that shows a better solution comparing to the literature in solving the unbalance problem but not for the throughput.

2.11.2 Scheduling

Scheduling is the allocation for the overall resources to perform the required jobs or tasks (Jawahar, Aravindan et al. 1998). The problem of scheduling could affect the system internally through the utilization of the resources such as the machine tools and fixtures, and externally through responding to the customer demand (Gupta, Evans et al. 1991). Jawahar, Aravindan et al. (1998) present a comparison of makspan time of different schedules using GA based heuristic. Given number of activities required for different jobs in the FMS, the goal is to minimize the makespan criterion to maximize the utilization of the system.

Yang (2001) introduce GA-based discrete dynamic programming (DDP) approach for generating static schedules in FMS . This method uses sequence-dependent schedule generation strategy. AGA is used to generate viable job sequences. This approach can work with multiple performance criteria and its ability to work in a parallel computing environment. Also, Sankar, Ponnanbalam et al. (2003) present a work to solve the scheduling problem. A genetic algorithm is applied to reach near to-optimum scheduling results with two different GA Coding Schemes.

Another scheduling problem has been solved by Chan, Chung et al. (2006). This problem appears when a company has a number of different factories located in separate locations. However, even though factories can produce the same products, each factory has a distinctive operations efficiency, capacity, and utilization level. Therefore, without acquiring a proper scheduling process the factory will end up having high production cost, long lead-time, over-loading, and idle-resources. Consequently, the objective is to determine how to allocate the jobs into the proper factories and away to allocate production scheduling in each factory. A GA with dominant genes is proposed to identify and record the critical genes in the chromosome and to augment the performance of genetic search (Chan, Chung et al. 2006). Under the same problem of distributed FMS scheduling, the authors propose GA with dominant genes approach. In this approach the author deals with distributed FMS scheduling problems subject to machine maintenance constraint.

2.12 Summary of Literature Review

This chapter gives an overview about previous work conducted in SMS to address the problem of configuring these systems. Upon emphasizing the importance of the planning phase while considering SMS, selecting the right configuration is very crucial to satisfy the current and future demand.

The literature indicates that in machine tool selection, queuing and AHP models are the most utilized tools to determine the configuration of the systems. While optimization models, particularly GA are used in FMS to solve the problem of machine loading and scheduling. Also, agents are used to solving the scheduling problem and the control of the job-shop.

2.13 Research Gap Analysis

As stated earlier, the need for innovative ways to embrace the manufacturing sector in the nation is crucial to convince investors particularly in the SMS. Industrial engineers play a vital role in the development of the manufacturing infrastructure through optimizing the planning and operational phases during the establishment of a manufacturing facility. One of the major decisions that top management has to consider upon deciding the establishment of SMS is the system configuration. This includes the type of machines and the required amount from each type to perform the job efficiently with the minimum cost.

Figure 2.6 illustrates that in the literature queuing and AHP models are the most utilized tools to determine the configuration of the systems. As mentioned previously, the introduction of queuing network models allows manufacturer to evaluate the throughput, work in process, and lead times. Mathematical models were developed based on a closed queuing network to determine the configuration of the system. Although various queuing models determine the configuration of the FMS, there is an absence of a coherent framework that can consider different scenarios and not solely depends on the global optimization of the FMS. Agents on the other hand, treat each resource autonomously. This will give the opportunity for each resource to negotiate with each other to achieve the desired objective.

Gap Analysis

FMS-Configuration Models

AHP

Saaty (1977)
Shang and Sueyoshi (1995)
Arbel and Seidmann (1984)
Stam and Kuula (1991)
Shang and Sueyoshi (1995)
Rao (2007)
Mohanty and Venkataraman (1993)
Borenstein (1998) Chan, Jiang et al. (2000)
Maniya and Bhatt (2011)
Karande and Chakraborty (2013)
Myint and Tabucanon (1994)
Tabucanon, Batanov et al. (1994)
Lin and Yang (1996)
Yurdakul (2004)

Queuing Models

Solberg (1977)
Vinod and Solberg (1985)
Dallery and Frein (1988)
Dallery and E. (1990)
Buzacott and Shanthikumar (1992)

Literature Gap

Development of a framework and a methodology

Proposed Methodologies

ABM

Van Dyke Parunak, Baker et al. (2001)
Kouiss, Pierreval et al. (1997)
Goldsmith and Interrante (1998)
Ouelhadj, Hanach et al. (1998)
Mohanty (2004)
Srivastava, Choudhary et al. (2008)
Nejad, Sugimura et al. (2011)
Guo and Zhang (2009)
Park and Tran (2012)
Renna (2011)
Chen and Chen (2010)
Ouelhadj, Hanachi et al. (2000)

Analytical Optimizing Models and GA

Lee (1999)
Tetzlaff (1995)
Shin, Park et al. (1997)
Matta, Tolio et al. (2001)
Tiwari and Vidyarthi (2000)
Yang and Wu (2002)
Kumar, Prakash et al. (2006)
Yogeswaran, Ponnambalam et al. (2009)
Yogeswaran, Ponnambalam et al. (2007)
Abazari, Solimanpur et al. (2012)
Basnet (2012) Yusof, Budiarto et al. (2012)
Jawahar, Aravindan et al. (1998)
Yang (2001)
Sankar, Ponnanbalam et al. (2003)
Chan, Chung et al. (2006)

Figure 2-7: The Literature Gap

Whilst AHP decision support frameworks were developed to assist top-level management in selecting the most suitable FMS from various configurations during the planning phase. These frameworks are mainly a combination of AHP and discrete models.

AHP criteria are mostly based on subjective weight where discrete simulation is limited with statistical attributes that cannot accept different negotiation protocols between resources (agents). For example, a model such that the one illustrated in Chan, Jiang et al. (2000) aids the design of SMS through a discrete-event simulation and multi-criteria decision-making (MCDM) techniques. The simulation model along with an expert system is used to construct and test alternative designs. AHP is then used to select the most suitable alternative design to perform the task according to the specified criteria in the model. The proposed ABM is used to solve the scheduling problem and the control of the job-shop in the manufacturing industry. Despite the advantages of the ABM, it is not yet utilized to enhance the performance of the SMS generally and the configuration specifically. In addition, GA is proposed to merge with the ABM to seek an optimum configuration design. In fact, GA is used in SMS to optimize the machine loading and scheduling.

Traditionally, discrete-event simulation was fulfilling the needs of modeling manufacturing systems. However, with the emergence of the new technology and trend in SMS make it difficult to model and simulate the behavior of the system. Specifically, modeling the communication between the different resources. Nevertheless, Bi, Da Xu et al. (2014) mention that distributed and decentralized system architectures are effective. As it reduces the complexity of the system. Centralization creates interruptions in the flow of the processes, authorizations, and decision-making.

Therefore, ABM is a better way to simulate SMS. The system consists of resources connected to sensors that collects real-time data and at the same time share and exchange this data with other things (devices, systems, organizations, etc.) for instant decision making process. Certainly, ABM is capable to model and analyze the behavior of the individual "things" autonomously and most importantly model the interactions and communication between them. Agents are capable to model data acquisition, communication, and decision-making that are essential functions of the SMS.

Upon reviewing the literature, it is found that there is a lack in integrated dynamic models that can assess and evaluate systems based on the number of specified factors that will aid decision makers to determine the SMS configuration. Therefore, this research aims to develop a framework that determines the SMS configuration using hybrid simulation model using ABM and discrete event. Hence, optimize the final decision of the top management.

CHAPTER 3 RESEARCH METHODOLOGY

This chapter gives an overview about the research methodology applied in this work to achieve its objectives. The methodology encompasses multiple phases that work together starting from the problem identification to solution formulation. It is a systematic way to answer the research question.

3.1 Research Methodology

The diagram in figure 3.1 illustrates the research methodology followed in this study. Initially, the research starts by exploring the different technologies within the AMS that include: computer-aided design (CAD), robotics, group technology (GT), flexible manufacturing systems (FMS), automated material handling systems, automated storage and retrieval systems (AS/RS), computer numerically controlled machine tools (CNC), and bar-coding or other automated identification techniques. Then the research focuses on problems within the frame of FMS from the industrial engineering perspective. One of the major decisions that have been found in the planning phase is determining the system's configuration.

This has been the starting point to conduct a literature review in order to understand the current research and deduce the literature gap. That is a lack of an integrated framework to generate a SMS configuration that will aid decision-makers in selecting the optimum components of the system. Once the literature gap is identified and analyzed, the framework development takes a place. To formulate the framework different phases are considered as illustrated in the next chapter. Each phase consists of a number of tools. The integration of these leads to an optimized configuration for SMS. A hybrid simulation model then is applied to develop the final configuration.

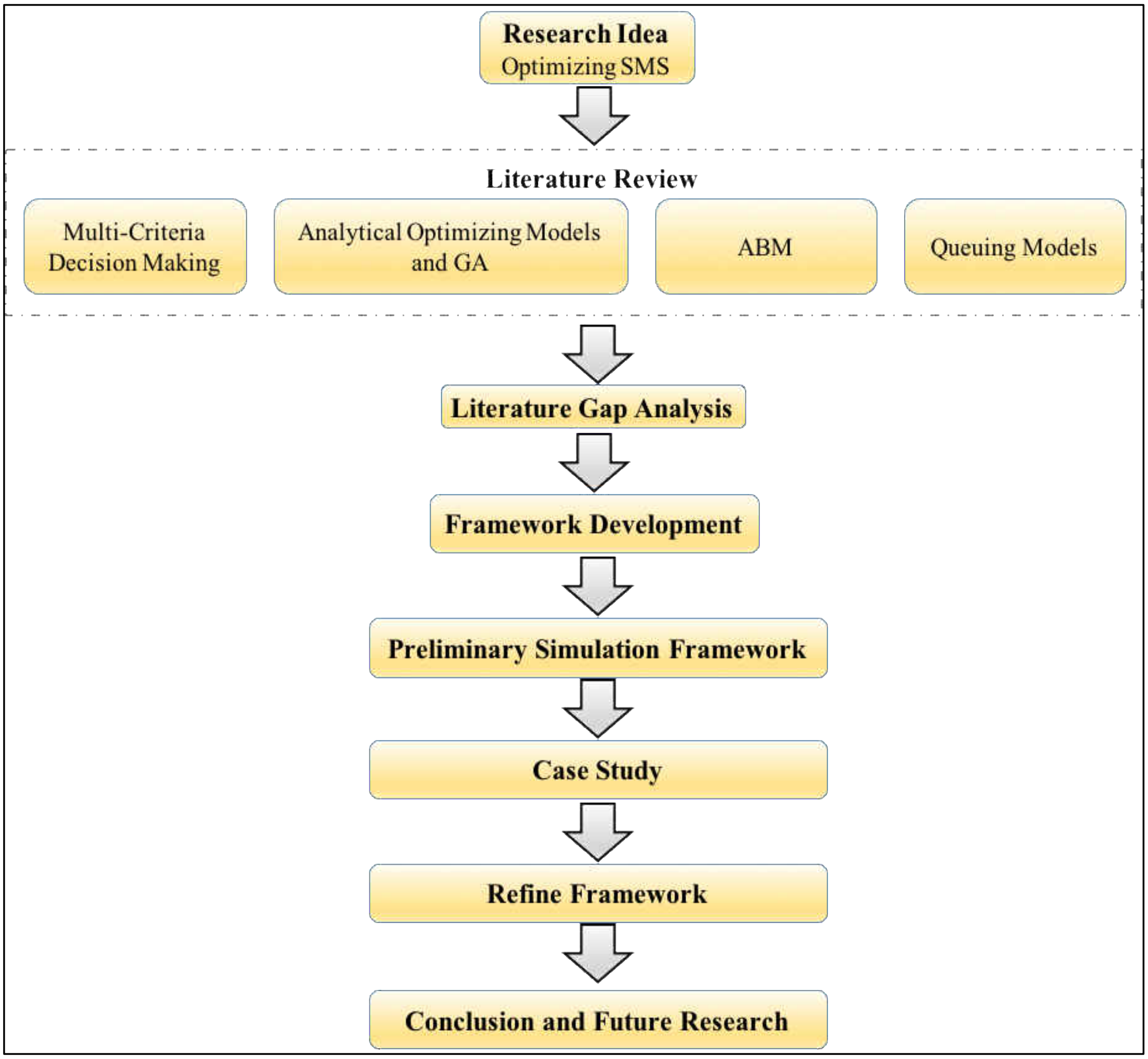


Figure 3-1: Research Methodology Diagram

3.2 <u>Research Idea</u>

One of the industrial engineers' duties is to act upon the difficult economic climate that the nation is facing today. Innovative solutions are required to form a new era that will enhance the economy through jobs creation while ensuring a better life, products, and services. There are many tools and approaches available for industrial engineers that will enable them to contribute to the knowledge and hence a breakthrough will happen.

Different sectors are responsible for shaping today's economy including manufacturing, agriculture, construction, transportation, information, education services, finance, wholesale trade, and retail trade. Within these many sectors, manufacturing has the ability to flip the economy. This is based on a recommendation report that came from the PCAST (States 2012). The report has been submitted to the president of the USA focuses on the enhancement of the advanced manufacturing systems. In fact, this matches a keen interest to conduct a research on the AMS specifically on SMS.

A literature review is then made to explore opportunities for improvement. The purpose is to find a literature gap that will consequently optimize the utilization of the SMS. Hence, offer a better economic environment in the near future.

3.3 Literature Review

Reviewing the literature is a main element to conduct any academic research. The literature review covers many academic resources to feed the research with the past studies in the field. This gives a clear understanding about what has been written under the same or nearly same topic. The literature provides the insight about the problem and hence progress to reach the proposed solution.

The literature review in this work started with the research idea by searching under the main umbrella of AMS. Particularly on: SMS, multi-criteria decision-making, queuing models, agent-based modeling, and analytical optimizing models / genetic algorithms. The most similar system to the SMS is the AMS particularly, the FMS. A deep investigation has been made under this area.

3.4 Gap Analysis

Today, many researchers and manufacturers tend to optimize the use of manufacturing systems to satisfy the market demand efficiently. This work is following the same trend by searching for new ways to optimize the design of SMS. The literature is studied from different angels to understand the current research and hence identify a valuable gap. Then a bridge is built to fulfill this gap.

The search started by a simple question: what are the current models available to improve the design of the SMS? In fact, there are many factors that can contribute to obtain better designs. Within these factors, the system configuration considered to be one of the main decisions while establishing or improving a SMS. Therefore, the question has been modified to be: what are the available models in the literature that deal with the determination of the system configuration? Two different models were found: queuing models and multi-criteria decision making models.

Although numbers of models exist to solve the configuration problem, yet it is not able to practically consider different scenarios based on the market demand. The literature shows an absence in an integrated framework that determines the system's configuration. The determination of the configuration is crucial to guarantee end products that will offer quality, lead-time, and cost that will at least satisfy customers' requirements. In addition, choosing the right configuration will optimize the usage of the capital investment.

The question has been modified to describe the nature of the problem: What are the suitable components of a framework that will lead to optimizing the configuration of a SMS? The answer should lead to two issues: machine type as well as the number of machines required from each type. The framework will provide the optimal option to aid the decision-makers in the design phase.

The literature review then covers potential solution areas: agent-based modeling, and optimization and genetic algorithms. In contrast with previous models, dynamic modeling such as agent modeling allows the decision maker to consider different scenarios to find the suitable configuration for a given system.

3.5 Framework Development

Companies aim to maximize their profits, increase their market shares, and of course minimize their costs. One of the main obstacles that prevent these companies to achieve these aims is the optimal determination of the system configuration. This decision is crucial to determining the capital investment of any facility. This is because most of the costs is going towards the manufacturing equipment.

Fulfilling the literature gap with an integrated framework and methodology to optimally determine the system configuration will support the top management in their decisions to allocate the right budget. Hence, the framework can justify the investment based on the market requirements. Industrial engineers are inspired with many effective tools that will improve today's economy to seek a better future. Merging fields such as quality and software engineering yield to robust framework to satisfy the research questions. The framework serves as a strategic guidance to configure the system. Starting with identifying the initial components of the system until a final configuration is set up.

3.6 Preliminary Simulation Framework

Here, the outcome of the previous phase (block diagram) is transferred into a simulation framework. This research is proposing that interactions and dynamic behaviors between the different components and entities in the system are important improvements in intelligent decision-making.

This phase is the heart of the framework. It is the outcome of the study. Based on certain factors that are determined earlier, the simulation framework will enable decision makers to determine the system's configuration. Consequently, the preliminary simulation framework considers the system's component characteristics and planning requirements greatly to enhance the strategic planning based on the market requirements.

3.7 Case Study

The goal of the case study is to evaluate the effectiveness of the proposed framework. The current state is compared with the conducted results from the proposed framework. Then, results are analyzed for accuracy and effectiveness. In addition, the framework will be refined if required. Based on the refining phase the framework will provide the following benefits:

1. Evaluate different configurations dynamically. Hence, enable decision-makers to optimize their decisions toward better capital investment allocation while establishing manufacturing systems.
2. Enable decision-makers in the future to adapt to any changes due to the market's fluctuation.

3.8 Conclusion

After passing through different phases in this research to achieve the objective of developing a framework that will enhance the process of selecting the optimal system configuration, periodic adjustments to the model has to be maintained to sustain consistent valuable outcomes. The result of this research will absolutely enhance the ability of practitioners to determine the system's configuration as well as demonstrates how agents could be used and applied in such field.

3.9 Further Research

Continues improvement is always needed to augment the body of knowledge. The proposed framework intends to demonstrate the integrated use of agent-based simulation and optimizations to improve the decision-making in SMS. With the discovery of the gap that this dissertation is all about, it opens new doors for researchers to improve decision-making in SMS. The utilization of agent-based simulation is further required to enhance the decision-making for organizations.

CHAPTER 4 THE FREAMEWORK

4.1 Introduction

Mainly the performance of manufacturing facilities is evaluated based on customers' expectations that are formed from different angles as shown in figure 4-1 (Vinod and Solberg 1985), (Yurdakul 2004), and (Chen and Chen 2010). The proposed framework deals with the lead-time (finding the optimal configuration from the lead-time perspective).

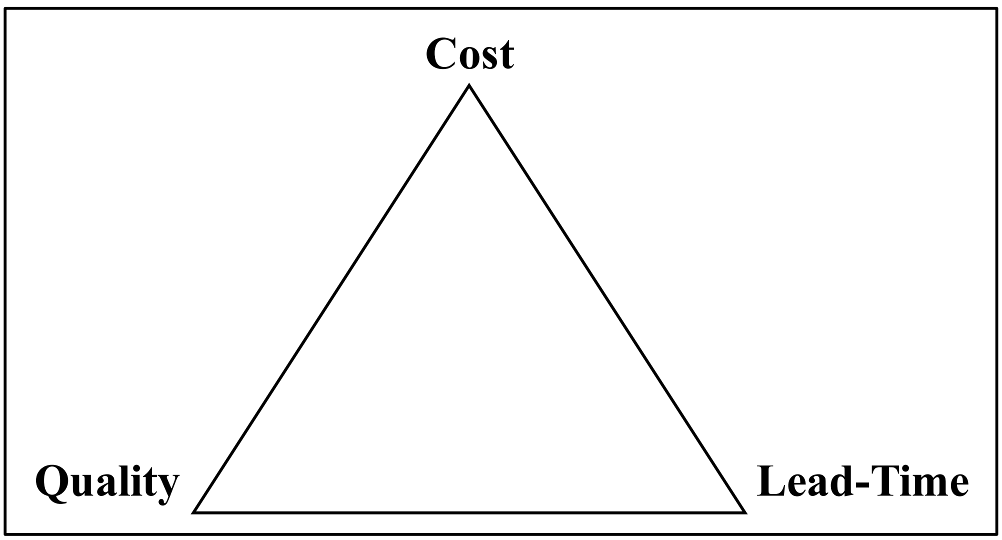


Figure 4-1: Manufacturing Performance Measures

This chapter presents the heart of the study, "the framework". It consists of structured conceptual layers. The components of the framework are combinations from the fields of quality engineering and software engineering. Linking these components to form an integrated framework is the contribution of this research. The framework serves as a strategic guidance to solve SMS configuration problem. That is identifying the optimum type and number of machines that satisfy the market demand.

Based on the analysis of the literature review, it showed the need for an integrated framework to aid organizations in making decisions during the planning phase or to optimize an existing one. As described in chapter two, multiple methods have been used to tackle this problem. Yet, according to the author's knowledge there is no an integrated framework that serves as a guidance to configure SMS. The objective of the framework is to convert and translate the management's requirements into a system configuration. Figure 4.2 summarizes various perspectives about frameworks used to accelerate the SMS maturity.

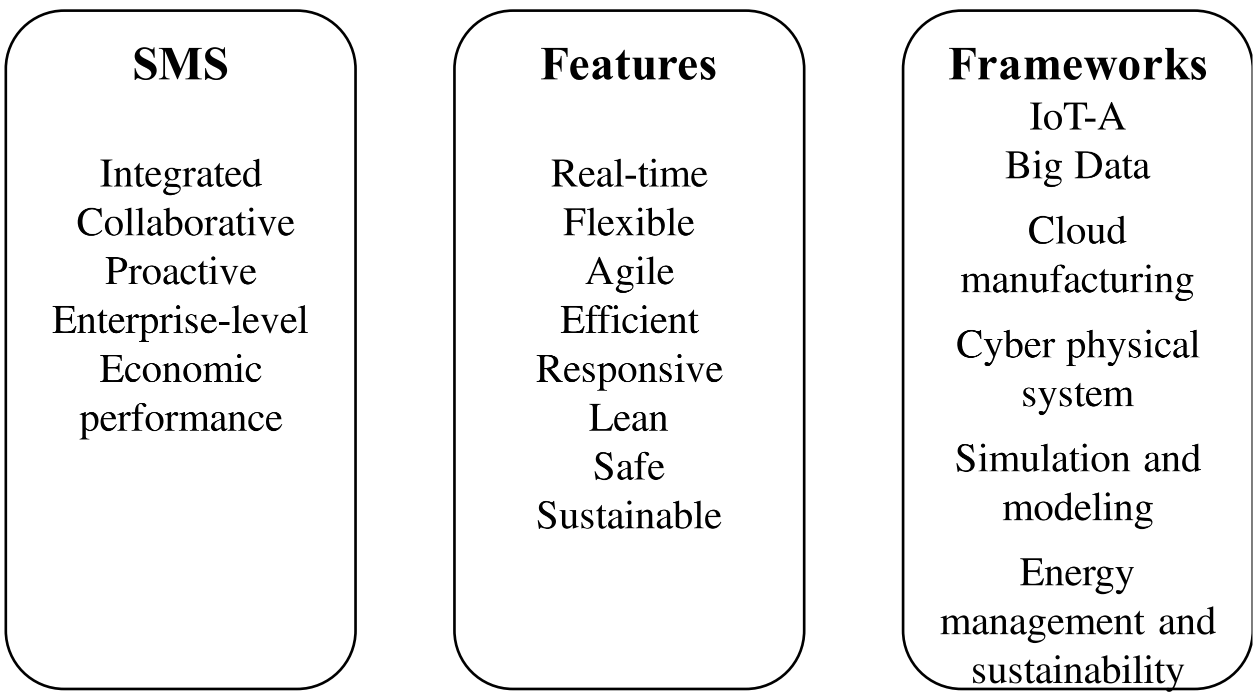


Figure 4-2: Frameworks applied to SMS

This chapter explicates the framework as shown in figure 4-3. Each phase is demonstrated in a separate section. While the first section (4.2) takes customers' requirements and translate it to the initial system components, the second section (4.3) captures the detailed process plan for the parts that is the sequence route for each part. The third section (4.4), analyzes the system behavior. Since agent based-model is used, each entity in the system is designed autonomously and then connected together in the same environment. In section (4.5) a simulation model is developed to do the final configuration. Finally, (4.6) discusses the importance of IoT architecture and how is integrated with the framework.

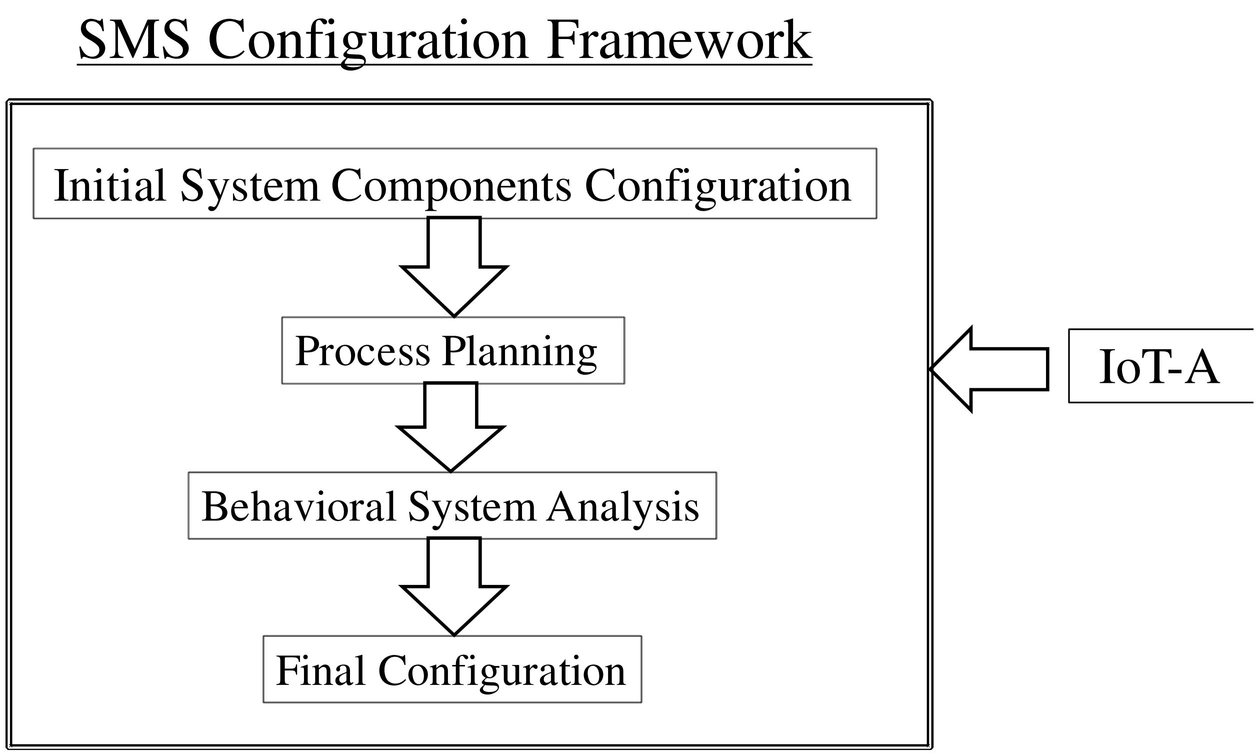


Figure 4-3: Frame work to generate SMS configuration

4.2 Initial System Component Configuration

The scope of the research problem covers the type of machines and their quantities. The former one is the output of this phase. Four drivers lead to machine type selection as shown in figure 4-4. These drivers merged together and called “Machine Type Selection Model”.

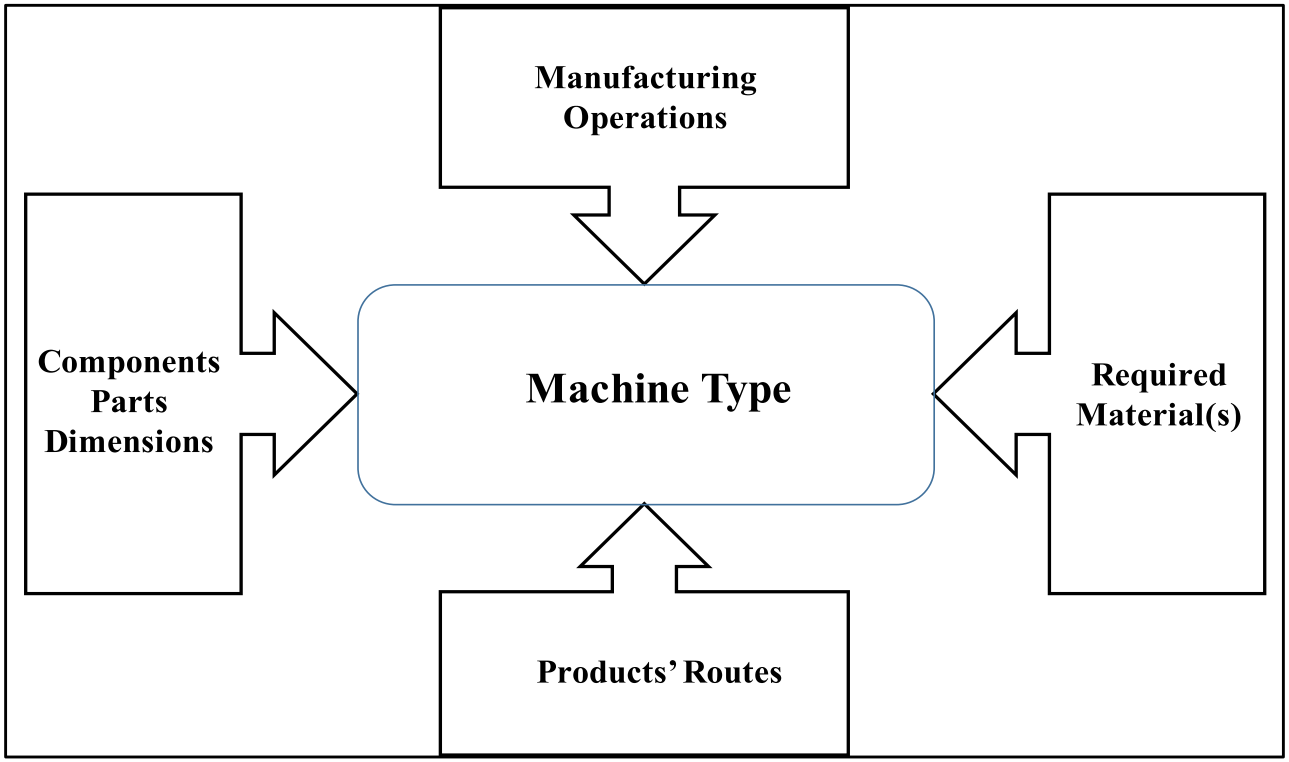


Figure 4-4: Machine Type Selection Mode

Machine Type Selection Model is away to combine different inputs to achieve the objective of machine type identification. The model consists of four drivers. **Components parts dimensions:** based on the strategy of the business and objectives, a starting point is to know the produced parts. This is a given input. Parts' sizes and dimensions are input to this model. Tools within the machines depend on such input. Then**, identifying materials** needed for production. As different machines are available for different materials. **Manufacturing operations and routing**: expert manufacturing engineers determine the required operations to produce the parts. Parts are divided to components/sections that form the shape of the part. Each component needed certain operation for formulation. Hence, determine machines associated with each operation. These drivers are given and not within the scope of the research to identify it. Yet combining them together is part of the research.

There are two tools associated with the Machine Type Selection Model: Expert System's Components Matrix that is responsible for choosing the right machines and Machine Parameter Matrix to list machines' specifications.

Expert System's Components Matrix

Information is gathered from the machine type selection model and inserted to expert systems' components matrix. With the assistance of expert manufacturing engineers, this matrix is fulfilled. As shown in figure 4-6 the left-hand side of the matrix includes a list of the expected "finish parts". This section lists all parts that are manufactured in the facility or planned to manufacture. Then, components of each part are listed in the next column. From there experts identify the operation needed for each component. Hence, determine the required type of machine for that operation.

Considering the fact where number of operations might join the same machine or different components might go to the same machine.

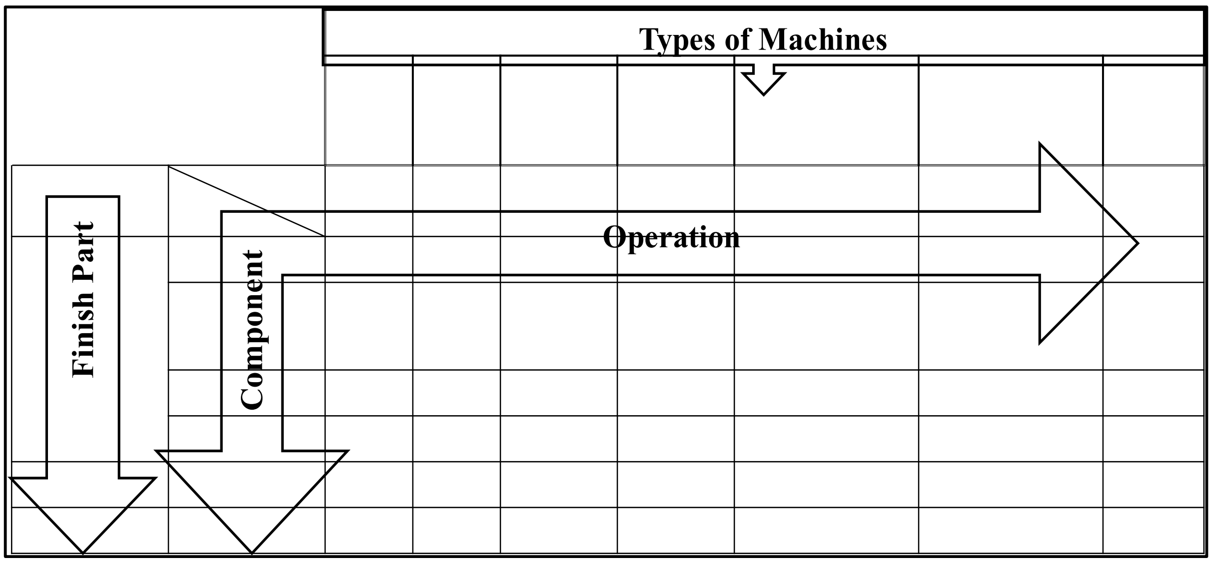


Figure 4-5: Expert System's Components Matrix

Machine Parameter Matrix

Along with the machines' types, different parameters should be stated to satisfy the throughput rate. Upon selecting the machines, experts list the machines' parameters/specifications. Machine parameters matrix is used record the list. For each parameter there is a range expected for machine's performance. Figure 4-7 illustrates the matrix.

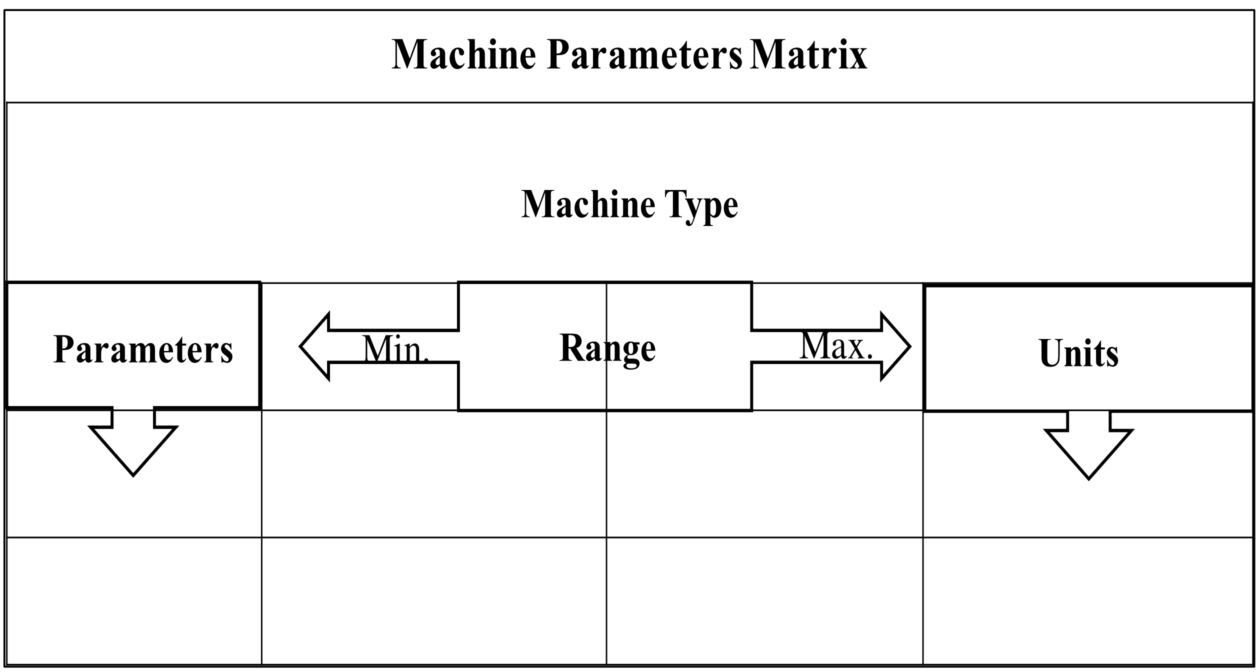


Figure 4-6: Machine Parameters Matrix

4.3 Process Planning

To this point the machine types and the produced parts are known, this phase depicts the route for each product. Since machining flexibility is part of the SMS attributes, parts are machined with different routes. Once mechanical engineering department completes the drawing designs, parts' process plan takes a place. With the objective of minimal number movements.

Capturing each rout is an essential input to finalize the configuration. While the next phase captures the system's behavior the final stage simulates the whole system. Machines' utilizations and systems' throughput are affected by the process planning.

Business Process Modeling and Notation (BPMN) is used for each product's process plan. According Davenport (2013) "a process is simply a structured, measured set of activities designed to produce a specified output for a particular customer or market. It implies a strong emphasis on how work is done within an organization". A process is thus a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs.

Business processes can take the shape of the process of developing a new product, ordering goods from a supplier, creating a marketing plan, Processing and paying an insurance claim, etc.

Business Process Modeling

Business Process Modeling (BPM) a graphical or textual notation that represent the business processes. These models demonstrate the tasks, events, states and business rules that comprise a business process. Process models are used as a key tool in organizational decisions, to understand the business flow, make decisions toward improving operational efficiency and/or cost reductions (Recker, Safrudin et al. 2012).

According to Havey (2005) using BPM can support the organization in formalizing existing processes, helping in identifying opportunities for improvements, ensuring process flow, increasing productivity, and simplifying regulations and compliance issues.

Designing a business process model starts with defining its purpose and then find how each process within the model interacts with other processes. Figure 4-8 depicts what to consider during the design stage (Silver 2009).

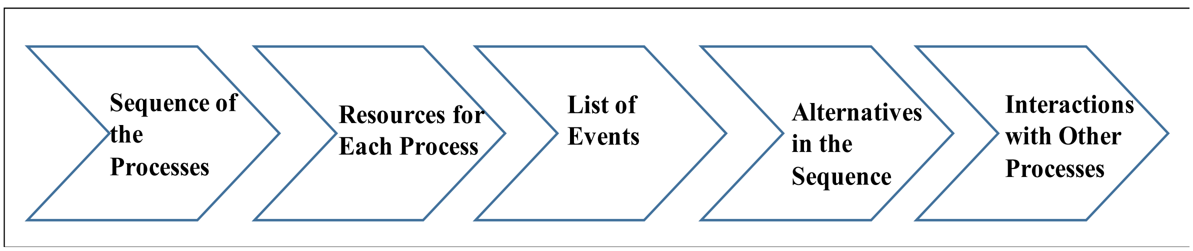


Figure 4-7: Design BPM

Business Process Modeling and Notation

According to White (2004) the Business Process Management Initiative (BPMI) developed in May, 2004 the first version of the standard Business Process Modeling Notation (BPMN). The main objective for this development is to create a common graphical language between business analysts, developers, and users to manage and control those processes. BPMN is a graphical technique that represents the business process operations through a network of graphical objects.

BPMN is considered in this research. Building the structure of the BPMN is based on the standard specification (version 2.0) from the Object Management Group (OMG) (Group 2011). Tables 4-1 and 4-2 illustrate common notations to use BPMN.

Table 4-1: Business Modeling Elements adopted from (Group 2011)

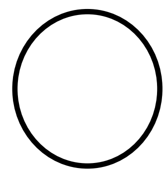
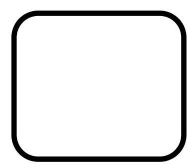
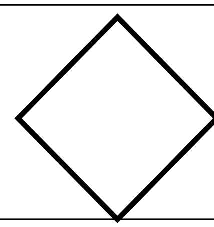
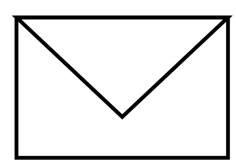
Element	**Description**	**Notation**
Event	Events affect the flow of the process and usually have a cause or an impact	
Activity	Is the form of performing a task, work, or a process	
Gateway	A Gateway is used to control the divergence and convergence of Sequence Flows in a Process	

Table 4-2: Business Modeling Elements adopted from (Group 2011)

Sequence Flow	Order that Activities will be performed in a Process	
Message Flow	Messages between two Participants that are prepared to send and receive them	
Pool	Graphical representation of a Participant in a Collaboration. It also acts as a “swimlane” and a graphical container for partitioning a set of Activities from other Pools	
Message	depict the contents of a communication between two Participants	

4.4 Behavior System Analysis

One of the primary concepts in SMS is the communication through messaging between resources. Different technologies are used for acquiring data, exchange it, and communicate it such as radio frequency identification (RFID) and wireless sensors network (WSN). Each device (thing) is connected to sensor(s) (Bi, Da Xu et al. 2014). Modeling and simulation appears prior implementation. Therefore, one of the main purpose of exploiting ABM is to model the communication between agents.

This section gives a better understanding on how the system should work and behave. The analysis is based on a qualitative description. Different graphical representative diagrams are used to analyze the behavior. Figure 4-9 illustrates the qualitative system analysis. Generally, the system structure is identified; including elements, entities, and parts within the system environment. Then, behavior analysis takes a place to understand the interaction between the different entities in the system. Mostly, interactions occur due to single or multiple events. Therefore, understanding these events are crucial to grasp a complete picture about the components of the system.

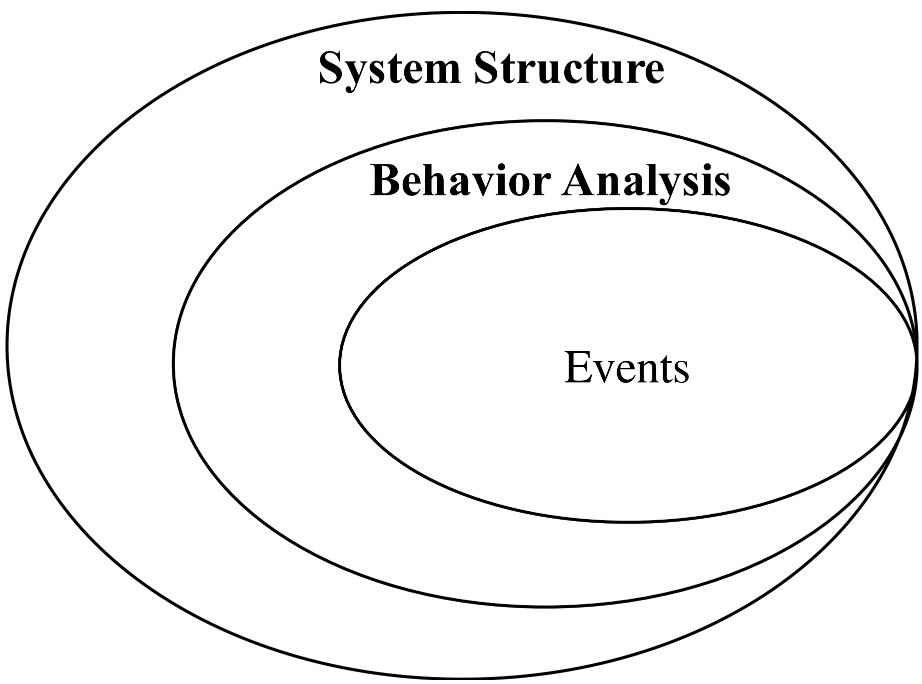


Figure 4-8: Qualitative System Analysis

System behavioral analysis assists modelers to accurately build simulation models. Since the final configuration of the SMS is based on a hybrid simulation model, behavioral analysis is an essential stage in the framework. Two main diagrams are used: message sequence diagram and statecharts.

The implementation of these two diagrams are based on a standardize document from the Foundation for Intelligent Physical Agents (FIPA). A mutual work between FIPA and OMG has been done to develop Agent Unified Modeling Language (AUML). It is under the Institute of Electrical and Electronics Engineers computer society standards. AUML is formalized way to visually model agents.

Message Sequence Diagram

Message sequence diagram, is a graphical presentation depicts the communication between agents. Each agent is placed vertically while communication and messaging between agents are horizontally. Time starts from top to bottom. Internal events for an agent can be represented vertically in side the agent line. Figure 4-10 illustrates the diagram.

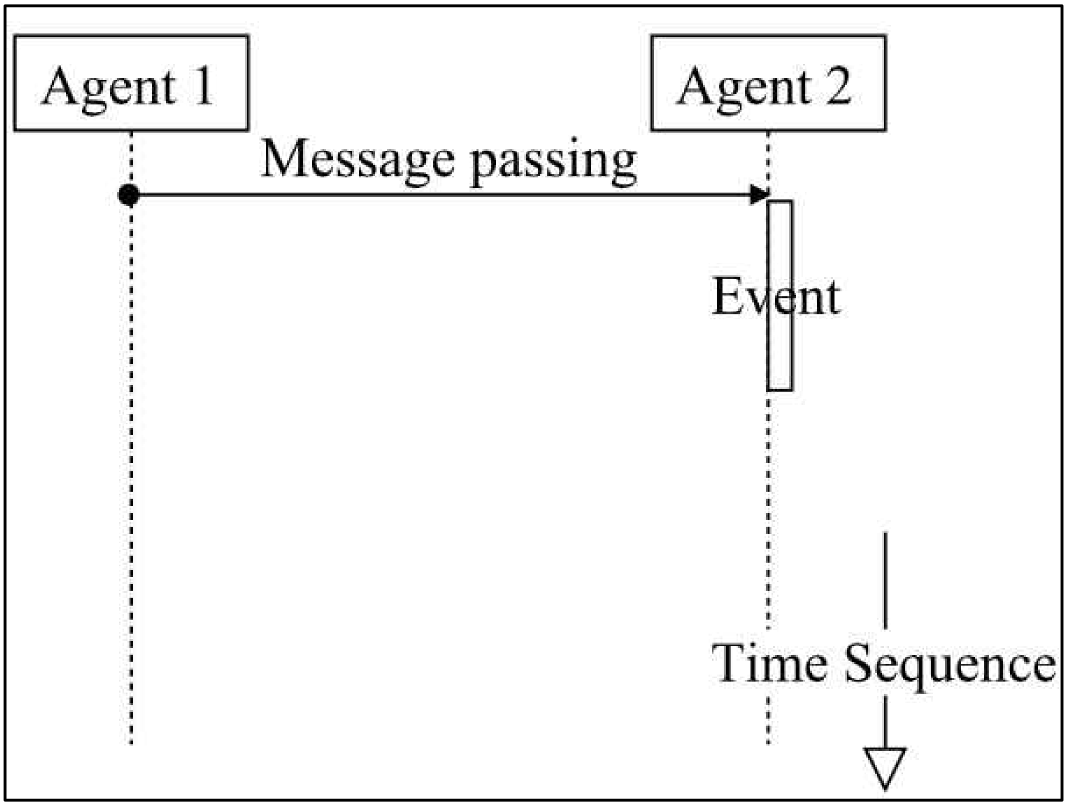


Figure 4-9: Message Sequence Diagram

Agents and objects can communicate with each other through messages. Once an agent sends a message an event takes a place. On other words events are triggered via messages. Time sequence in from top to bottom. This diagram helps in predict the “what if” statements. The output is helpful to design the next phase. Knowing when an event could happen, helps in determining the triggers in the next section.

Statecharts

According to Borshchev (2013), a statechart is a graphical diagram that allows to define event and time-driven behavior for different agents. Each statechart consists of states and transitions. States are defined as the different situations or status an agent can take. Where triggers are the gate the allow agents to shift and move from a state to another. Trigger can take the form of: message, arrival, condition, and timeout. Figure 4-11 depicts the statechart.

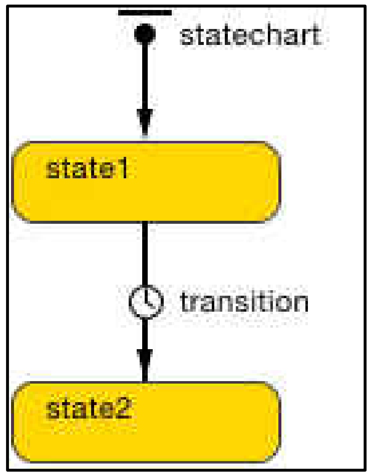


Figure 4-10: Statechart

In figure 4-11, statechart is the entry point of the model. State1 represents the initial state. The agent stays in this state until a trigger happens. Transition is what cause the trigger. It could be: rate, message, timout, etc. State2 is another state and depends on the model it could be a final destination or it might go back the initial state or any other different state.

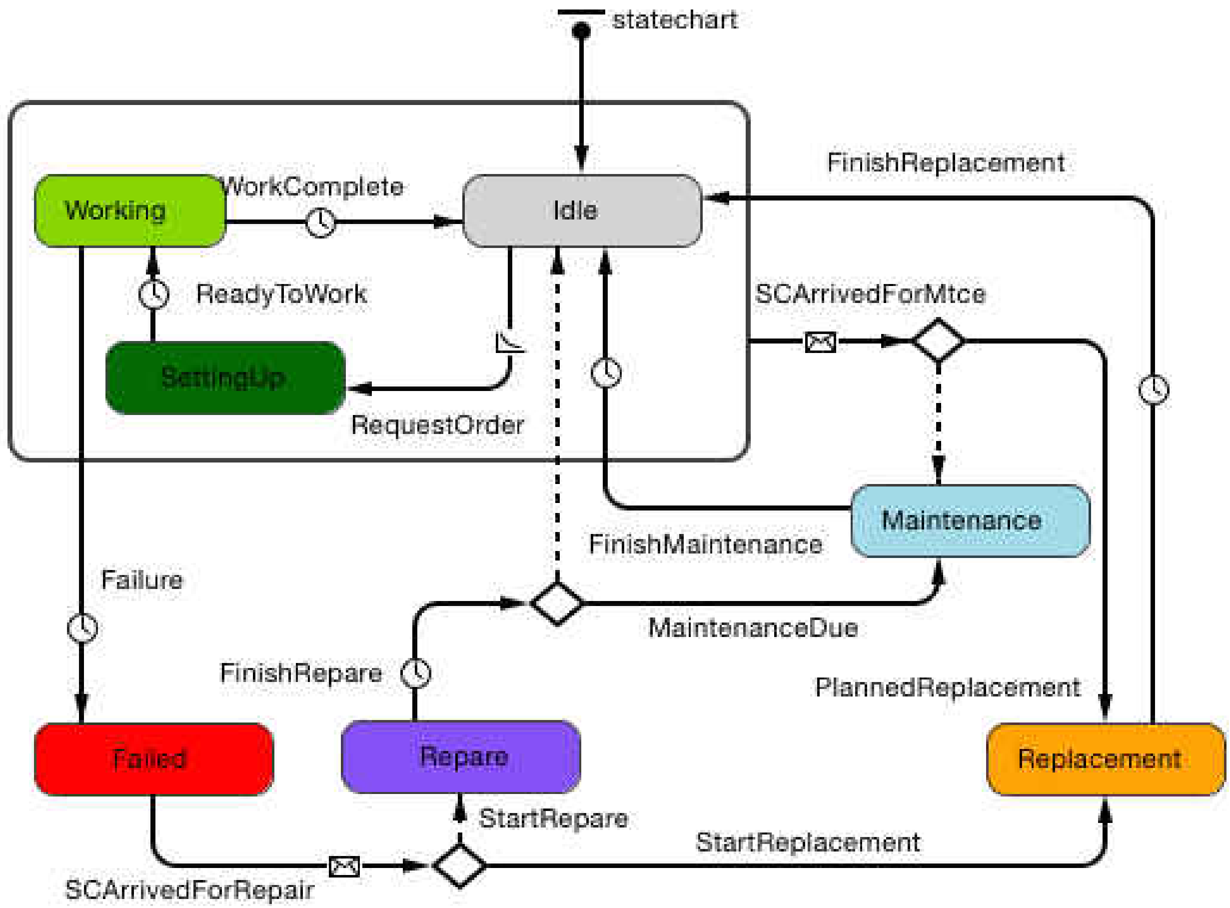


Figure 4-11: Example of a statechart

Figure 4-12 is an example of a statechart for a machine that carry seven different states as shown in the figure. Initially the machine is in idle state waiting for order request. As long as the order is received the machine is set up for the order specification and start working after that. This depends on the set up time of the machine. Upon the completion of the orders, machine either goes back to the idle state or it fails depends on defined failure rate. As soon as it fails the machine send a message to the service crew and the machine stays in this state until the arrival of the service crew. Upon arrival the service crew send a message to the machine to notify its arrival and this what makes the trigger happens to move the machine from the failed state to the next state. Most of the failures require repair otherwise, replacement is the other option. Moreover, scheduled maintenance is defined in the system. Each agent knows when the maintenance is due and notifies the crew. If the maintenance happens to be trigger while the service crew is repairing the machine, service crew will do the maintenance at the same time to avoid multiple trips. Agents enable the machine and the service crew to communicate via messaging. This is exactly what is needed to model the communication in in the IoT-A. Messaging plays a critical role in modeling the communication between different entities in the IoT.

4.5 Optimize Configuration

Now, all required details about the system is collected. It is the time to mimic the system into a virtual and controllable engine (a hybrid model that includes an agent-based and discrete event simulation models that is capable to configure a smart manufacturing system). Since lead-time is the main driver for this framework, throughput rate a crucial factor to the success of the work. The objective is configuring the SMS while meeting customers' demand. This happens when the throughput rate equals customer's demand. Keeping in mind that each machine parameter has a certain range and each machine has a minimum utilization rate.

Simulation Model

The first objective from the configuration that is type of machines is achieved in the first phase. Preceding phases are inputs to this finals phase. The simulation model is expected to find the optimized number of resources to satisfy the market demand. Three measurements are defined prior the simulation model as shown Table 4-2. "AnyLogic" is the simulation software that is used in this research.

Table 4-3: System Measurements

	Definition	**Objective**	**Function**
Throughput Rate	System output per unit of time	satisfy expected customer demand	Finish goods/hour
Machine Utilization	Availability of the machines within a period of time	Maximize the utilization of the machines	Available Working Time/Ideal Working Time
Work-In-Process (WIP)	Total number of parts in queue + under process	Minimize work in process	Parts in queue + parts in machine

Throughput is the objective of the model; it has to meet customers' demand. Machine utilization and WIP are considered as constraints in the model.

Let,

Machines: MC

Throughput: TH

Parameters: P

Minimum Machine Utilization: MMU

Minimum Work-In-Process: MWIP

The objective

TH = Demand

Constraints

$Pmin \leq Pn \leq Pmax$

$MC\ Utilization\ \geq MMU$

$WIP\ \geq MWIP$

Discrete Event-Simulation

Discrete events are sequence of operations performed over entities. This research refers entities as parts. As explained in phase two each part has its own route. Based on the process plans from the BPMN, the discrete model is created. Figure 4-12 illustrates a simple discrete model that consists of entry point “source”, queue that usually can handle limited number of entities “queue”, delay where entities are hold for sometime before it is released.

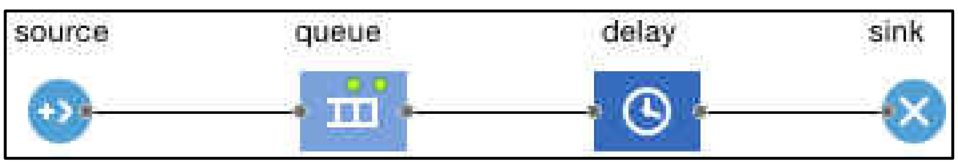


Figure 4-12: Simple Discrete Model

The model consists of: raw material storage area, number of machines, queue prior each machine, finish good storage area. However, machines are created as agents. Each agent is able to communicate and interact with the rest of the model.

Agent-Based

Generally, agents can take the form of any object including: machines, parts, patients, ideas, organizations, etc. In the context of the research, each machine is considered to be a separate agent that has its own behavior. The behavior is the different states a machine can present. Agents has the ability to communicate with the queues or with other agents in the model.

Figure 4-13 illustrates an interaction between agent model and discrete event model. The discrete event in the left hand side process number of parts. They are generated based on certain rate, enter the queue line, then go to the machine (hold), and finally exit the system. Consider the agent in the right hand side as a machine. Once the part enters the (hold) module it goes into a different simulation type (agent-based model). There, depends on the design of the statechart/behavior of the machine, parts are processed.

The software is based on Java. In order for agents to communicate or interact with discrete models or other agents, java code has to be inserted in specific areas.

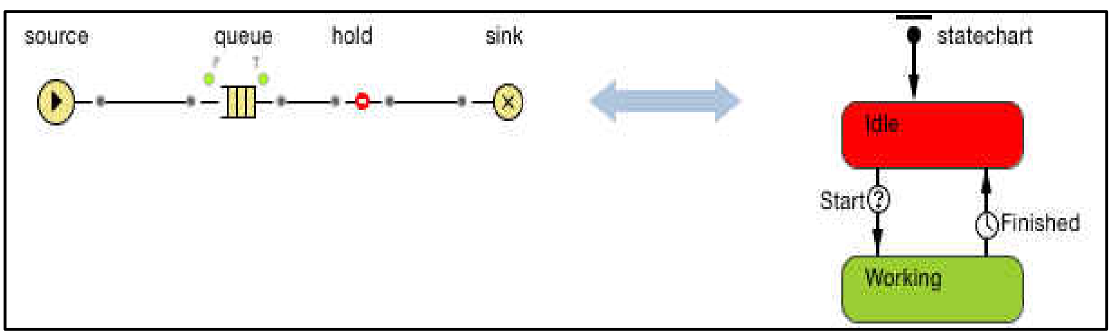


Figure 4-13: Simple Hybrid Simulation Model

Verification and validation

To ensure the user, the expected output; the simulation model is verified and validated (figure 4-14). According to Sargent (2013) verification is building the model correctly in a right manner while validation is to ensuring the model presents the real system. The paper presents different approaches for validation and verification. This research is considering the following techniques:

Animation: the model graphical representation during the simulation running time.

Degenerate tests: degeneracy of the model's behavior is based on the appropriate selection of the input and internal parameters values. i.e. does the average number in queue line for a machine continue to increase over time when the arrival rate is larger than the service rate.

Event Validity: comparing events occurrence to those that happen in the real world. For example, maintenance periods or utilization of the machines.

Face Validity: experts about the system are asked whether the model and its behavior are similar to the real system. This can be used to verify the conceptual model.

Operational Graphics: values of different system performance indicators are shown graphically and correctly. For example, WIP, throughput, number of parts in queue, etc.

Parameter Variability (sensitivity analysis): this is based on changing inputs and internal parameters to observe then changing impact on behavior and results.

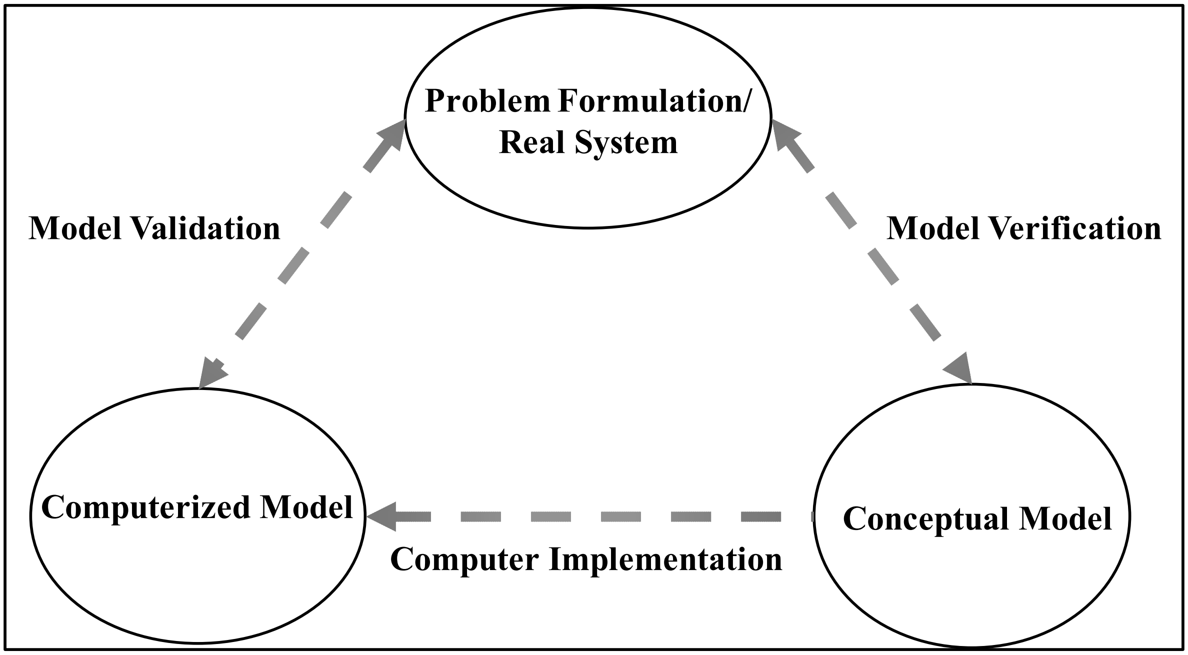


Figure 4-14: Verification and Validation Development

4.6 Importance of the IoT Reference Architecture

The main purpose is establishing a standardized document to have a common ground or language between practitioners and researchers in the field of IoT. It started by a reference model that serves as an abstract framework to merge concepts that enable the understanding of relationships between “things” and the environment.

This drives the introduction of the next level of IoT reference architecture. A building blocks that aim to aid designers dealing with conflicts in functionality, performance, deployment and security. The way of modeling should be standardizing to control the whole proposed system as well as share common understanding between stakeholders. IoT Reference Architecture is providing a base for concrete architecture to design specific application or design a certain problem. Hence, implementation takes a place as shown in figure (4-15).

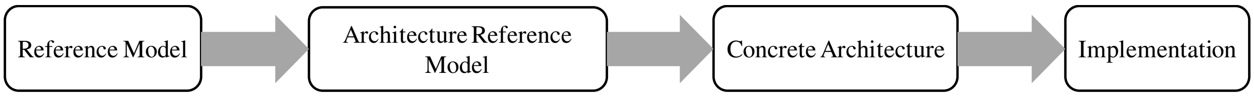


Figure 4-15: IoT Reference Architecture

Beside the main purpose of establishing the IoT reference architecture there are number of benefits including but limited to the following:

1. Cognitive Aid: it clarifies a common vision within the development team with a high level of sufficient information even though it has an abstraction level of presentation. Furthermore, the building blocks support project leaders during the planning phase to determine preceding tasks.
2. Generating Architectures: one of the most advantage feature is the capability of the reference model is generating architectures for different systems based on the requirements. A fully integrated guidelines are provided to translate IoT reference architecture to concrete one.
3. Identifying Differences in Derived Architectures: the usage of IoT reference architecture provides can embrace wide aspects of functionality. Once it is applied a list of system of system functional blocks and data models together with estimates of system complexity can be derived for the architecture generated. Moreover, it can define policies and procedures for meeting qualitative system requirements. It can also help in reverse mapping.
4. Achieving Interoperability: one of the challenges in designing the architecture is having multiple design choices; the IoT reference architecture is not able to ensure interoperability

among any two concrete architectures although they are derived from the same requirements. Yet, it plays a key role achieving interoperability between IoT systems. In fact, this is embedded in the design-choice process. Throughout the process, modeler critiques the choices by evaluating the design choices made as deriving two architectures. Hence, modeler identifies how to achieve interoperability. This is accomplished through the integration of IoT system as subsystem in another system, or bridging between vital functionalities to another IoT system used. Note that bridging between two systems are much more efficient than rebuild the integrated systems to achieve interoperability.

5. System Roadmaps and Product Life Cycles: the previous point shows the approach of how design choices are made in deriving a particular architecture. Accordingly, the IoT reference architecture is available to build roadmaps that ensure least modifications between two product generations and at the same time securing enhancement in system functionalities and characters.
6. Benchmarking: IoT reference architecture ensure benchmarking. Leading organizations such as NASA applies its reference architecture for the exploration vehicle in order to receive better benchmarking proposals in a public bidding process. Whilst the reference model provides the framework to design system architectures, the reference architecture offers the minimum functionalities for system architectures. Standardizing the design lead to benchmarking process with a high level of transparency and inherent comparability.

Integration with framework

This section demonstrates how the IoT reference architecture model integrates and govern the proposed framework. The first building block in the framework is the initial system components configuration that matches the domain model in the IoT reference model. In both models concepts (machines, parts, entities, etc.) are identified. However, the framework in the research proposes a systematic way to identify these concepts that is Expert Machine Selection Matrix and their precise specifications are determined through Machine Parameters Matrix.

The IoT information model govern the process planning block in the framework where BPMN is used to capture the required information and relationships between the different machines. On other hand, the system behavioral block gives an understanding about the behavior of each machine individually and the system holistically using messaging sequence and statecharts diagrams based on AUML that is special case from the the UML used in the IoT reference model. Here, functionality, policies, and procedures are set as the case in the functional model. Finally, communication in the reference model shows the relationships between the entities and how they interact while in the research ABM are used to illustrate this communication. In fact, this is the substantial add value to the framework; as until now there are no clear vision about consequences of connecting all of the smart objects to the internet (Bassi, Bauer et al. 2013). ABM has the ability to simulate behavior and policies aiding future perspectives of these systems.

4.7 Cyber Physical Systems

According to Lee, Bagheri et al. (2015) Cyber Physical Systems (CPS)is known as technological devices able to manage interconnected systems throughout its physical entities and virtual networks. The advancement in these technologies created vast amount of data that forces manufacturers to analyze the “big-data” using high technological components. This will make it feasible to achieve intelligent, durable, and reliable machines that can act autonomously.

Furthermore, the ability to integrate the whole supply chain including vendors, logistics, production, and services will accelerate the maturity of IoT. In the same paper the authors propose CPS 5C level architecture for manufacturing application as follow:

Connection

In developing CPS, an initial stage that is smart connection determine how to acquire accurate and reliable data from machines. Two vital decisions including type of data as well as type of devices required to collect these data with its capability to share and exchange information.

Conversion

Defined as the methodology that aid in converting the collected data to a useful information. Recently, complex algorithms have been developed for health management systems. Adopting such algorithms to the manufacturing industry is helpful to make these data useful and valuable. Nevertheless, this deep analysis can built a proactive attitude within machines.

Cyber

This is the main part in the architecture. Information from all machines are gathered in one hub where further analysis takes a place. Consequently, the performance of each machine is compared with its historical data as well as with other machines. This provide an insight about the overall system performance and hence predict any future trend.

Cognition

In this level CPS provides users with an info-graphics that are necessary to understand the behavior of the system as well as consider any immediate or future actions.

Configure

At this stage the loop is closed and the system is monitored. Moreover, machines are capable reacting towards changes due to the sufficient information that has been gathered to aid this stage in decision making.

Integration the study framework with the 5S architecture

The figure below shows the integration between the SMS configuration framework and CPS architecture. At the initial phase of the framework, required devices and sensors for gathering data are determined in addition to the data collection methodology. Then cyber is used in the process planning where the design of the hub and data architecture takes place. Cyber also is influenced with the behavior of the system. Finally, the final configuration in the system provides users with graphical informative interface as well as complex algorithms enable machines to act upon massive data analysis.

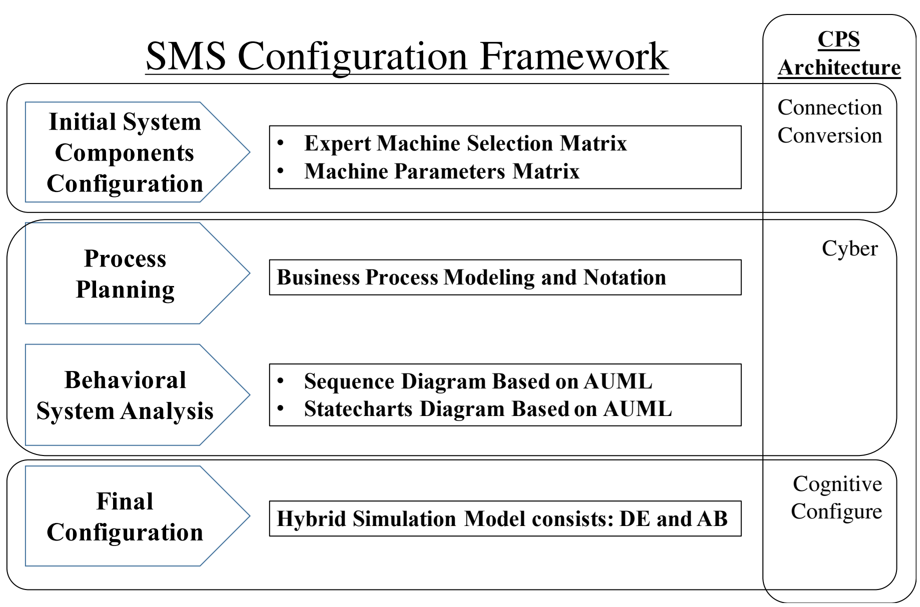


Figure 4-16: Integration of SMS configuration framework and CPS architecture

4.8 Conclusion

This chapter presents the framework. The objective of the framework is to generate SMS configuration. There are four different phases. The substantial stage is modeling the potential messaging and communication between machines to optimize the final configuration. The first phase resolves part of the configuration problem that includes the identification of the machines' types. Phase two and three combined together to design the simulation model accurately and effectively.

Each phase consists of number of tools. Initially, some tools were considered and then eliminated due to the fact that they did not function in an effective manner as the selected ones; such as quality function deployment. It was selected initially in the first phase, but expert machine type selection matrix is then designed to fit the requirements of the problem. Hence, the problem has been tackled from different perspectives; including quality and software engineering.

Hybrid simulation (discrete-event and agent-based) is used to model the problem. Therefore, the system behavior and interaction is captured through. BPMN: a graphical presentation to address the sequential flow of the parts in the system. Message Sequence diagram: a graphical presentation to depicts the communication between agents. Each agent is placed vertically while communication and messaging between agents are horizontally. Time starts from top to bottom. Internal events for an agent can be represented vertically in side the agent line. Statecharts: represents the different state an agent can take. Agent moves from a state to another through a transition. Each transition has a trigger that allows the agent to change its state.

Next chapter is serves as a verification stage for the framework. The framework is implemented to an existing manufacturing facility to evaluate its performance. Based on the criteria proposed in the framework.

CHAPTER 5 FRAMEWORK VERIFICATION

5.1 Introduction

This chapter focuses on implementing the framework to verify and evaluate its effectiveness. Also to illustrate the implementation of the hybrid model into SMS. A manufacturing facility in North America has been chosen to test the framework. Therefore, the aim is to assess the configuration of the manufacturing facility. Expert manufacturer engineers are interviewed to contribute in the different phases of the framework. The operational processes are captured to mimic the real system. Different assumptions are taking into consideration while building the hybrid model. The chapter started by a brief description about the facility 5.2. Then the framework implantation is clarified in section 5.3. Section 5.4 illustrates the messaging between agents.

5.2 The manufacturing facility

A manufacturing facility is located in north America specialized in hydraulic pumps (figure 5-3). These are very complex products with complex processes and supply chains. Raw materials are supplied from different vendors and finished parts are assembled in south America, then returned back to north America as shown in figure 5-1. It produces the internal components of the hydraulic pumps: front plate, body, and back plate as shown in figure 5-2.

Figure 5-1: The Overall Supply Chain

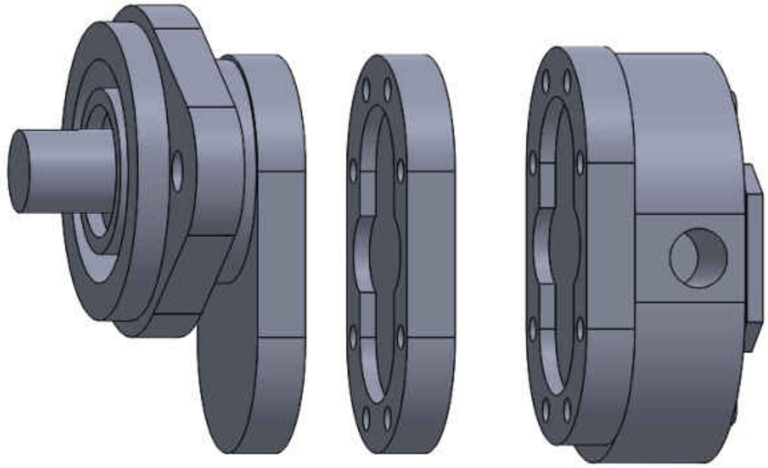


Figure 5-2: Hydraulic Pump- Internal Parts

Figure 5-3: Sample of hydraulic pump from the university lab

The manufacturing facility consists of number of cells to perform certain operations that produce the different parts of the hydraulic pump. However, machines sometimes break down and needs to be repaired. Maintenance is scheduled. However, late maintenance as well as advanced age, increase the probability of failure.

5.2.1 The Business Process

This is a brief description about the business processes at the manufacturing facility. Figure 5-4 depicts a global view about the internal order processing using business process modeling and notation. It starts with customer initiation to request an order. The orders are received by the Supply Chain Management (SCM). Then, SCM creates an order and send it to the Manufacturing Engineering Department (ME). As soon as the ME receives the order, a balloon print is created. Based on the print ME procures the required new tools (if not available). Once the tool is available ME programs CNC machines and notify the SCM.

Upon the receipt of the notification, SCM checks it for approval before sending it to the shop floor. The shop floor, creates a sample to be sent to the Quality Engineering department (QE). The QE checks the samples. If there are no comments, it is shipped to the customer. Otherwise, QE sends it back to the shop floor.

Customers receives the sample, checks it, and confirm the order if there are no any modifications. Otherwise it is shipped back to the SCM. Thus, SCM perform what is necessary to fulfill customer requirements.

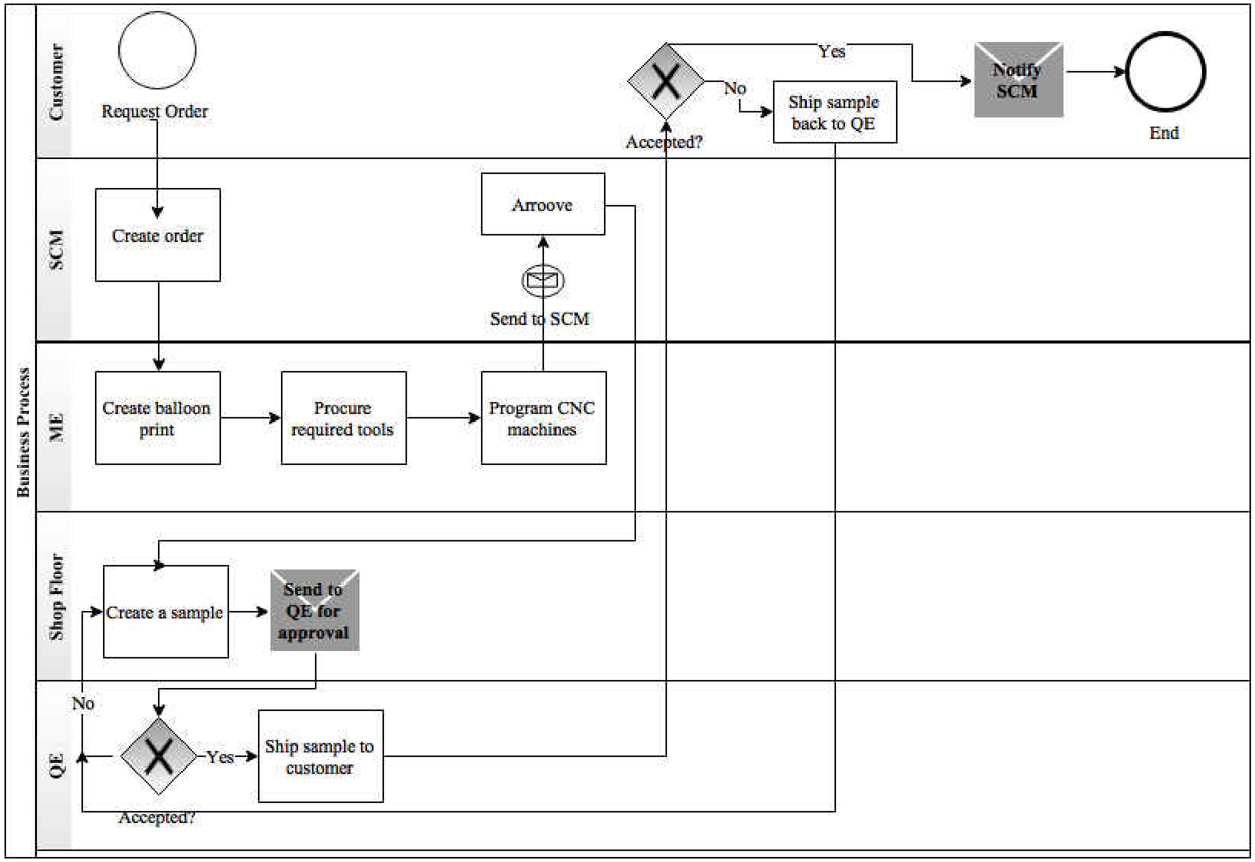


Figure 5-4: Overall Business Processes at the Facility

5.3 Framework Implementation

The framework is a systematic way to configure the smart manufacturing facility. In this section the focus is on the *back plate* of the hydraulic pumps. The framework is implemented on the case study. Results are reported and discussed at the end.

5.3.1 Initial System Components Configuration

Prior the investment it is crucial to decide the product type and material to have the right system configuration. In this phase interviews have been conducted with expert matters in the organization (manufacturing engineers). The back plate is chosen for the study (figure 5-2). This phase consists of two tools: expert system's components matrix and machines' parameters matrix.

1. Expert System's Components Matrix

Information is collected based on machine type selection model (figure 4-3); and combined graphically to fulfill expert system's components matrix. Subject experts' matters have been interviewed to fulfill the matrix.

The expert machine selection matrix assists in identifying the required operation and type of machine for a certain task. Table 5-1 shows the implementation of the matrix. The internal parts of the hydraulic pump are listed in the first column. Each part consists of number of components/sections. Experts determine the required operation for each component and then select the appropriate type of machine to perform the job.

The benefit of this tool relies on the fact that it can merge different dimension in a single visualized graph to obtain the needed output (machines' types).

Table 5-1: Expert System's Components Matrix

		Types of Machines						
		CNC Vertical Machine	**Angle Drilling Machine**	**Lap Machine**	**CNC Horizontal Machine**	**Tapping machine**	**Vertical Pressing Machine**	**Manual operation**
Part	Operation / Section	**Milling**	**Drilling**	**Lapping**	**Drilling**	**Tapping (threading)**	**Shearing (pressing/punching)**	**Deburring**
Front Plate	O-Ring Groove Depth	x	x					
	2 Bushing Bores & Dowel Pin Bores		x			x	x	x
	Bolt Holes		x			x		
	Face Flatness			x				
Body	Thickness	x						
	Alignment				x			x

		Types of Machines						
		CNC Vertical Machine	Angle Drilling Machine	Lap Machine	CNC Horizontal Machine	Tapping machine	Vertical Pressing Machine	Manual operation
Part	Operation / Section	**Milling**	**Drilling**	**Lapping**	**Drilling**	**Tapping (threading)**	**Shearing (pressing/punching)**	**Deburring**
	Perpendicularity				x			
	Bolt Holes				x	x		x
Back Plate	O-Ring Groove Depth	x						
	Bore (2) Bushing & Dowel Pin Bores						x	x
	Bolt Holes		x					x
	Face Flatness			x				

		Types of Machines						
		CNC Vertical Machine	**Angle Drilling Machine**	**Lap Machine**	**CNC Horizontal Machine**	**Tapping machine**	**Vertical Pressing Machine**	**Manual operation**
Part	Operation / Section	**Milling**	**Drilling**	**Lapping**	**Drilling**	**Tapping (threading)**	**Shearing (pressing/punching)**	**Deburring**
	Pressure Port				x	x		
	Suction Port				x	x		

2. Machine parameter matrix

Once the required types of machines are identified, manufacturing and maintenance engineers determine the necessary parameters for each machine based on the expected throughput of the facility. The throughput rate depends on these parameters. Tables 5-2 to 5-8 depicts the machines' parameters for the back plate. While tables 5-9 to 5-14 depicts the front plate and the body is depicted in tables 5-15 to 5-16.

Table 5-2: Angle Drilling Machine Parameters

Angle Drilling Machine-1				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Unit**
1	Process mean time	80	120	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.08	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Service Crew Arrival	10	480	Minutes
9	Buffer size	50		Parts

Table 5-3: CNC Vertical Machine (Milling)

CNC Vertical Machine (Milling)-2				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Units**
1	Process mean time	80	100	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-4: CNC Horizontal Machine (Drilling)

CNC Horizontal Machine (Drilling)-3				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Units**
1	Process mean time	90	120	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-5: CNC Horizontal Machine (Tapping, Drilling)

CNC Horizontal Machine (Tapping, Drilling)-4				
	Parameter	**Value - Minimum**	**Value- - Maximum**	**Units**
1	Process mean time	360	400	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-6: Tapping machine

Tapping machine-5				
	Parameter	**Value - Minimum**	**Value – Maximum**	**Units**
1	Process mean time	20	40	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-7: Vertical Pressing Machine

Vertical Pressing Machine-6				
	Parameter	**Value – Minimum**	**Value – Maximum**	**Units**
1	Process mean time	20	40	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-8: Lap Machine

Lap Machine-7				
	Parameter	**Value – Minimum**	**Value – Maximum**	**Units**
1	Process mean time	60	80	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Front Plate

The parameters of the front plate are listed in the tables below.

Table 5-9: Angle Drilling Machine Parameters

Angle Drilling Machine				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Unit**
1	Process mean time	85	125	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.08	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Service Crew Arrival	10	480	Minutes
9	Buffer size	50		Parts

Table 5-10: CNC Vertical Machine (Milling)

CNC Vertical Machine (Milling)				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Units**
1	Process mean time	90	100	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-11: CNC Horizontal Machine (Drilling)

CNC Horizontal Machine (Drilling)				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Units**
1	Process mean time	90	120	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-12: Tapping machine

Tapping machine				
	Parameter	**Value - Minimum**	**Value – Maximum**	**Units**
1	Process mean time	30	50	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-13: Vertical Pressing Machine

Vertical Pressing Machine				
	Parameter	**Value – Minimum**	**Value – Maximum**	**Units**
1	Process mean time	30	50	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-14: Lap Machine

Lap Machine				
	Parameter	**Value – Minimum**	**Value – Maximum**	**Units**
1	Process mean time	60	100	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Body

The body parameters are listed in the tables below.

Table 5-15: CNC Horizontal Machine (Drilling)

CNC Horizontal Machine (Drilling)				
	Parameter	**Value - Minimum**	**Value - Maximum**	**Units**
1	Process mean time	90	120	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	Per year
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

Table 5-16: Lap Machine

Lap Machine				
	Parameter	**Value – Minimum**	**Value – Maximum**	**Units**
1	Process mean time	120	160	Seconds
2	Maintenance period	60	90	Days
3	Maintenance mean time	20	30	Minutes
4	Average failure rate	0.05	0.1	
5	Repair mean time	30	40	Minutes
6	Replacement mean time	20	40	Minutes
7	Probability of replacement	0.1	0.2	
8	Average set up time	10	2880	Minutes
9	Buffer size	50		Parts

5.3.2 Process Planning

One of the essentials requirements in manufacturing is the process plan. Each produced part in the system has a detailed manufacturing process plan along with its drawing. Process plans of the back, front and body are depicted using BPMN in figures 5-5, 5-6, 5-7 respectively.

Generally, manufacturing engineers draw the appropriate process plan for each part. There are seven machines that are responsible to shape the back plate. Starting from the angle drill machine where an operator is installing the raw material in a fixture and the operation is done manually. Then, the part is transferred by the operator via a cart to a CNC vertical machine to mill the face that is transferred after that to a horizontal CNC machine to drill two bore bushing and dowel pin bores also to tap and drill J.I.C. ports. A tapping machine is then responsible for rapid tap bolt holes where the vertical pressing machine is responsible to press in bushing and coin. After that the lap machine, laps the face before the part is washed. Table 5-10 lists the advanced machines versus the manual ones.

Table 5-17: List of Advanced Machines

No.	Process	Machine	Advanced vs Manual
1	Drill Angle Holes	Angle Drilling Machine	Manual operation
2	Mill Face	CNC Vertical Machine (Milling)	CNC
3	Bore (2) Bushing & Dowel Pin Bores	CNC Horizontal Machine (Drilling)	CNC
4	J.I.C. Ports	CNC Horizontal Machine (Tapping, Drilling)	CNC
5	Rapid Tap Bolt Holes	Tapping machine	Manual operation
6	Press in Bushings & Coin	Vertical Pressing Machine	Manual operation
7	Lap Face	Lap Machine	Manual operation

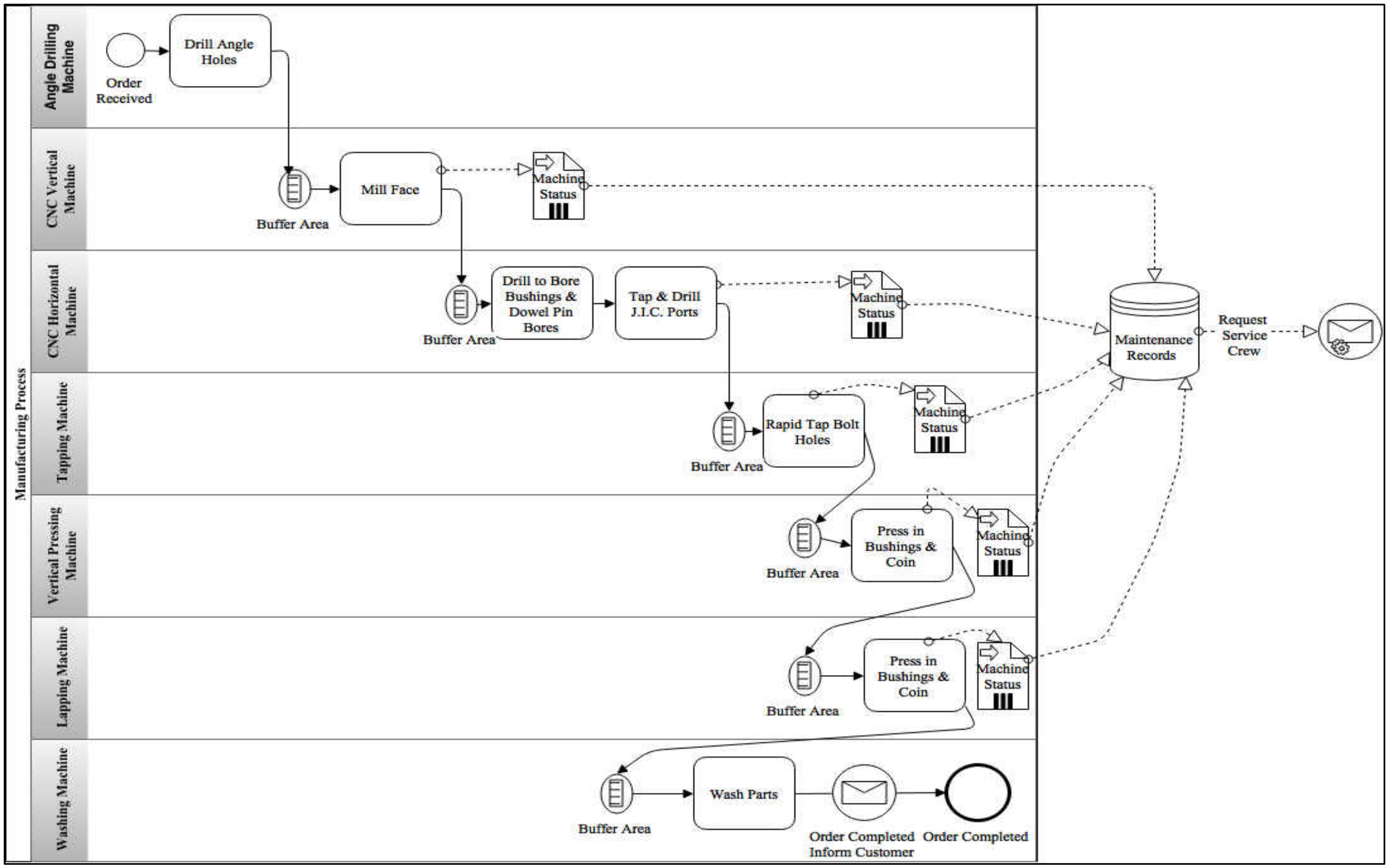


Figure 5-5: Back Plate Process Plan

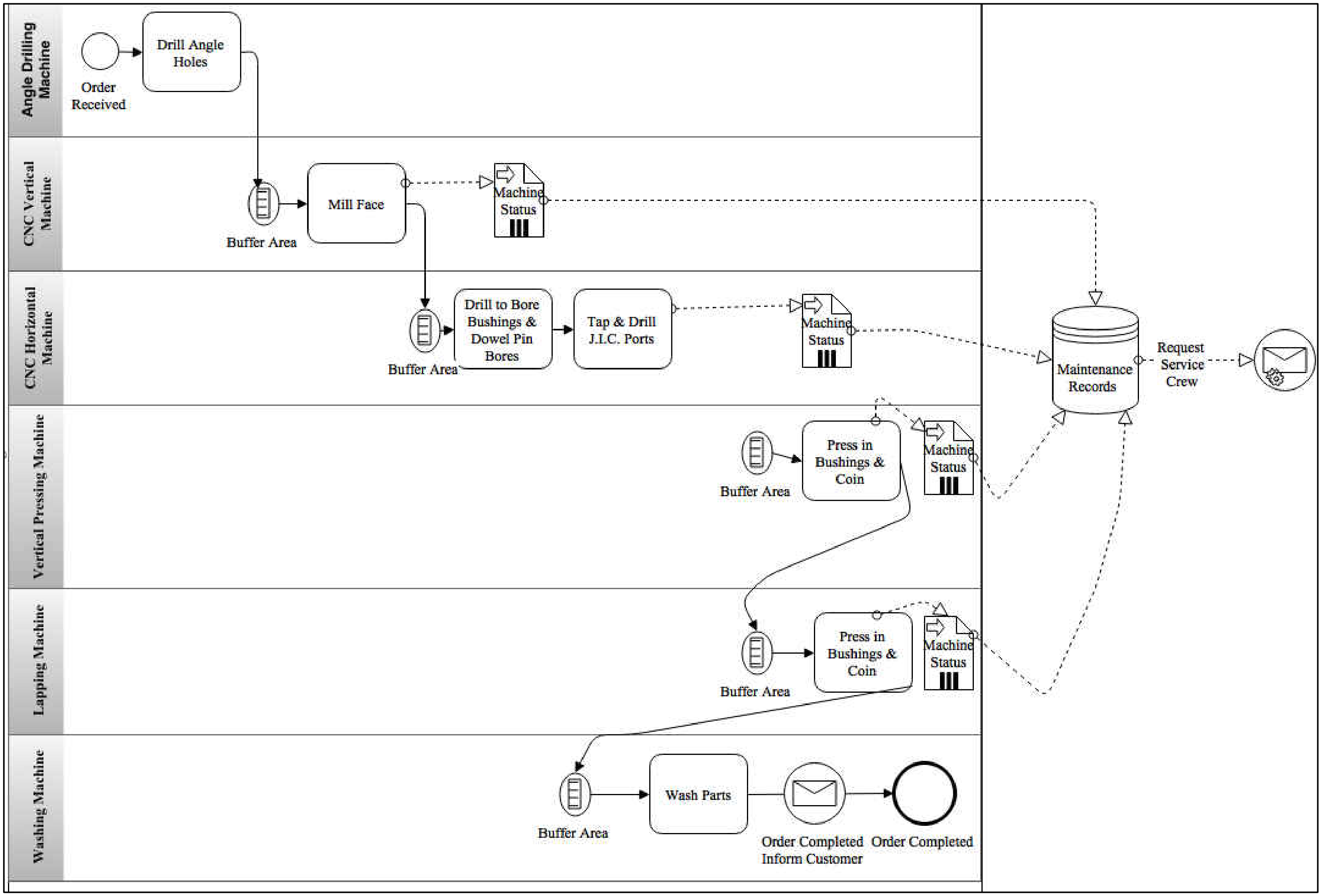


Figure 5-6: Front Plate Process Plan

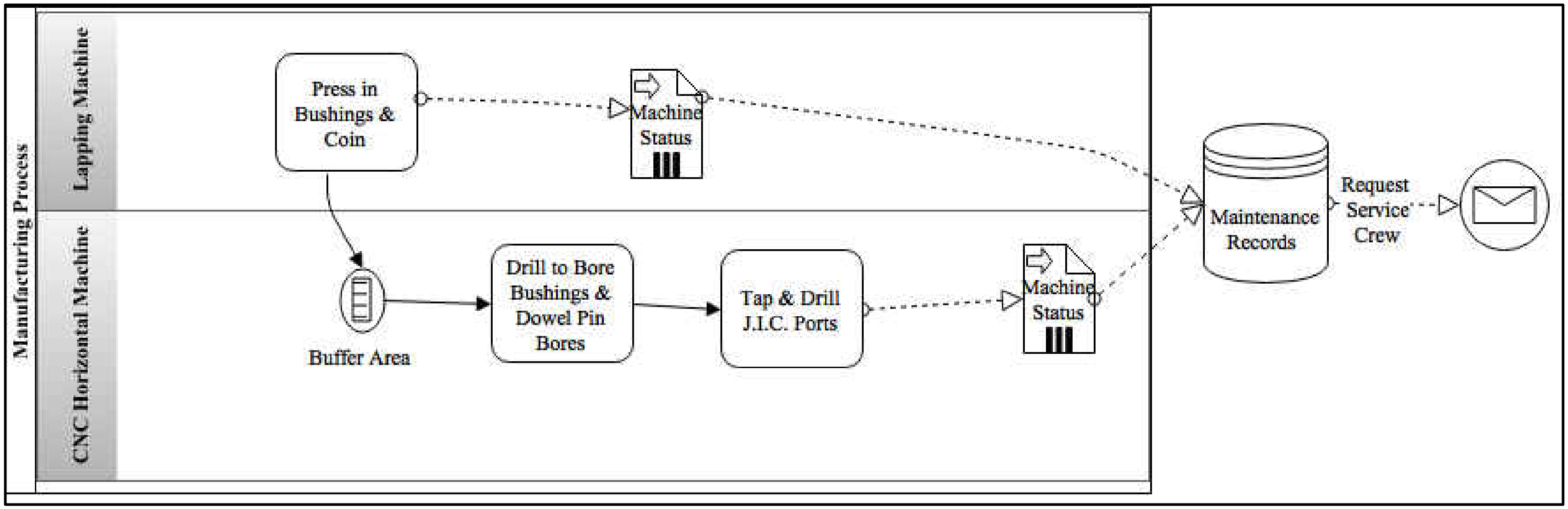


Figure 5-7: Body Process Plan

5.3.3 Behavioral System Analysis and Reference Models

Prior to this stage, the system's components are identified. The sequence of the different operations is known and captured. This information is enough to build a discrete simulation model. However, this section is needed to build the agent part of the model. Further understanding of the manufacturing system's behavior is covered. In order to analyze the system, two graphical diagrams are used: message sequence diagram and statecharts.

First, agents are identified. Then, messaging sequence diagram demonstrates the interaction in the model. In this research, machines serve as the agents (agent-based model part) where the sequence of the process and its queues are part of the discrete event model.

Messaging Sequence diagram based on AUML

Massage sequence diagram is used to represent the agents' communication graphically. There are seven agents in the system table 5-10. Each agent interacts with its own queueing zone to release parts and starts machining. Figure xx depicts the sequence of the interaction.

Table 5-18: Agents in the system

Agent type	**Queue**
Angle drilling machine	Queue 1
CNC vertical machine	Queue 2
CNC horizontal machine	Queue 3
Tapping machine	Queue 4
Vertical pressing machine	Queue 5
Lap machine	Queue 6
Washing	Queue7

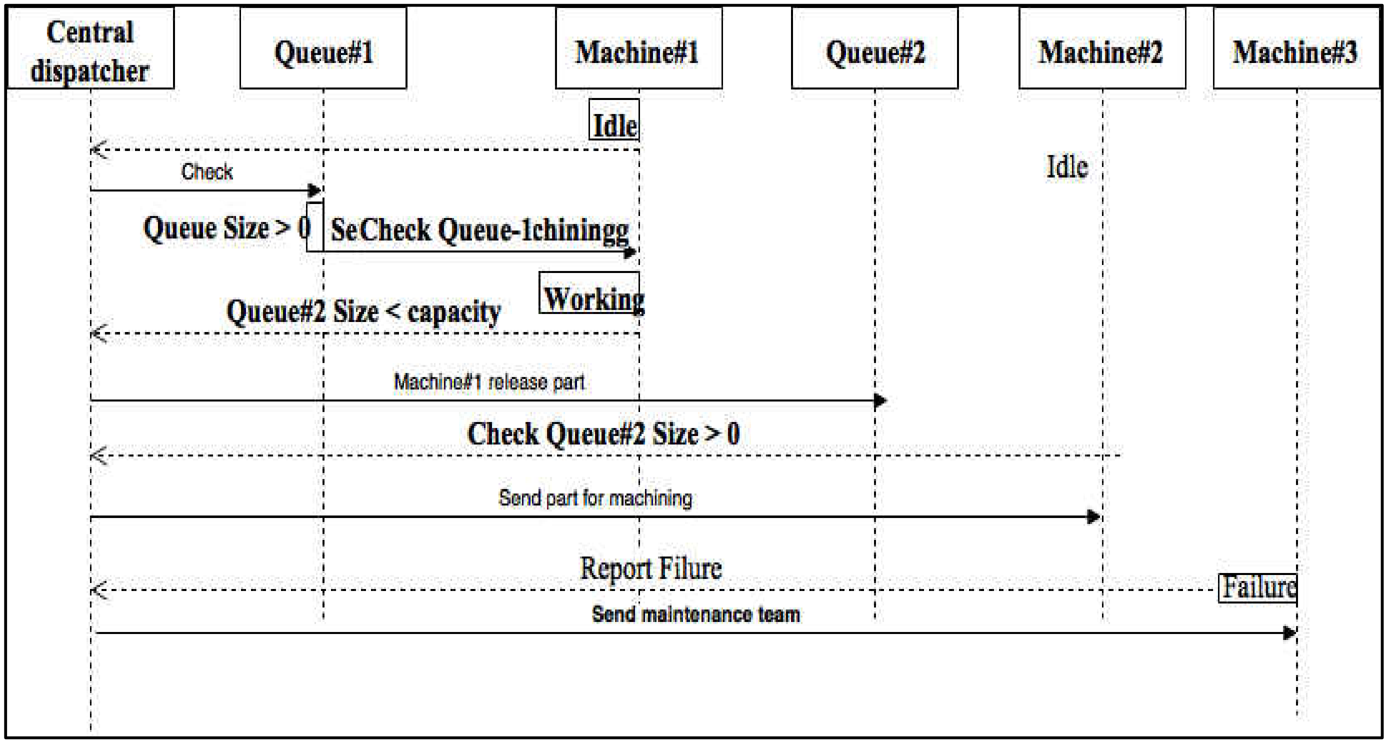


Figure 5-8: Message Sequence Diagram

Message sequence diagram demonstrates the interaction between both models agent and discrete event. The model consists of queues and machines. Central dispatcher as shown in the figure serves as the control unit for the whole model. It manages the sequence of events. For example, at the beginning, parts enter the system with a certain rate and goes to a queue-1. As long as machines are idle they are checking their queues for any arrival parts. Then, dispatcher checks if machine one is vacant and queue1 has one or more part. It sends a part to machine 1. Otherwise, parts stay in queue until machine 1 is free. Once machine one completed the job, it sends the part to queue 2 and if machine 2 is idle at that time; dispatcher will do the same process as machine 1.

What if parts are available in the queue but the machine is in a different state other than available to work? Different actions are taken. The machine in this case reports its state to the system and the system take the necessary action. As shown in figure 5-6; machine 3 failed. Therefore, the machine reports to the control system and the system is programmed to call the service team. The main notion is to understand how the to models are interacting. Note the that a detailed description about the different states are reported in the next section.

Statecharts based on AUML

Statecharts diagram represent the behavior of the agents. Two integrated parts shape this diagram: states (represent the behavior of the agent), transition (enabler to shift from a state to another).

States

The agent can be in different states that represent its behavior. Initially, there are two different states for the machines. The machine is either active/working or simply not working. However, there are different reasons that let the machine take the “active” or “not working” states. During the “active” state the machine can be *idle*; where it is waiting for parts or orders to be machined. Another state is that the machine is actually working on a job.

During the “not working” state, the machine can be; failed (failure happened to the machine that makes it stop working and the machine is waiting for the service team), repair (the service team arrives and is working on the machine to repair it), maintenance (the service team is working on the machine because its time for a scheduled maintenance), or finally replacement (upon a diagnostic of a failure, a service team decides to replace a part in the machine).

These reasons are considered to be different machine states. The modeler and the experts work together to distinguish between the different states that an agent can take. The states are different in the sense of time each state is taking and sometimes the reasons to shift from on state to another are different. Also, it is helpful to collect statistics for each state independently.

In this study, the interest is collect state-based statistics to lead to the optimal configuration. For example, the utilization (working state divided by (active + not working)). of each machine. Another example can be the time service team spent in each state repair, maintenance, and replacement.

Transitions

Transition is the change of the machine (agent) from a state to another. Initially, machines are idle until an order is initiated. In the event of failure, service crew arrives to examine the machine and decide whether a repair or replacement is needed. After that the machine goes to idle or work immediately if an order is waiting. Unless after repair a machine needs to be maintained (maintenance time is due).

The only missing part here, is to determine the trigger of these transitions. The trigger is what makes a machine changes its state. Idle is the initial state. Working is triggered by an order. While, failure is a stochastic event that depends on many factors including but limited to: aging, reliability, maintenance, etc. Service crew decides what is next. Upon repair it is a deterministic transition. If maintenance time is due, then machine is maintained first. All transitions entering the idle state is time driven, the time spent in a state. These times can be obtained from input data. More details about the transitions are demonstrated in the next section.

Behavioral analysis is drawn form message sequence diagram and statecharts. The former one captured the time sequence of events, interaction, and communication between agents. While the second diagram reflects the behavior of the individual agent and how agent changes its state. The next phase finalizes the configuration of the system through a simulation software.

5.3.4 Final Configuration

At this time a complete picture about the system is available and its time to develop a simulation model to determine the system's configuration. Discrete-event and agent based model are used. The model is programmed in a simulation software called "AnyLogic". The software is capable to merge and combine different types of simulation such as discrete-event simulation, agent-based simulation, and system dynamics in one model. According to Liraviasl, ElMaraghy et al. (2015) Anylogic is useful tool to model a hybrid simulation model; it is based on Java object-oriented programming language that enables to structure the behavior of the individual agents. In addition, imitate any communication that could happen between agents or between agents and their environment.

In this model machines are agents and queues are part of the discrete-event simulation. In this model agents are communicating with their environment (queues) to ensure a smooth flow. However, prior modeling different assumptions are considered including:

- Raw material is always available for production
- Movement time (material handling system) is neglected in the model
- Assuming no constraints associated with the area of the facility (in case of adding machines)
- Queue and machining is based on FIFO (first in first out)
- Quality control is embedded in the system: no rework and defective parts
- Machines have the same behavior with different parameters values

The following of this section is divided into discrete event model, agent based model, and a hybrid simulation model.

Discrete Event Model

Based on the facility's process plan, the sequence processes from Figure 5-5 is programmed into the simulation software. Figure 5-11 shows number of machines with their queues, raw material storage area, and finish goods storage area. Storage area releases parts with a certain rate equals to one part per time unit (figure 5-12). Parts go to queue1 and wait there if machine 1 is busy. Otherwise, it moves to machine 1. After a part is done from machine 1 it goes to the next queue and wait there until its machine is vacant and ready to work. This happens with the rest of the machines.

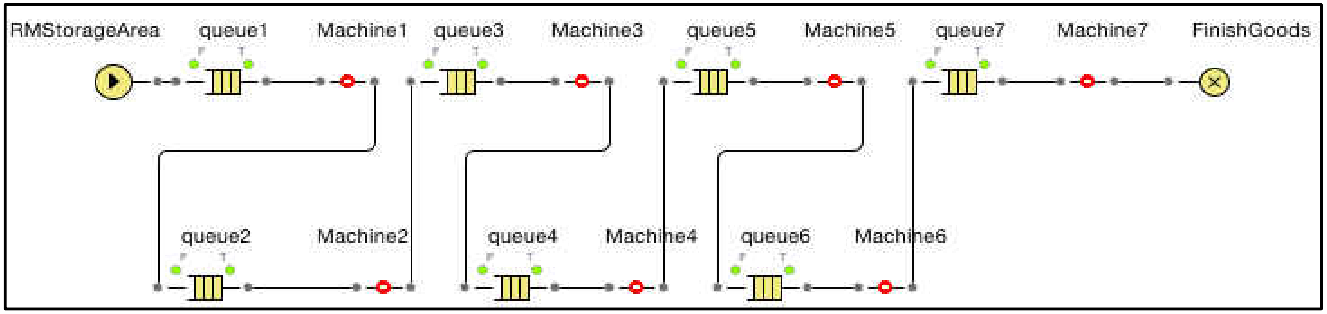


Figure 5-9: Discrete Event Model

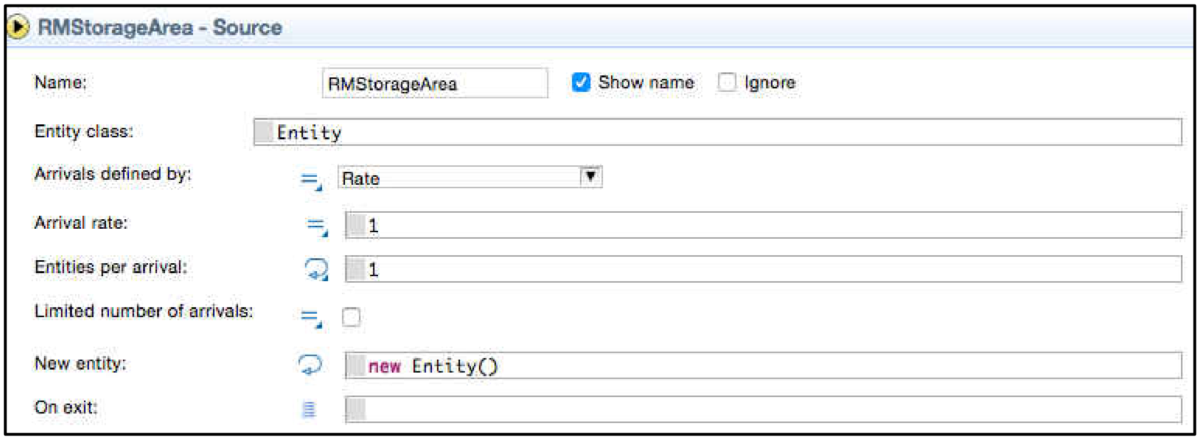


Figure 5-10: Parts Arrival Rate

In order for the queue to communicate and notify the machine about a new part, certain code is used at the entry gate of the queue as sown in figure 5-13. This will notify the agent corresponds to the queue.

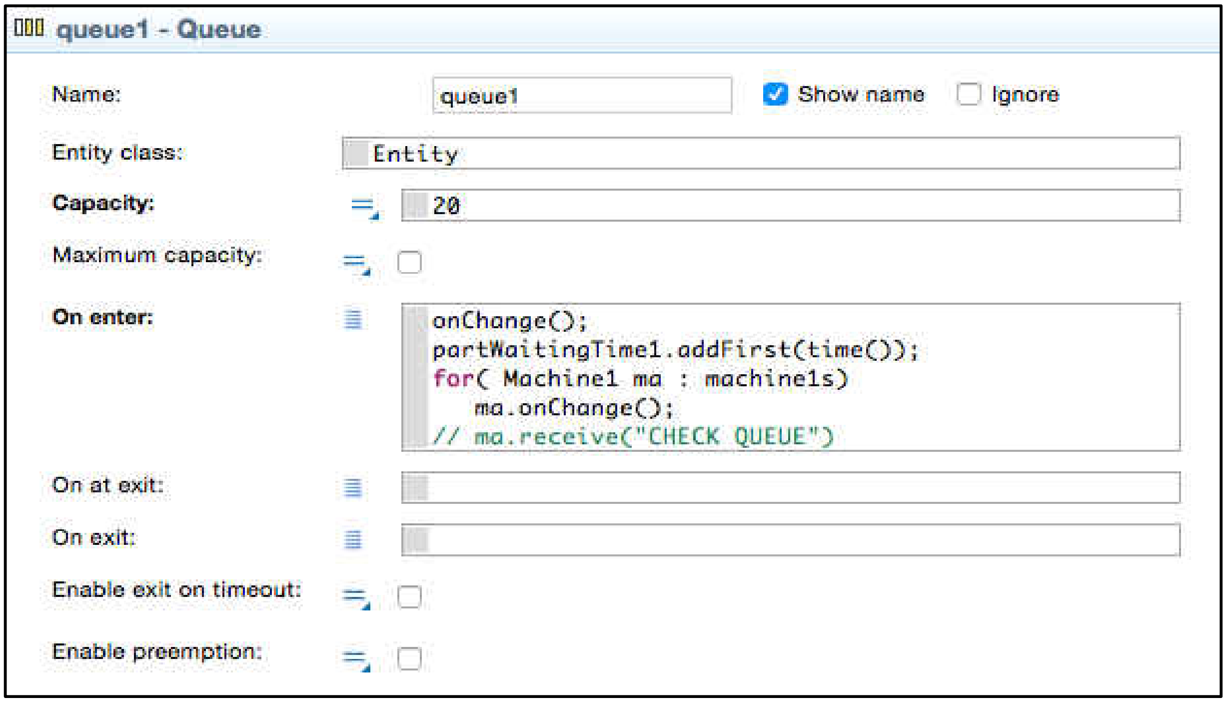


Figure 5-11: Communication between Discrete-Event and Agent Based Model

To merge between discrete and agent based model, machines use the “hold” module. The following code is used as shown in figure 5-13 each time a part enters the machine. In this way the machine notifies the queue that it is blocked. Hence, any coming part will remain in the queue until the agent/machine sends another signal to the queue; stating that it is unblocked. If the machine fails during the operation the part remain inside the machine until the machine is fixed or repaired.

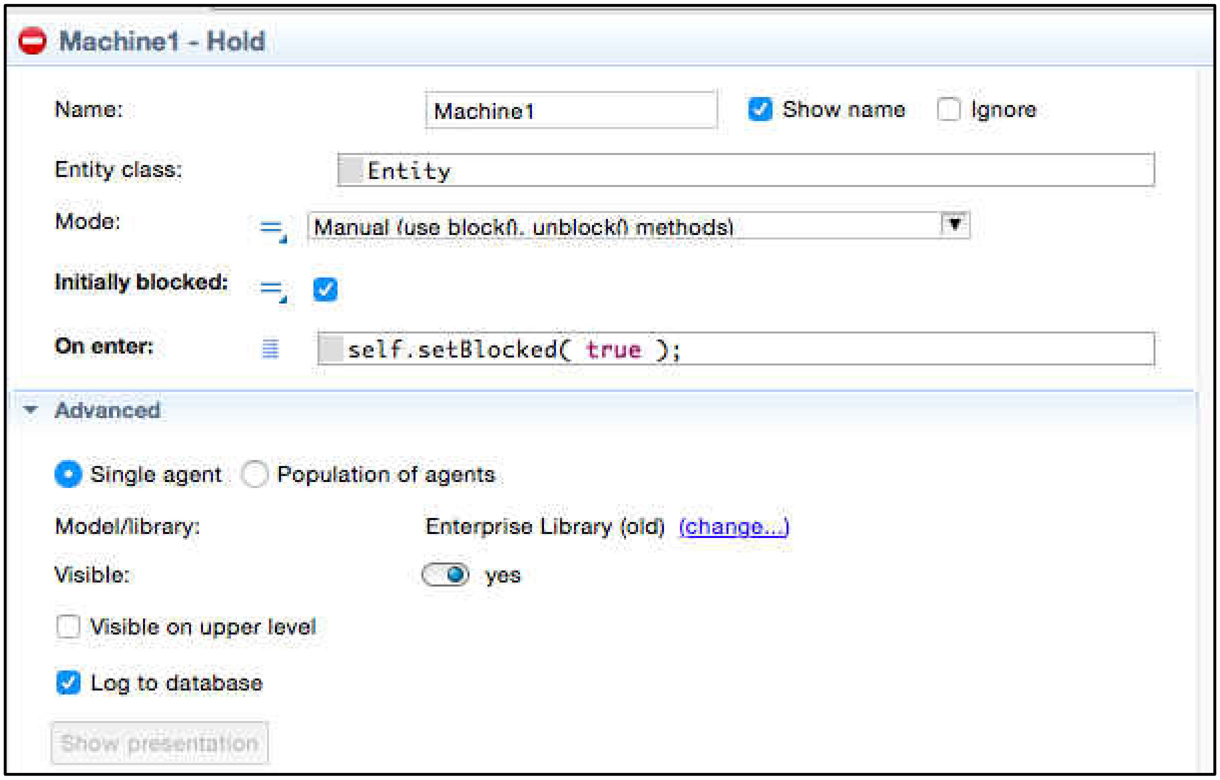


Figure 5-12: Hold Module

Agent-Based Model

In this research each machine is considered as an agent that operates independently and then connected to the discrete system (figure 5-15). Each machine has its own statechart or that represents its behavior. In the behavioral system analysis phase, the different states were identified. Figures 5-16 depicts how these statecharts are modeled in the software.

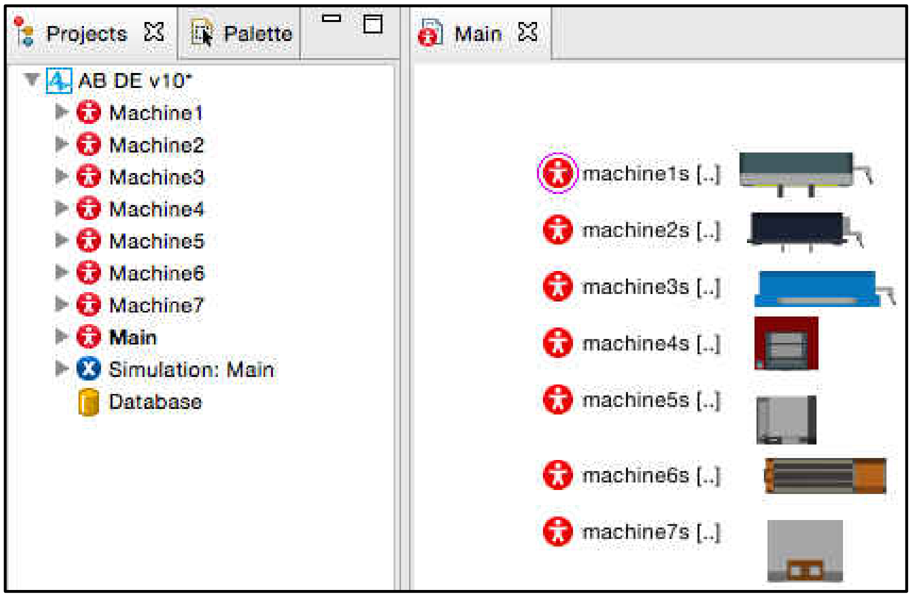


Figure 5-13: Agents Created in the Simulation Model

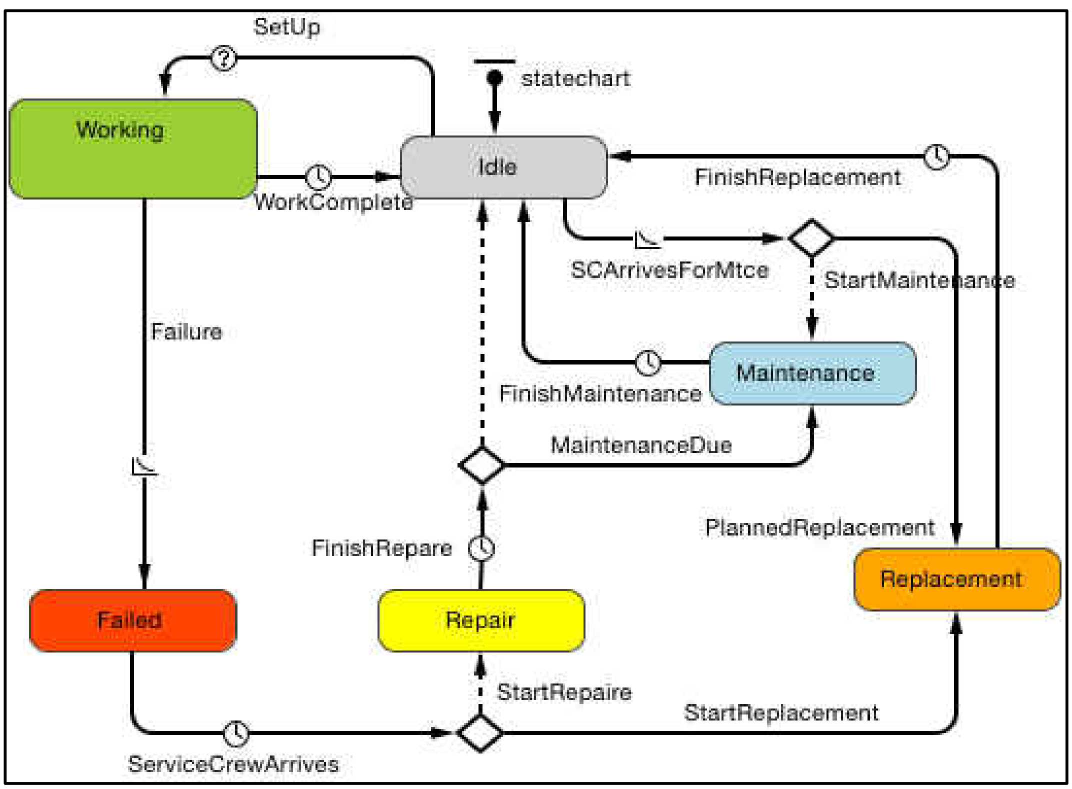


Figure 5-14: Machine's Statechart

Experts from the facility agreed that these states represent the different states that a machine can take. Along with these states there are transitions. As mentioned earlier, transitions are based on events. Figure 5-17 shows the different parameters that create these events. If needed, the model gives the option to modify these parameters during the run time of the model based on the limits provided by the experts.

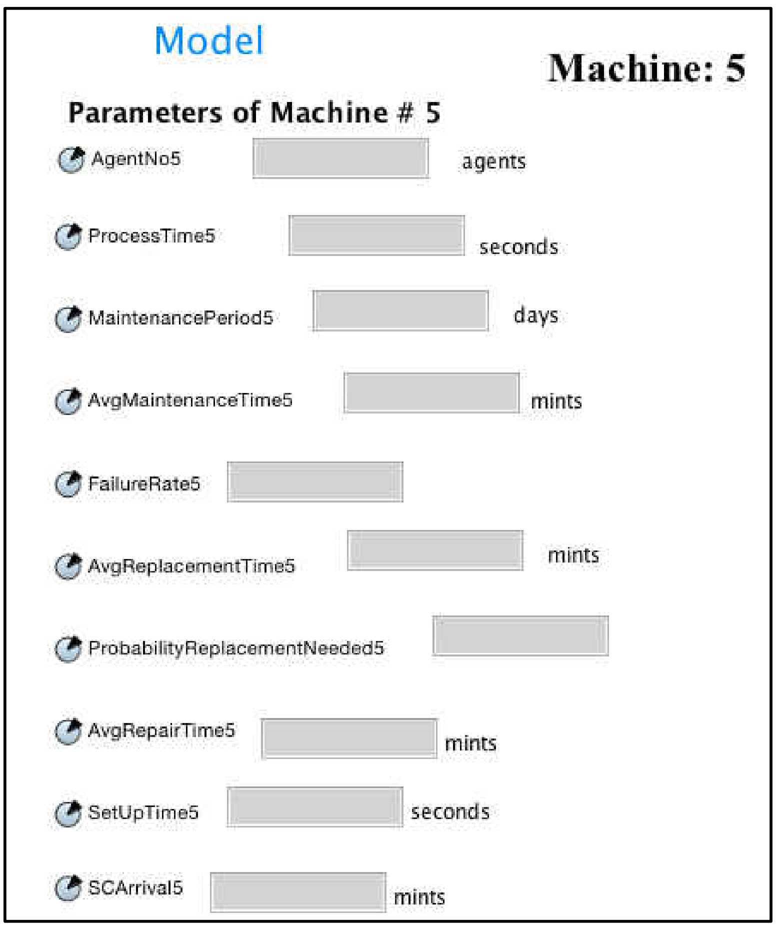


Figure 5-15: Machine 5 Parameters from AnyLogic

Initially, machines are in the *idle* state (figure 5-16). In order for a machine to start working, it checks the status of its queue. If the queue length is greater than zero, it starts recalling a part from the queue and enters the *working* state. This transition is illustrated in figure 5-18.

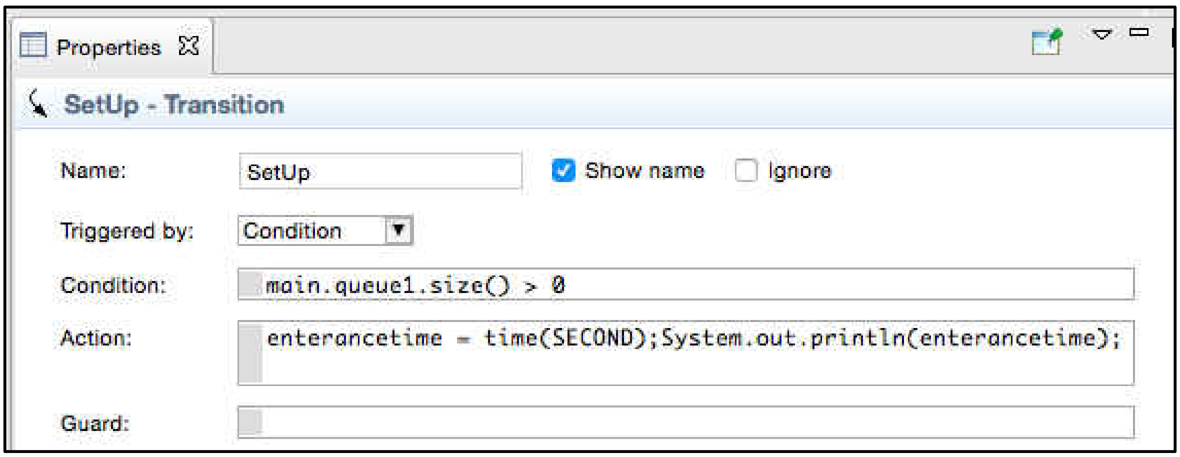


Figure 5-16: Machine Setup Transition

Work is completed based on the process time of the machine. A time driven is defined for this trigger. Moreover, when a machine completed the work it notifies the discrete model that the agent is vacant and back to the *idle* state. Figure 5-19 illustrates this action. The transition is triggered by “timeout” that is defined by the process time of the job. As soon as the job is completed, the machine takes an action by notifying the queue about its state.

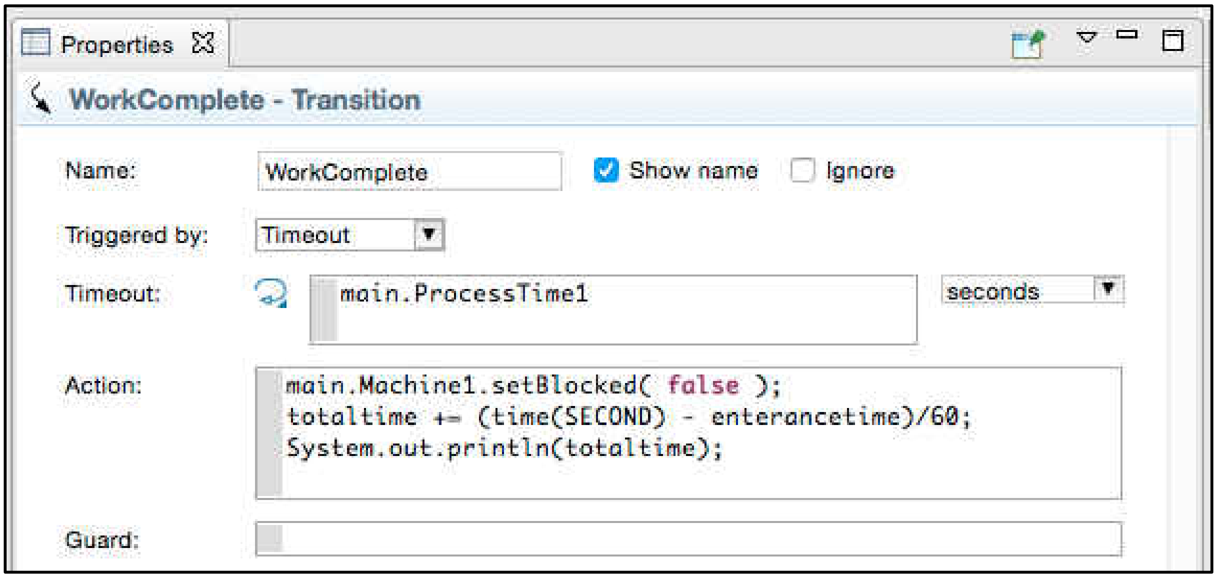


Figure 5-17: Work Completed Transition

What if a machine is working and sudden failure occurs? This transition is stochastic. It depends on its parameter (figure 5-20). In this case the machine turns to the *failure* state; where it is not working and waiting for the service team to arrive. A lack of SMS feature is clear gap in this incident. There is no automated technological data collection for failures and its causes. Therefore, failures are not predicted in this facility.

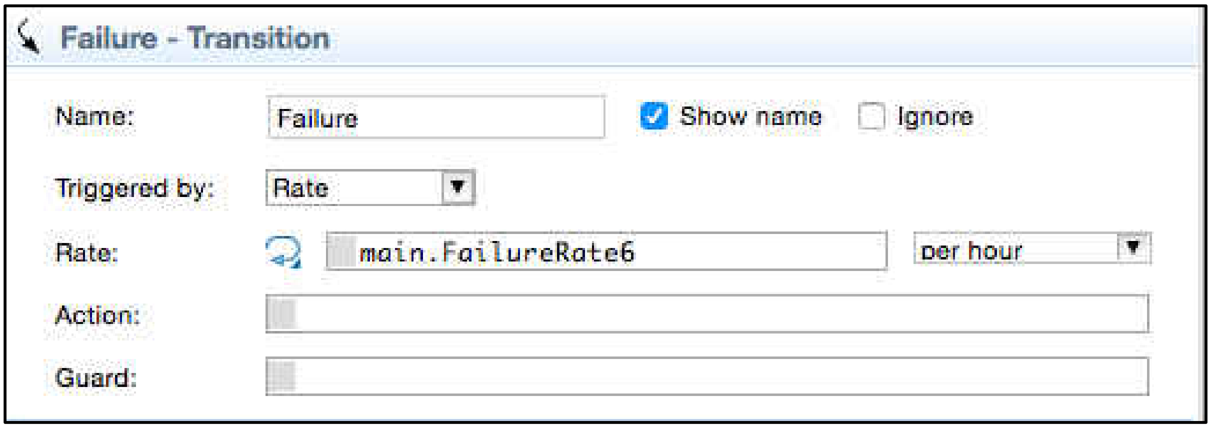


Figure 5-18: Failure Transition

Service crew arrives per an average rate as shown in figure 5-21. Then, the team decides whether to repair or to replace the part. The default value or decision is to repair unless replacement is the option. As per this study replacement policy exist nearly 10% to 20% of the times. Finish repair programmed as a triangular distribution as shown in figure 5-22.

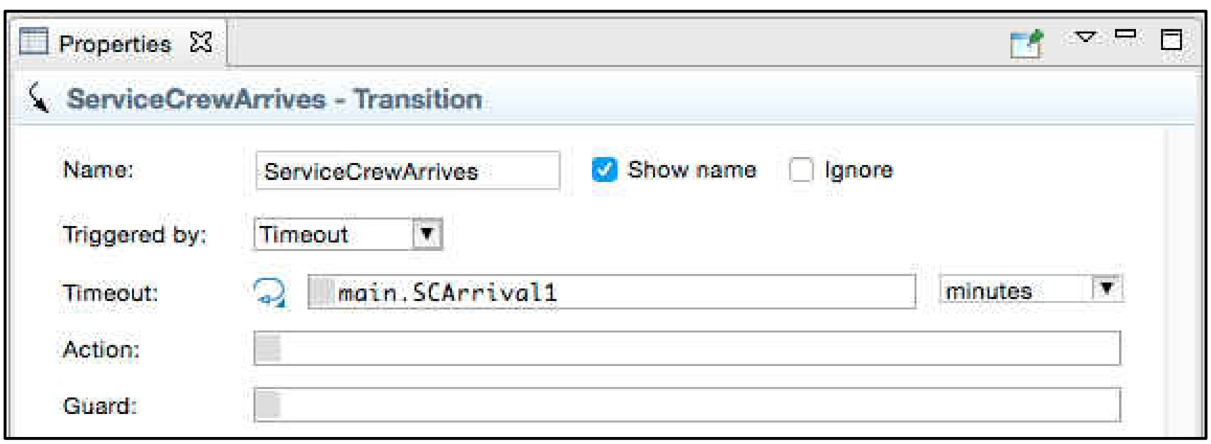


Figure 5-19: Service Crew Arrival Rate

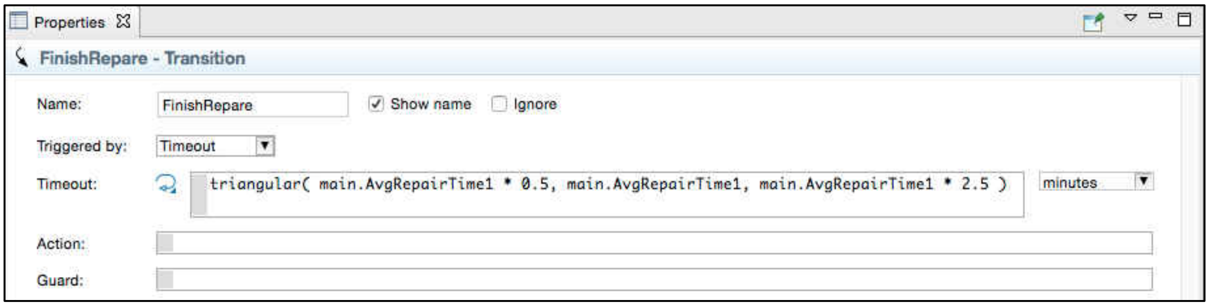


Figure 5-20: Finish Repair Transition

By default, after repair, the machine goes to idle again. However, if maintenance is due; service team maintain the machine and then it goes back to the idle state. If the 10% of the replacement policy is true, service team replace a spare part in the machine and let it go back to the idle state. Replacement part is based on the defined parameter of each machine. Figure 5-23 shows this transition. This trigger follows a triangular distribution. Once replacement is completed the machine notify the discrete system about its status.

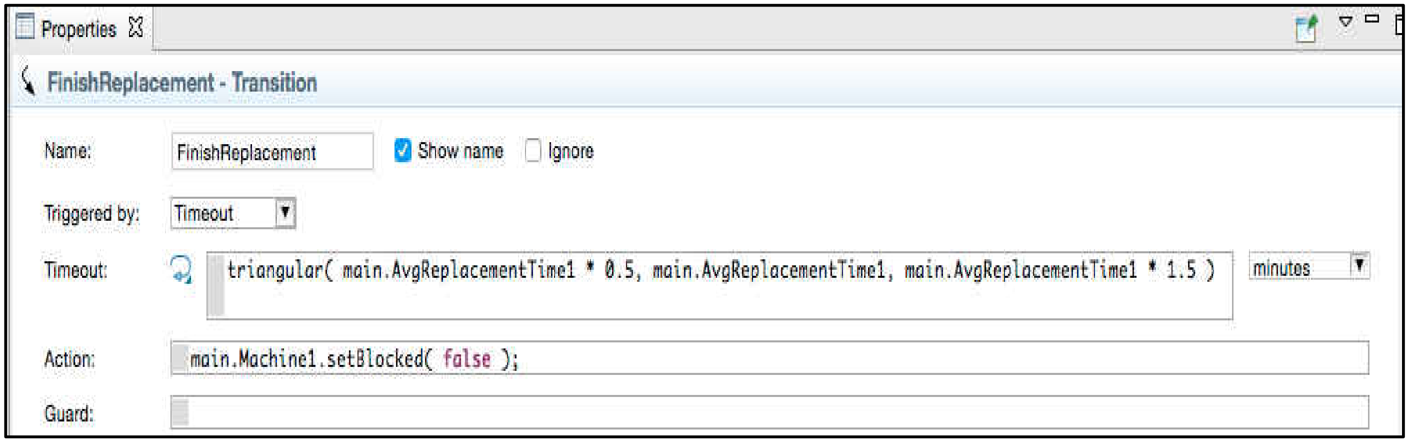


Figure 5-21: Replacement Completed Transition

What if a machine completed a work and goes back to idle and maintenance is due? Service team will arrive for maintenance. Before the maintenance a decision is made to either maintain the machine or part replacement is needed. If the decision is to maintain the machine, it goes into a *maintenance* state. Maintenance is completed with the transition shown in figure 5-24. An average maintenance time is a parameter defined and follows a triangular distribution. An action is also taken in this transition before the machine goes to the idle state; the agent notifies the discrete model that the machine is idle and can receive orders. Since machines have the same behavior; one machine was explained and the rest have the same states with different parameters.

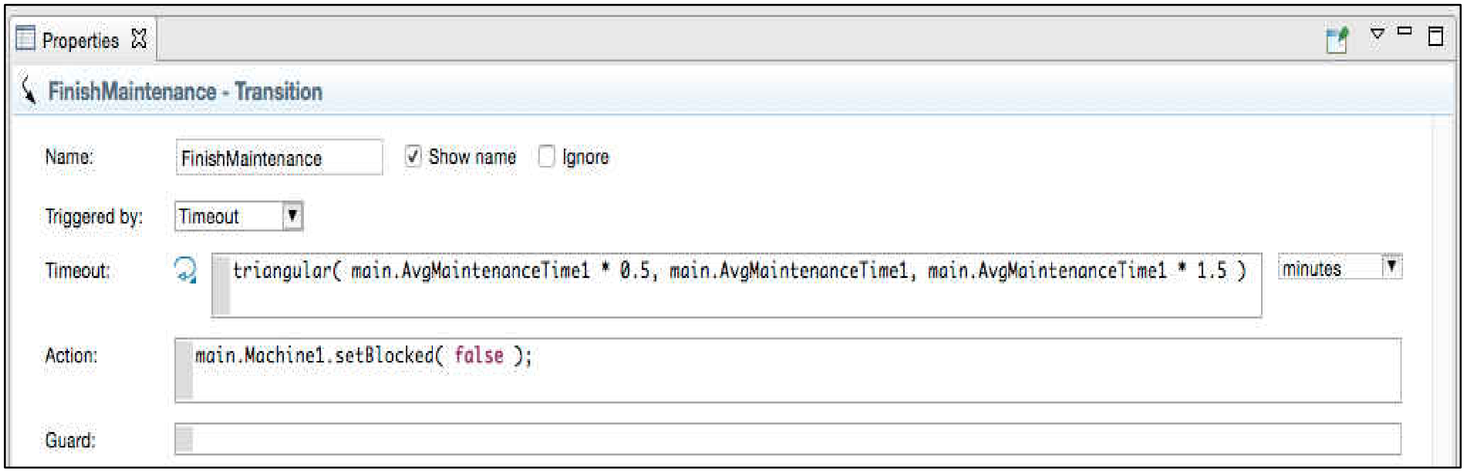


Figure 5-22: Finish Maintenance Transition

Hybrid Simulation Model

Machines are part of a complex SMS and each machine has its own behavior that is best modeled with statecharts and triggered by events. An interface between the manufacturing process and machines (agents) has to be built.

In this case, agents and manufacturing process are modeled separately and then connected together. There are situations where these connections appear. For example, once a machine is in the idle state; it checks the corresponding queue in the manufacturing process. If parts are available in the queue, the agent pulls a part and start working. Also, at all entry point to the idle state. The agent notifies the manufacturing process that the machine is idle. Figure 5-25 depicts both manufacturing process and the seven agents. The behavior of the agent is shown in figure 5-16.

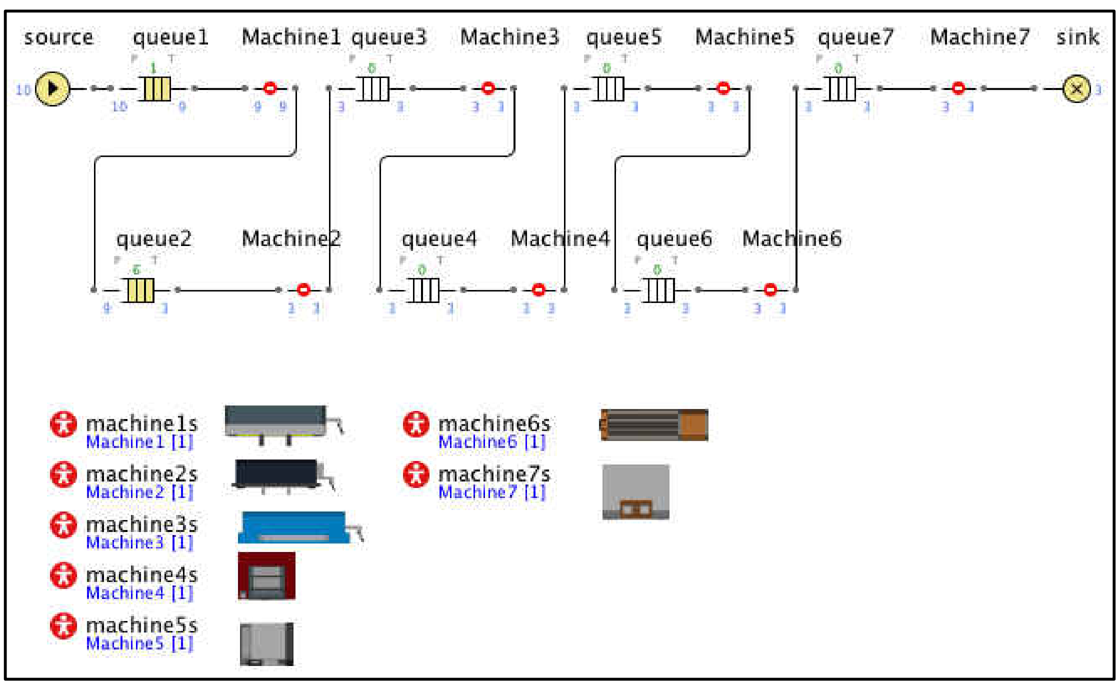


Figure 5-23: Hybrid Simulation model

Analysis

At this stage, the model is ready to run. Different statistics are collected to evaluate the current configuration including: system throughput, WIP, machines' utilizations, and a chart showing the state of the machine during the simulation run.

System throughput is calculated as number of finish goods divided by runtime * 60 = parts/second. The simulation run time is one year as shown in figure 5-26. The figure also where the utilization is calculated as the working time of the machine divided by total available time during the year.

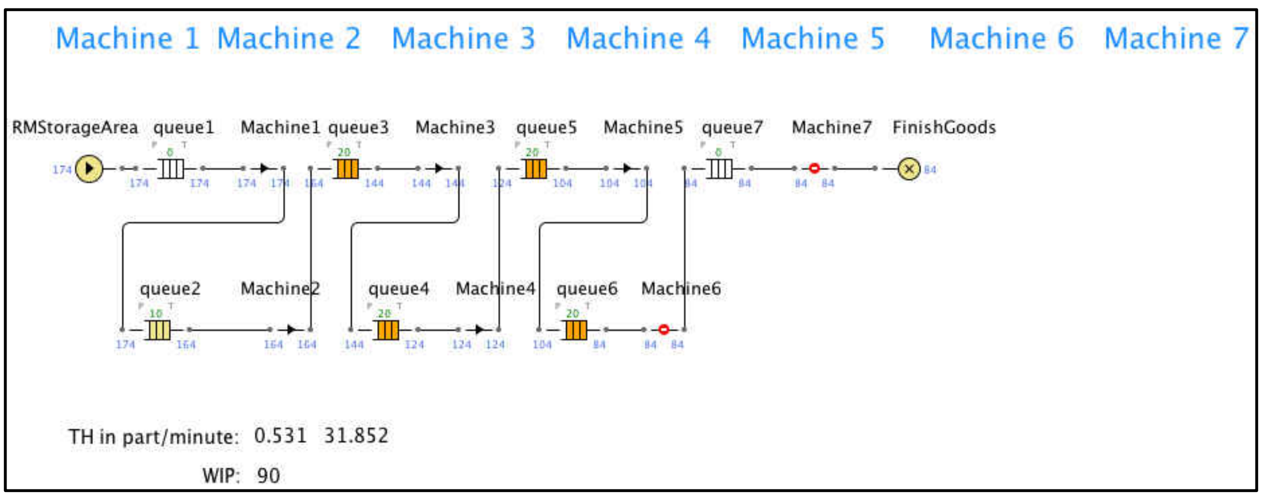


Figure 5-24: Model at Runtime Showing TH and WIP

During the run time utilization rates for each machine along with its states are charted. For example, during the 80% of the run time, machine one (figure5-27) shows a utilization of 60.35% at that time the machine was at the failed state, parameters are depicted from the software in figure

5-28. Machine 2 was in a working state as shown in figure 5-29. The utilization of the machine approximately 79%. Machine 3 had a utilization of nearly 50% as shown in figure 5-31. The low percentage is reflected due to the fact that it was idle for a long time. A reason for that comes from the fact that the preceding process was failed. This failing affected the rest of the machines as machine four and five were idle with utilizations of 55% and 57% respectively as shown in figure 5-33 and 5-35. Machines six and seven were failed as well with utilizations rate of 59% and 61.19% as shown in figures 5-37 and 5-39 respectively.

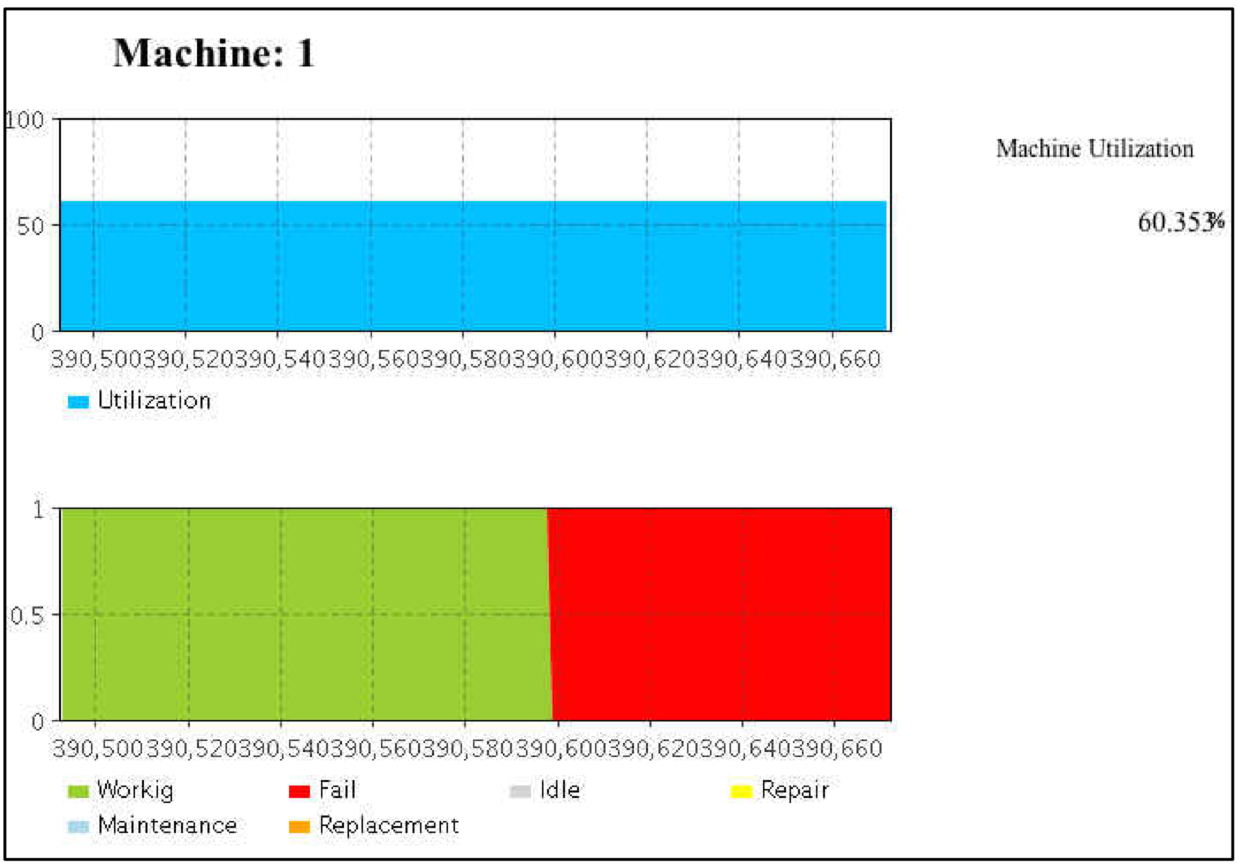


Figure 5-25: Utilization and State of Machine 1

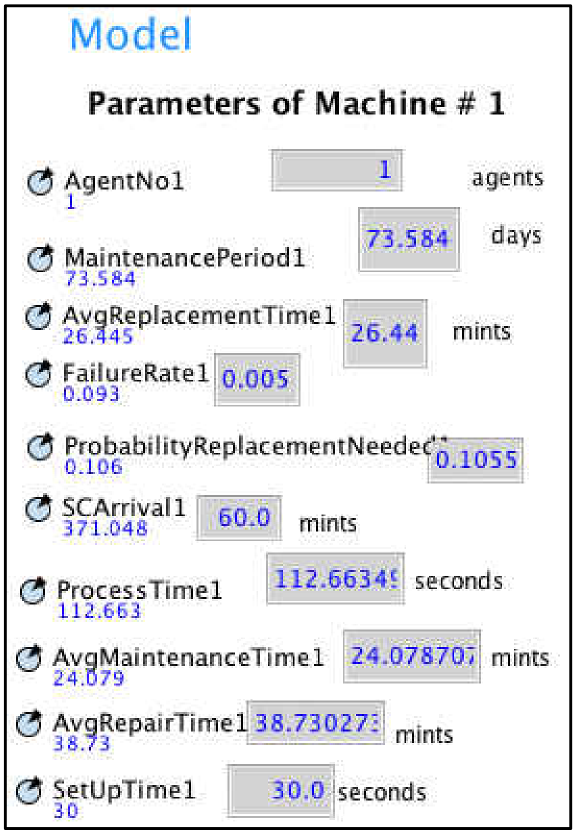


Figure 5-26 Parameters of Machine 1

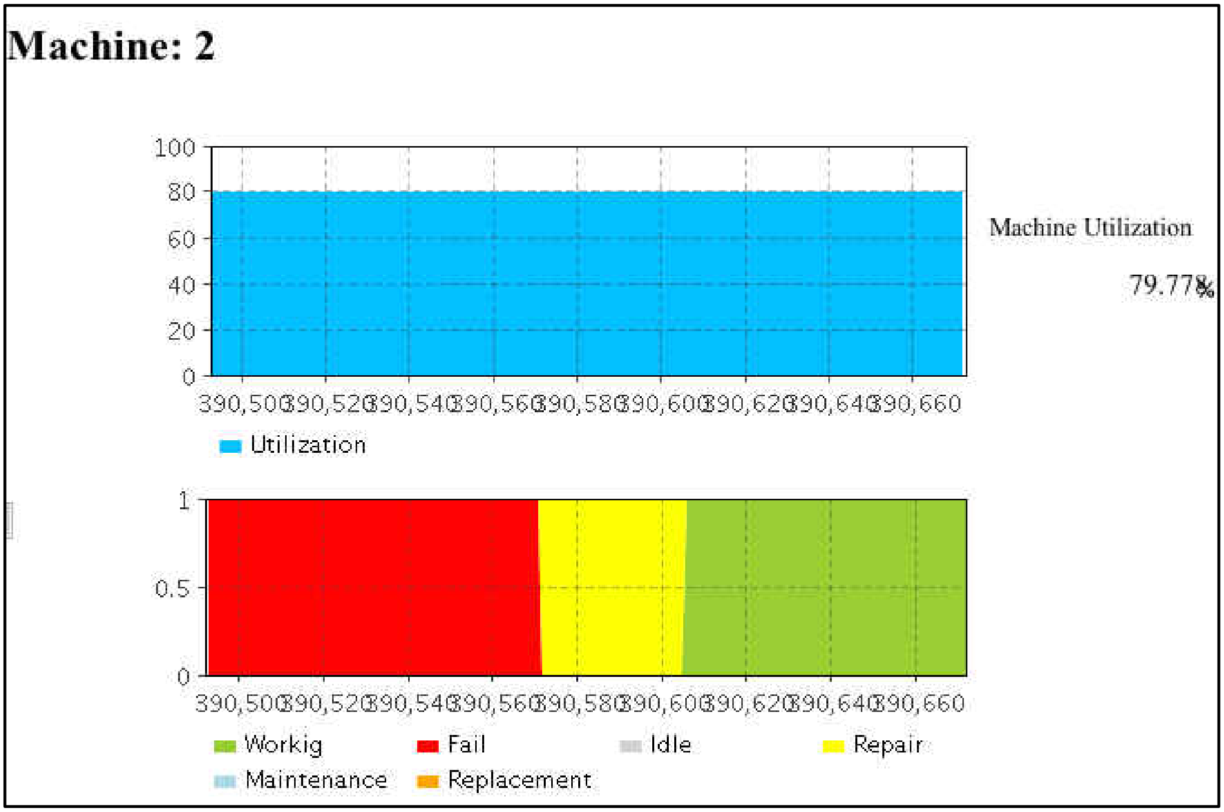


Figure 5-27: States of Machine 2

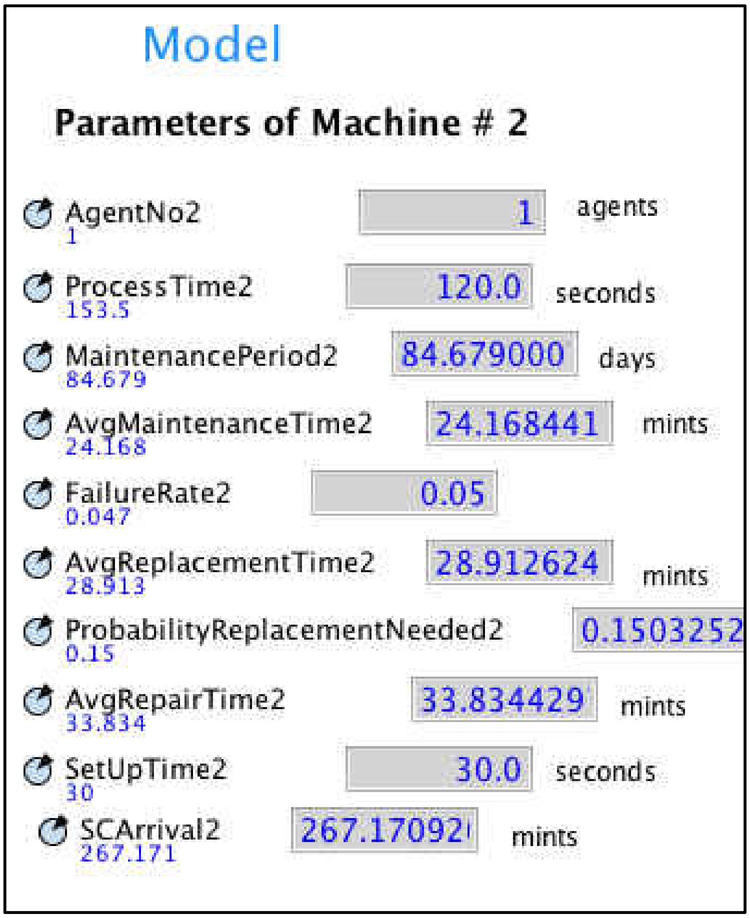


Figure 5-28: Parameters of Machine 2

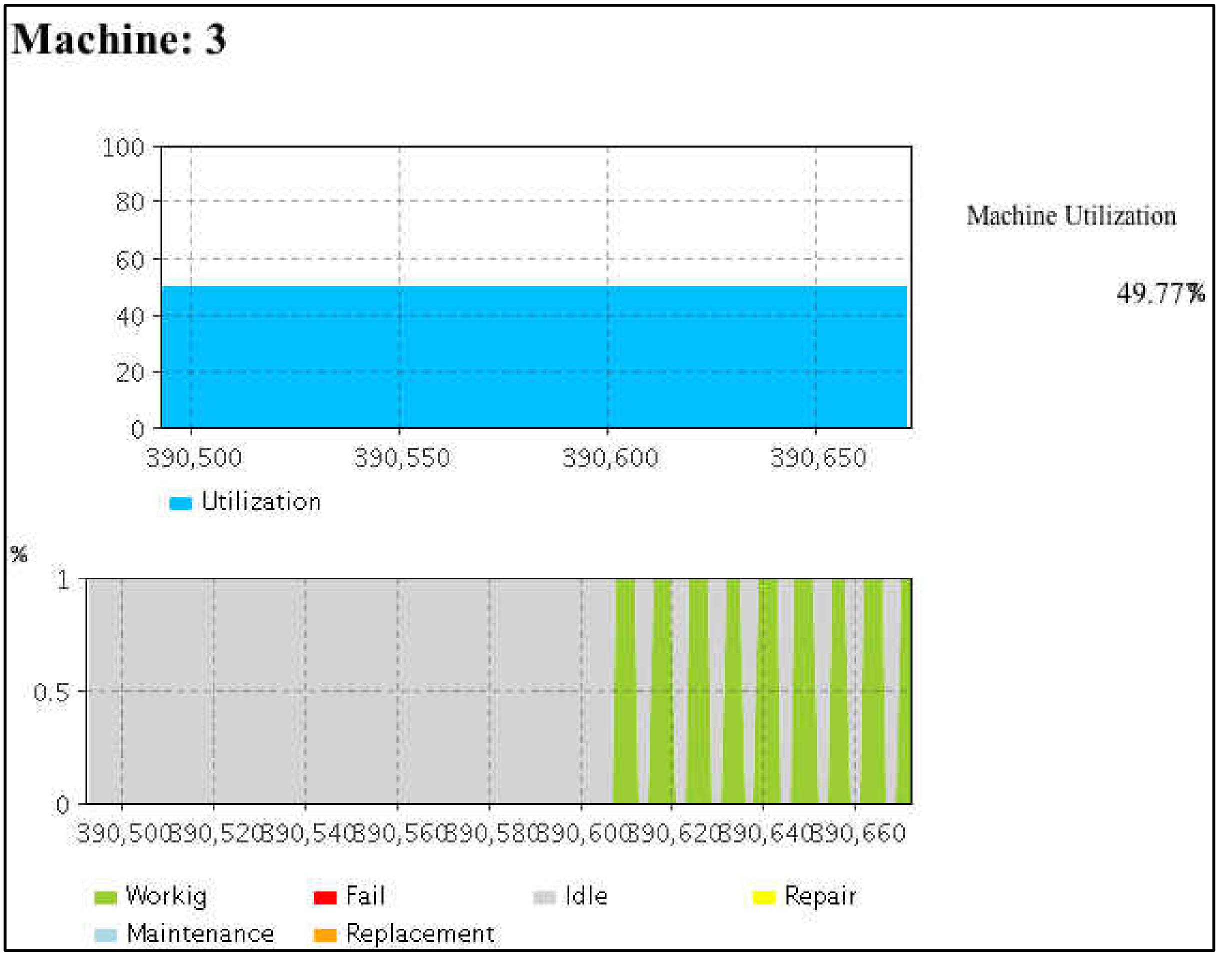


Figure 5-29: Utilization and States of Machine 3

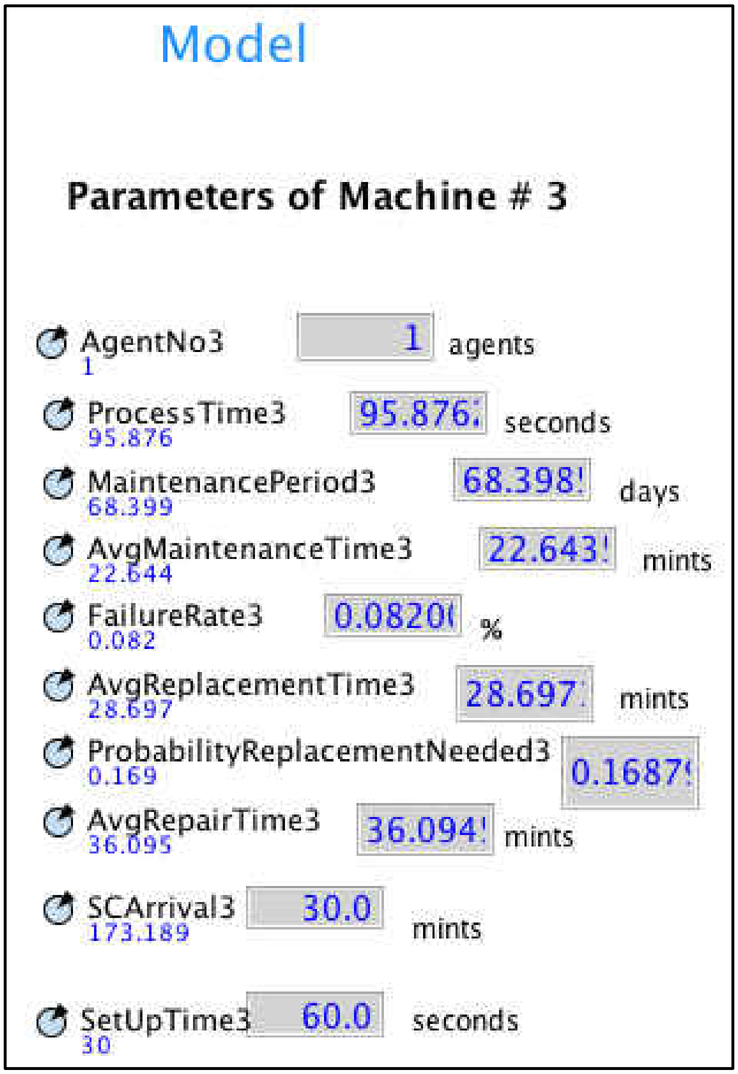


Figure 5-30: Parameters of Machine 3

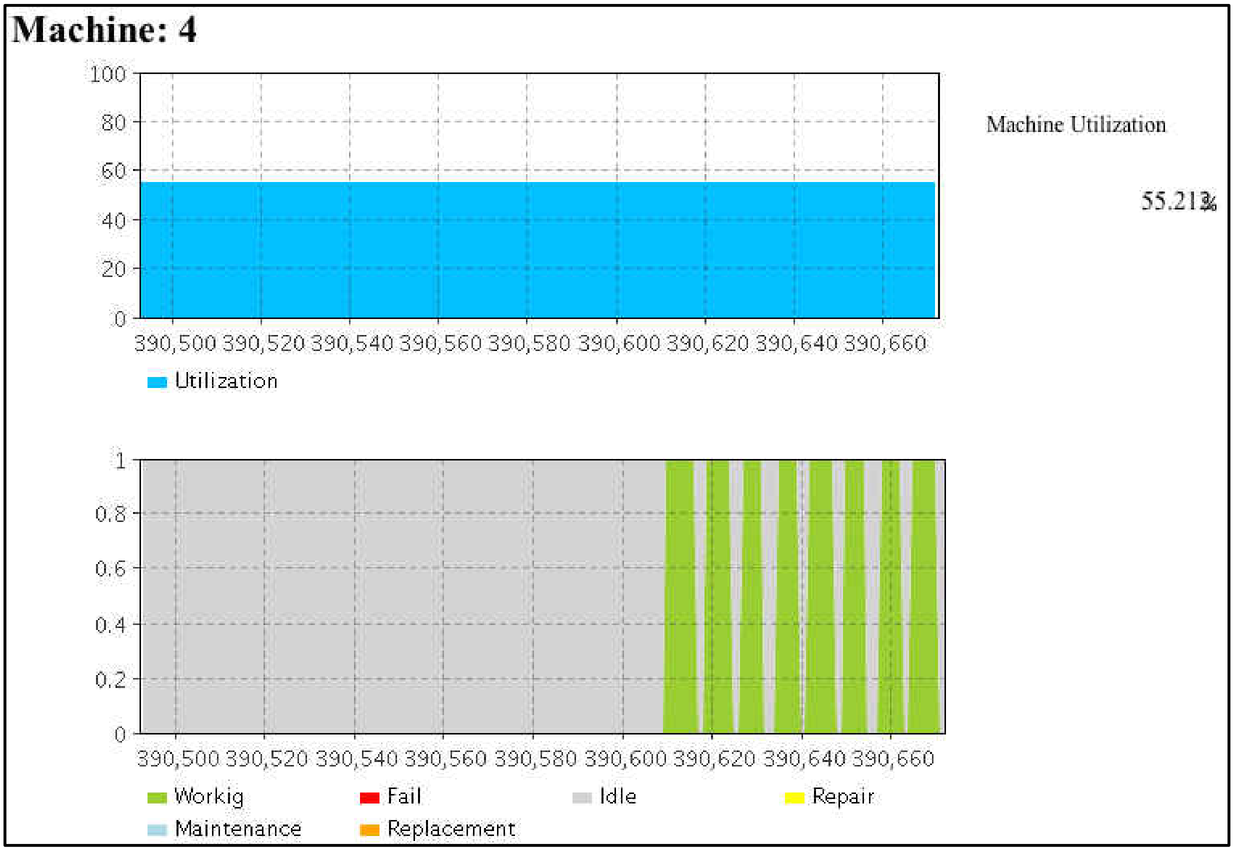


Figure 5-31: Utilization and States of Machine 4

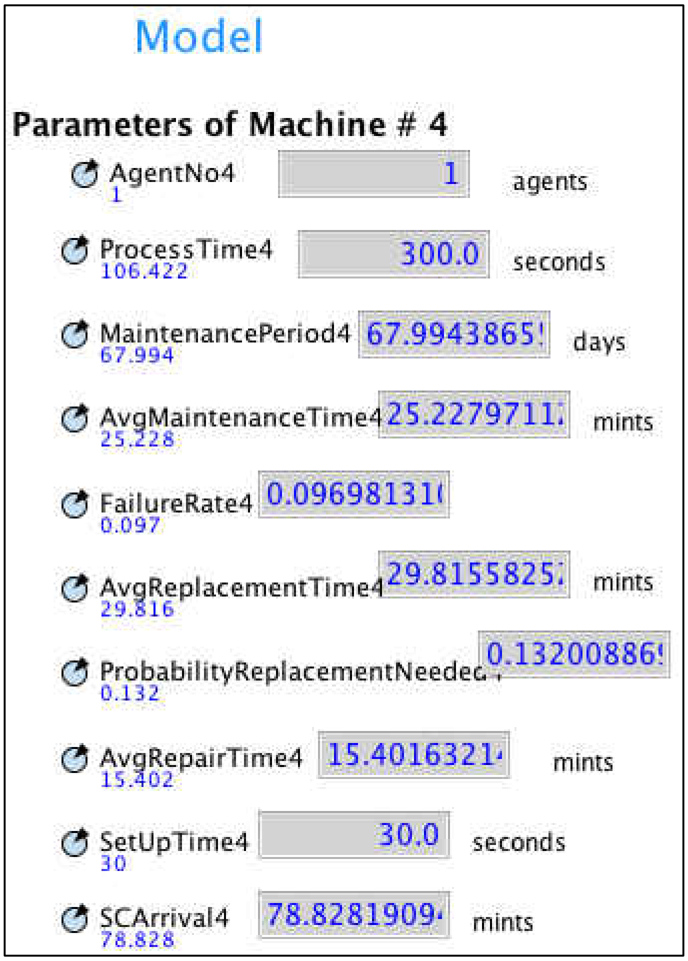


Figure 5-32: parameters of Machine 4

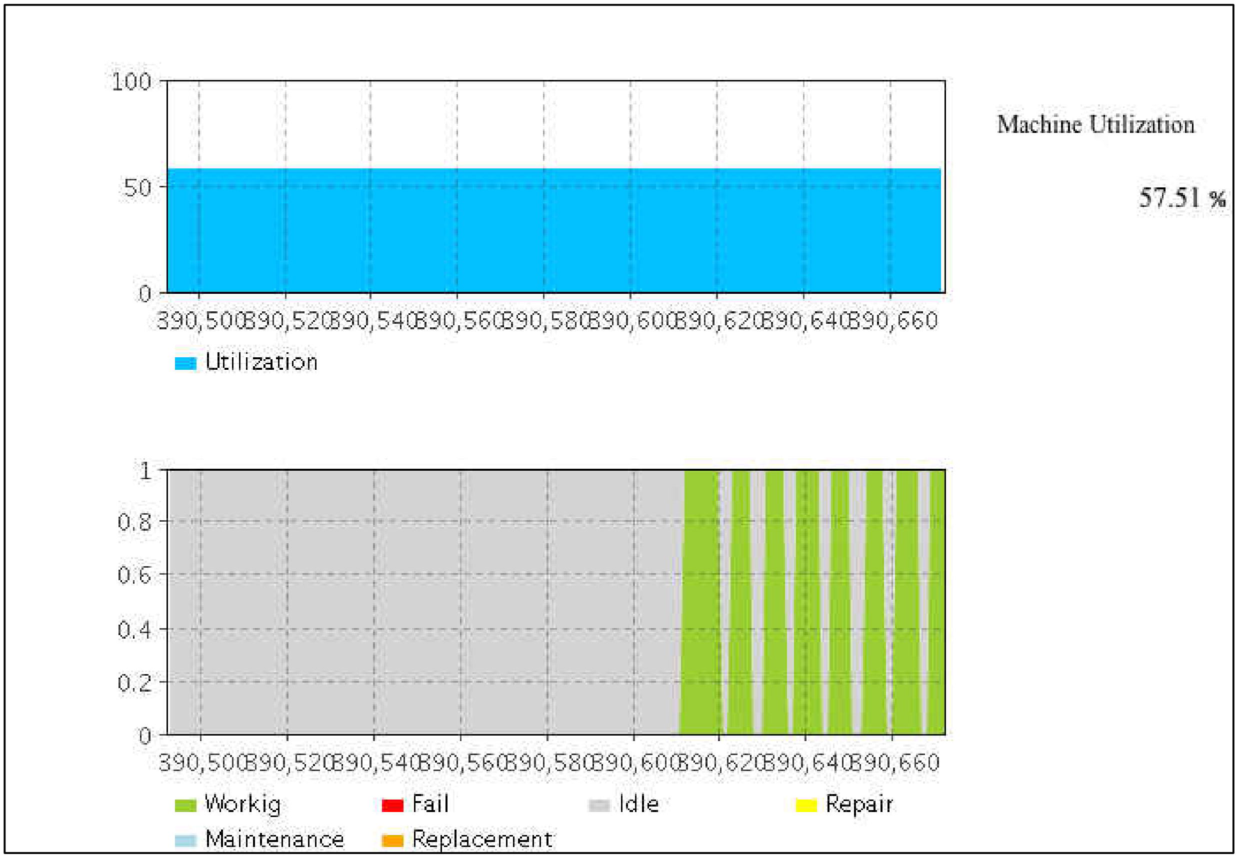


Figure 5-33: Utilization and States of Machine 5

Figure 5-34: Utilization and States of Machine 3

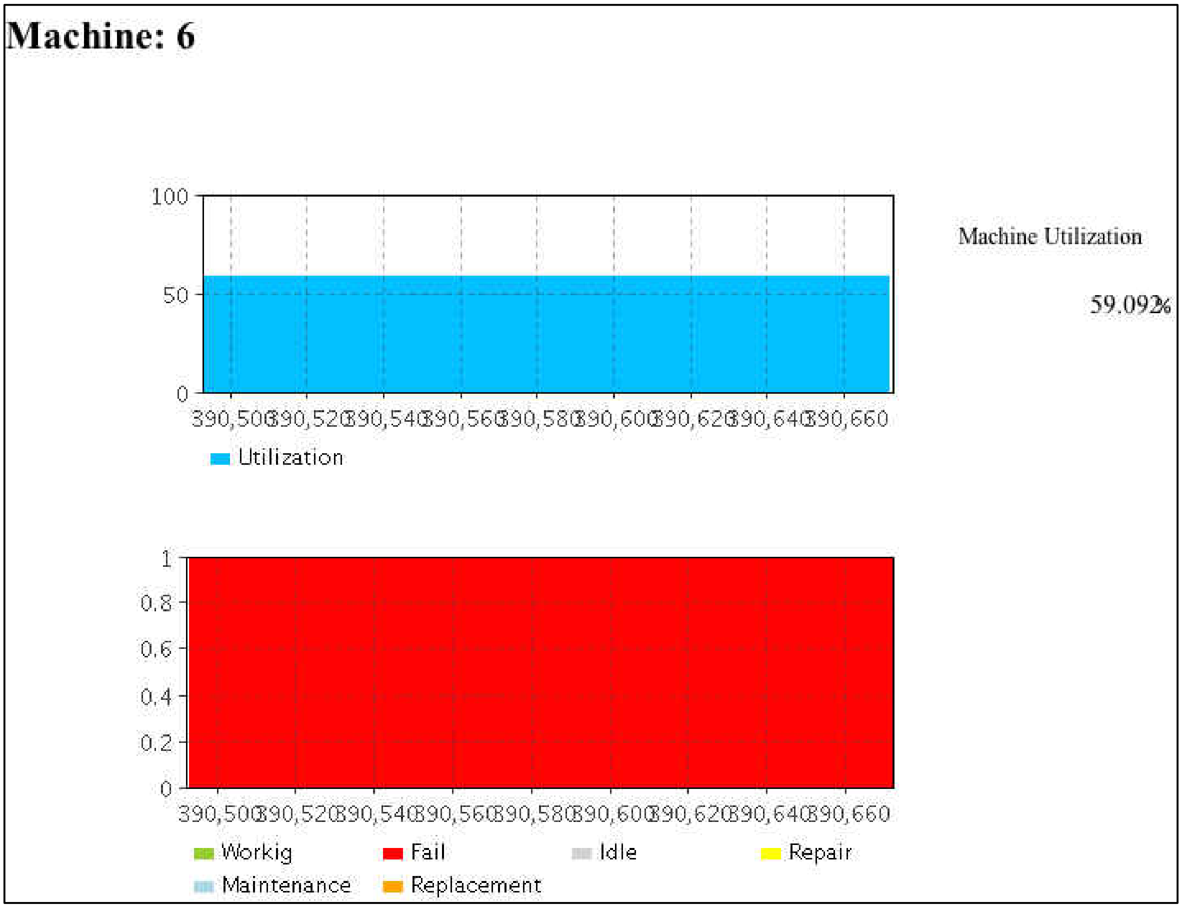


Figure 5-35: Utilization and States of Machine 6

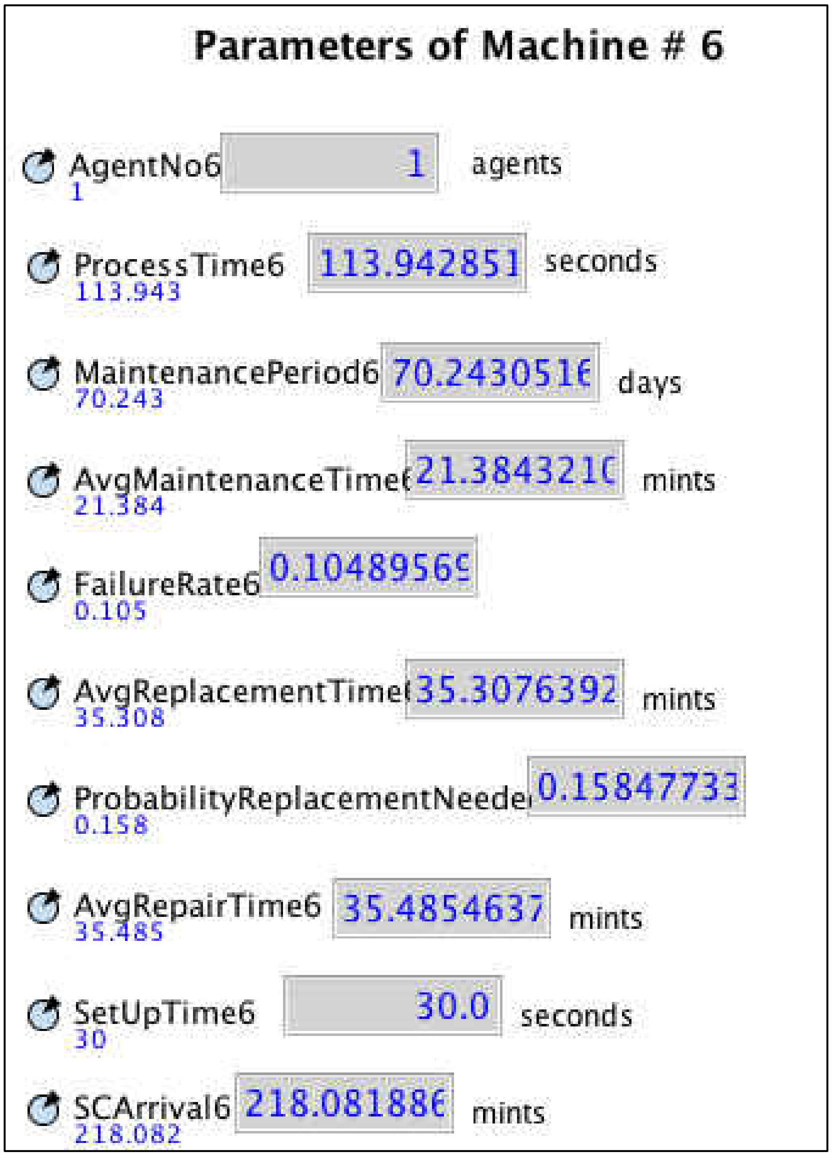


Figure 5-36 Parameters of Machine 6

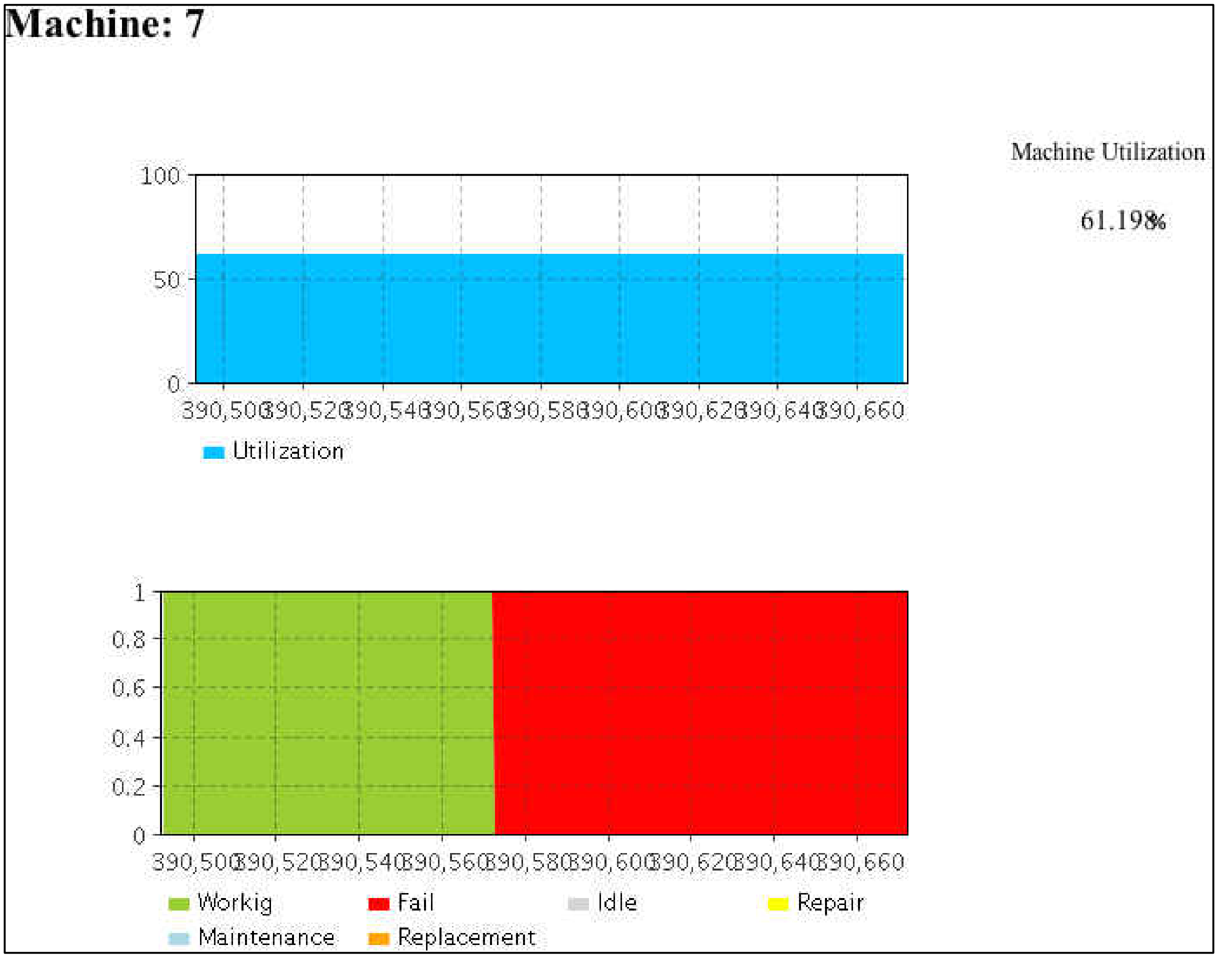


Figure 5-37: Utilization and States of Machine 7

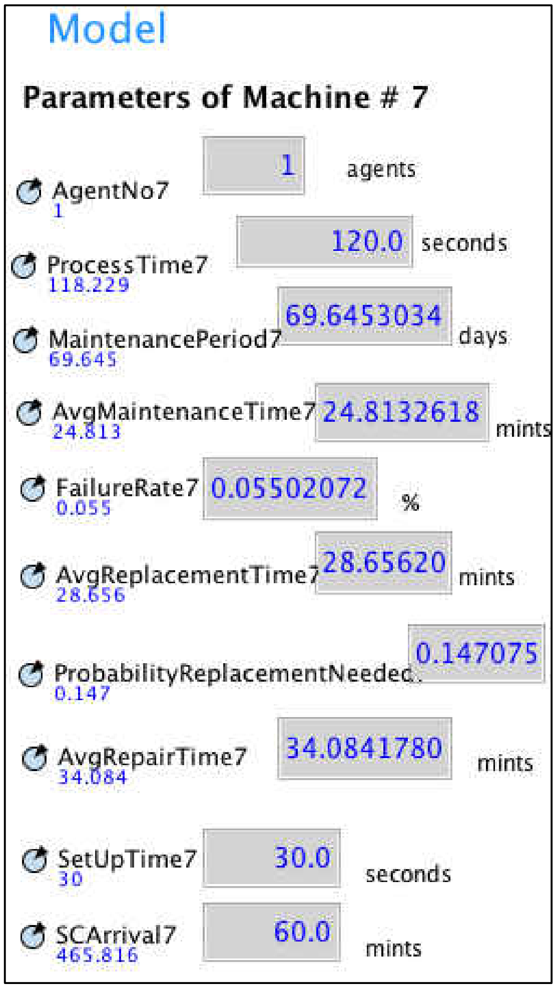


Figure 5-38: Parameter of Machine 7

5.4 Messaging and communication in SMS

Since the actual case study doesn't satisfy the full definition of SMS. The vision of SMS is based on innovative designs of hardware as well as information technology that is able to reshape the current situation to introduce the forth industrial revolution. This section assumes messaging and communication between different agents in the system. The purpose is illustrating the messages and demonstrating the benefit of using ABM.

Assume that each machine is connected to a sensor that records information about failures and scheduled maintenance. At the same time the sensor is able to send messages to the service crew unit in case of failure or maintenance due. Ideally each machine (sensor) is connected to a central warehouse unit that is connected to an ABS that is capable to analyze the real-time data (for example to predict failures, adjust predictive maintenance, better forecasting, etc.).

This assumption is applied to the statechart and sequence messaging diagram of the manufacturing facility. In this case when a failure occurs in a machine, it will send a service request to the control unit. An updated statechart in figure 5-37 shows this transition. Figure 5-38 shows how this transition is programmed using a Java, an action is taken when a failure happens.

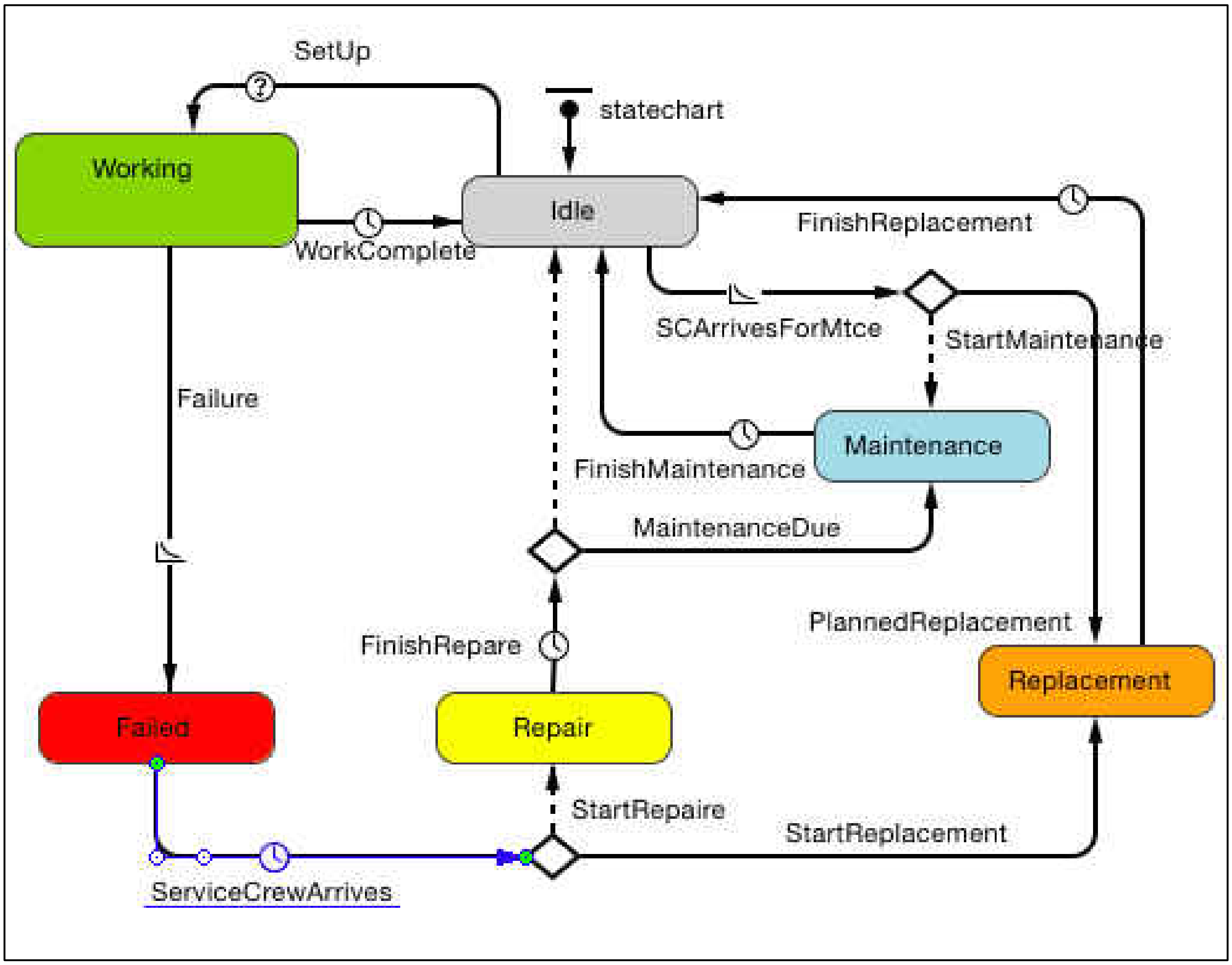


Figure 5-39: AnyLogic Messaging Transitions

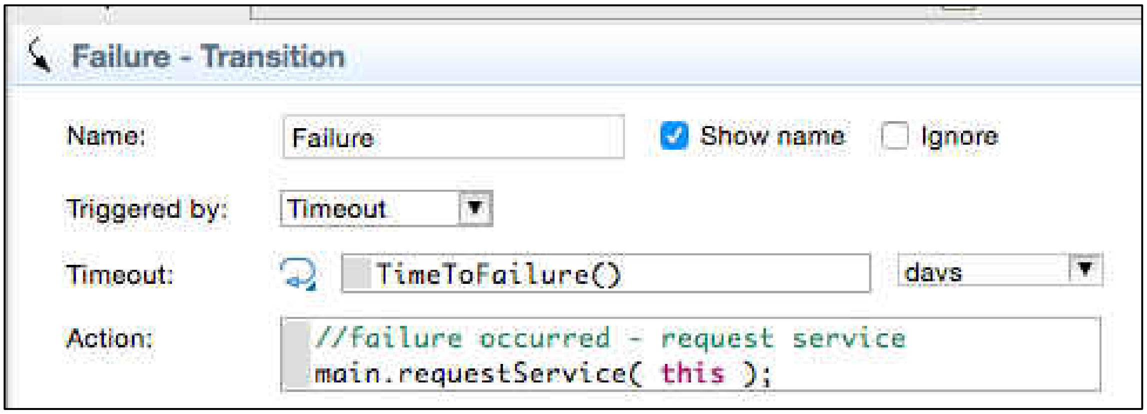


Figure 5-40: Failure Transition

The machine is connected wirelessly to a control unit where a request is placed in a queue and a decision is made to request the service crew. The control unit line up the request in a queue based on the policy of first come first serve. Figure 5-39 shows how the service request is coded. Actually, this is an example of the messaging and communication between agents; machine send a request to the central unit, central unit place this request in a queue, and at the same time send a message to the service crew asking for a team to response to the request.

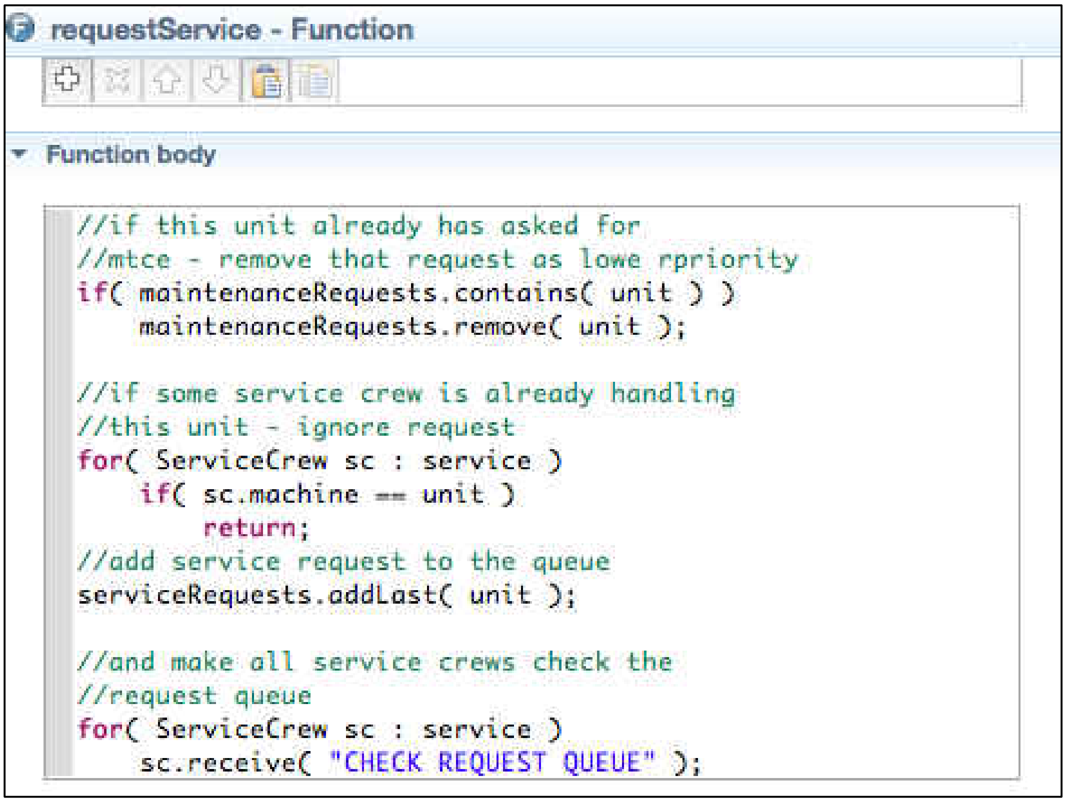


Figure 5-41: Service Request Queue

Depends on the state of the service crew an action is taken. Different policies can be programmed in ABM responding to different messages. Consequently, the service crew can go immediately to the request location if a team was available (idle), or can work on the request upon completing a current request/task. Once a service crew agent completed a request, a message is sent to the central unit informing about the new state. Figure 5-40 shows the statechart of the service crew agent that reflects the messaging transitions.

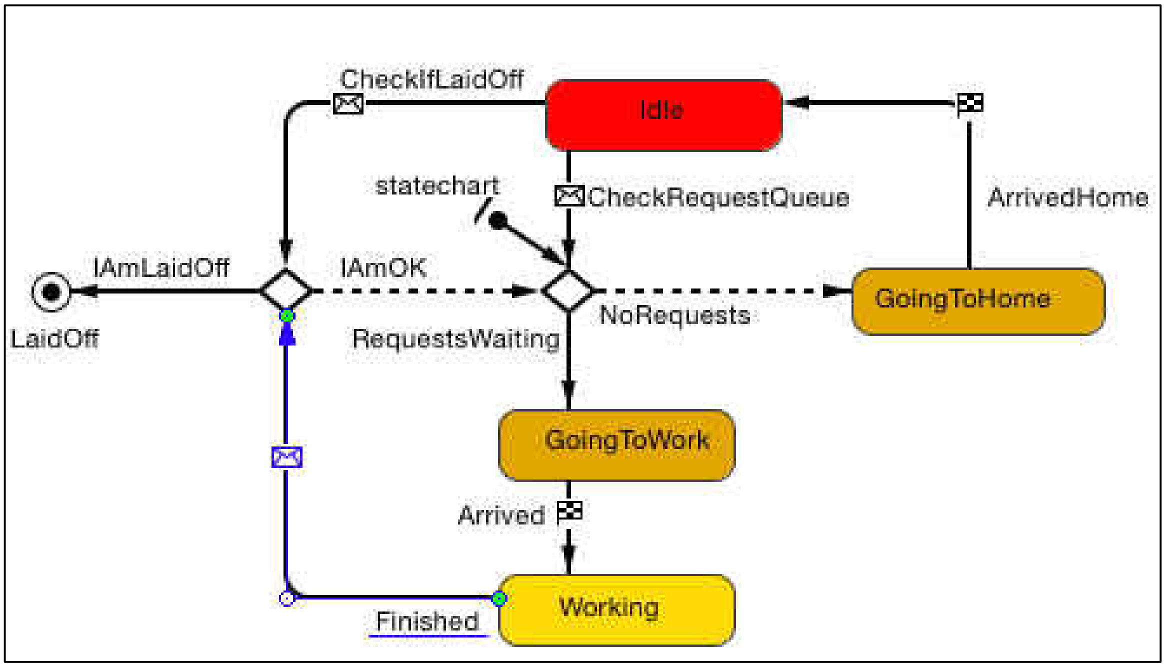


Figure 5-42: Service Crew Agent with Messaging Transitions

In fact, IoT is a crucial element in SMS. Therefore, embedding IoT reference model will positively advance the application of SMS. Like many approaches, the purpose of IoT reference model is to establish a baseline and a common language to standardize the modeling and system architecture. The reference model should guide the design of any future research or application work related to IoT. The IoT reference model consists of number of sub-models. Figure 5-41 illustrates these sub-models and their interactions.

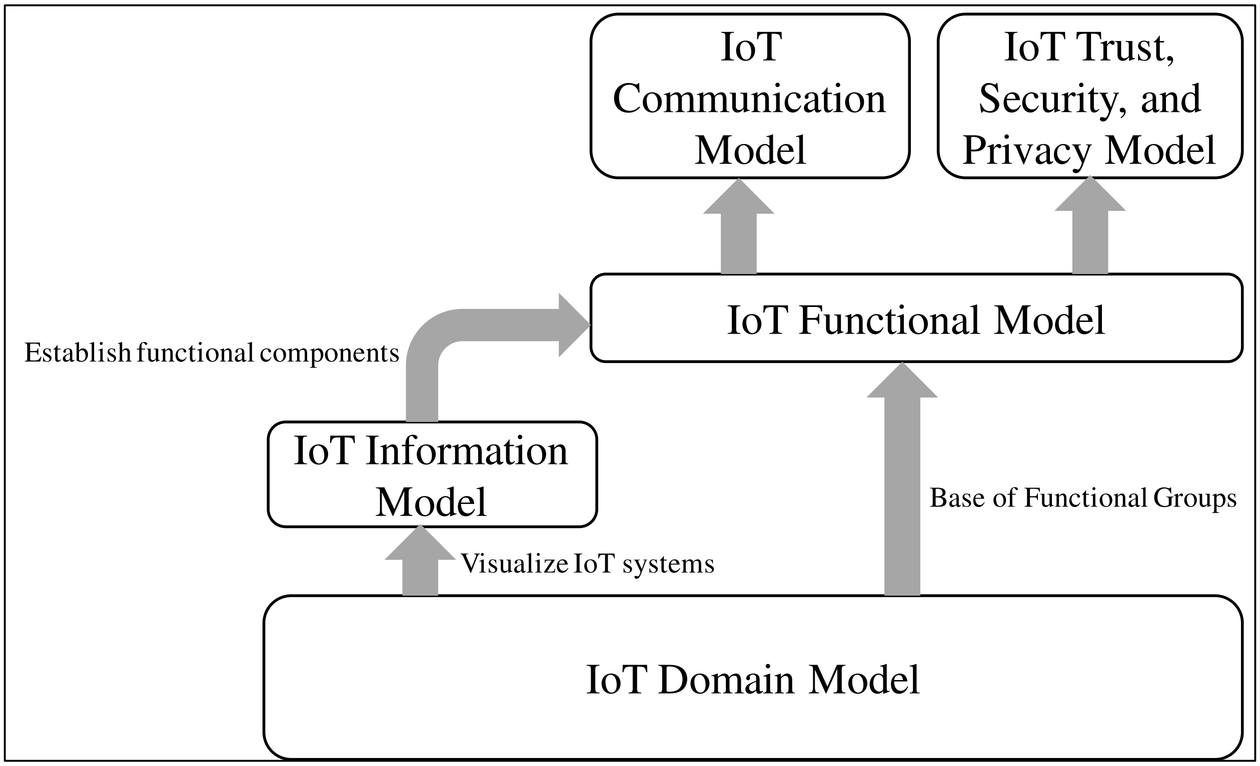


Figure 5-43: Interaction of all sub-models in the IoT reference model adopted from (Bauer, Bui et al. 2013)

The foundation of the reference model is called IoT domain model. Concepts are identified in this model including devices, services, and virtual entities as well as outlining the relations between them. The structure of the system in an abstraction level is defined in the IoT information model including for example relations, attributes, and parameters. Moreover, it models the flow of the information that is related to the concepts in the domain level such as how it is collected, stored, and processed.

The domain and the information models feed the functional model where functional groups are created to form policies that control activities and interactions between concepts. Hence, functional group is responsible to develop policies and procedures that define how the system is expected to behave.

The communication model establishes the protocol of the connection and communication between concepts. One of the main features of IoT systems is its ability to allow communication of concepts in heterogeneous environment. Furthermore, the functional model is also connected to trust, security, and privacy model to enhance the functionalities of the system. As these aspects are major concerns for many systems.

The Domain Level

Since this level is the foundation of the IoT-A; more details and description is provided based on the study of De Loof, SAP et al. (2013). While designing the domain level in IoT-A particular technologies or concepts is not named. Yet the attributes, specifications, and functionality is mentioned solely. An abstraction level of the behavior is considered in the domain level as shown in figure 5-42.

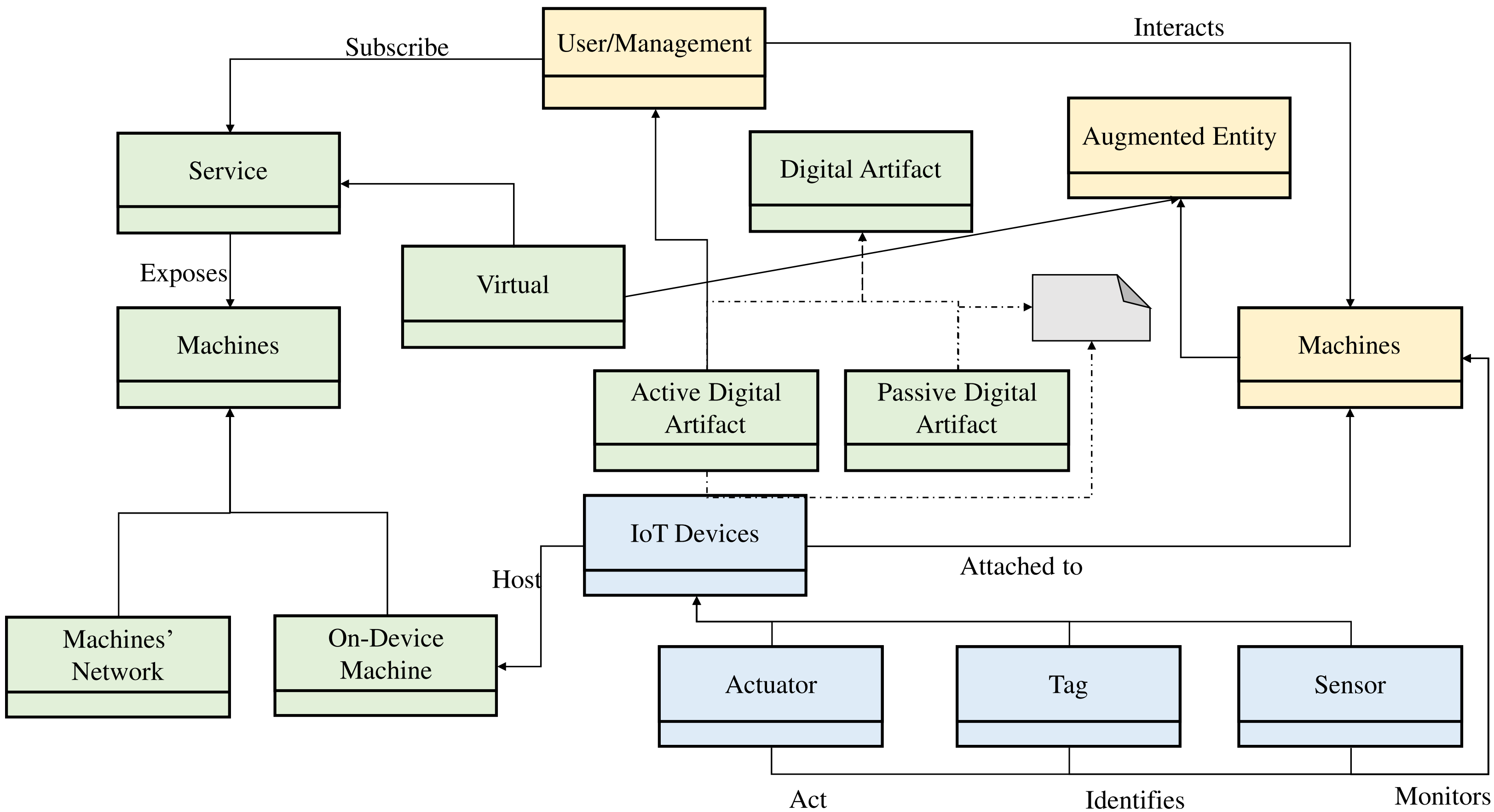


Figure 5-44: An Illustration of the IoT –A Domain Level (adopted from De Loof, SAP et al. (2013)

The domain includes the relationships between physical and virtual entities. In IoT calls a service that either provide an information or action is taken based that information. Physical entity is an objet in a physical environment that a user is interested in. In terms of collecting information or data about it or move it from a place to another. The object can be in any form such as human, animal, machine, etc.

As the objective is to collect, share, transfer information via internet; physical entities are presented in a form of virtual entities. This representation can take the form of 3D models, avatars, objects, and agents.

Therefore, in the IoT reference model the concept of an augmented entity is introduced to present and point the relation between each physical entity and its virtual reflection (for example the RFID tag and reader). The augmented entity is the "thing" in the IoT. It is important to mention that there are three types of devices that are considered in IoT.

Sensor has the ability to provide, share, collect, or transfer date or information about the physical entity in the physical environment. Sensors can be attached to a device, embedded into it, or otherwise located somewhere in the environment. Tags are attached to the physical entity get an accurate identification. The process of identifying the entity is called reading and done by a sensor device. The third one is actuator that has the ability to change the state of a physical entity (e.g. activate, deactivate, rotate, move, transfer, turn on or off). However, features of these devices can be combined in one device depends on the application and operational processes.

Resources defined as the software that is responsible to provide or share data or otherwise have the ability to control the actuators. The distinction here is between the on-device resources and network resources. The former one is embedded in a device so that each device can act autonomously but the second one controls and governs the whole network including its physical entities. Resources can link physical and virtual entities in a resource to control the whole system.

5.5 Towards SMS

Manufacturers tend to implement IoT to store full machining history in order preventing costly failures as well as predict maintenance times. Therefore, this section illustrates the adoption of IoT in the manufacturing facility specifically for the case study and how to turn the current facility smart by its definition. To become smart manufacturer, the company needs to introduce and employ intelligent systems. This includes installing processors, sensors, or transmitters in all machines and parts. Nevertheless, developing sophisticated software algorithms that ensure accurate store, process, and exchange data between machines and hence communicate within its environment. Generally, the proposed informational flow is depicted in figure 5-45.

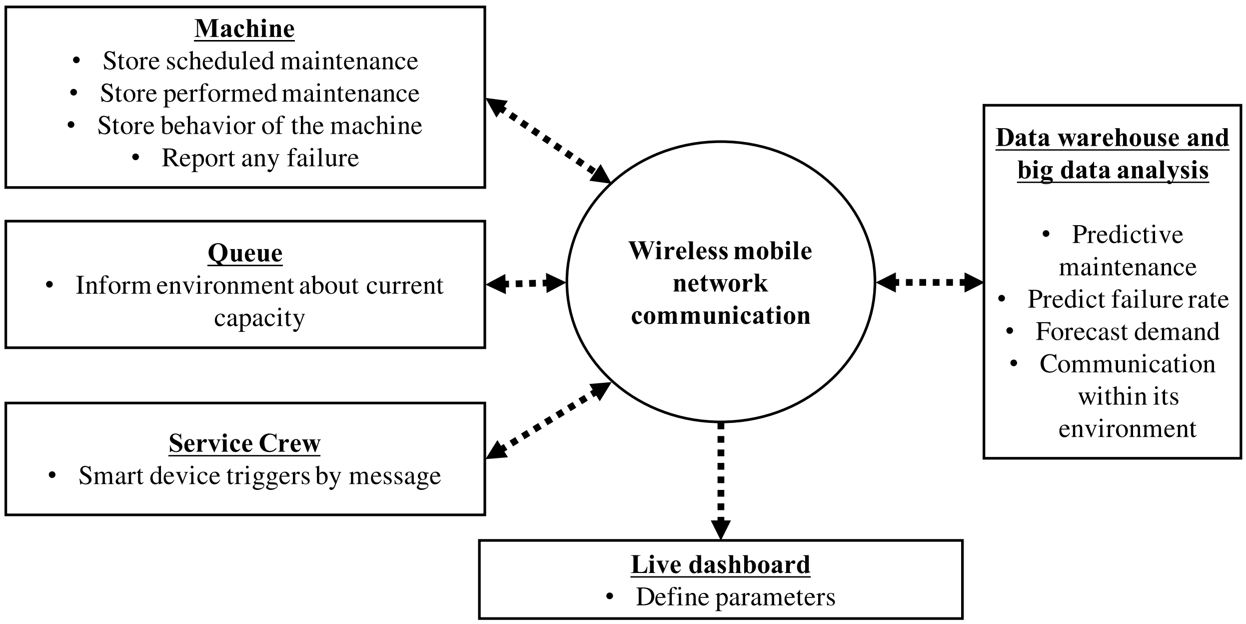


Figure 5-45: Proposed Flow of Information

In the case study three main resource are interacting to perform the job efficiently: machine, queue, and service crew. Data and information are exchanged over a wireless network. Devices are embedded to machines and queues, and service crew is provided with smart devices to share and exchange information. Sophisticated software algorithms analyze the manufacturing big data in the data warehouse. The smart transformation is based on IoT architecture reference model (De Loof, SAP et al. 2013). The IoT domain model is illustrated in figure 5-46.

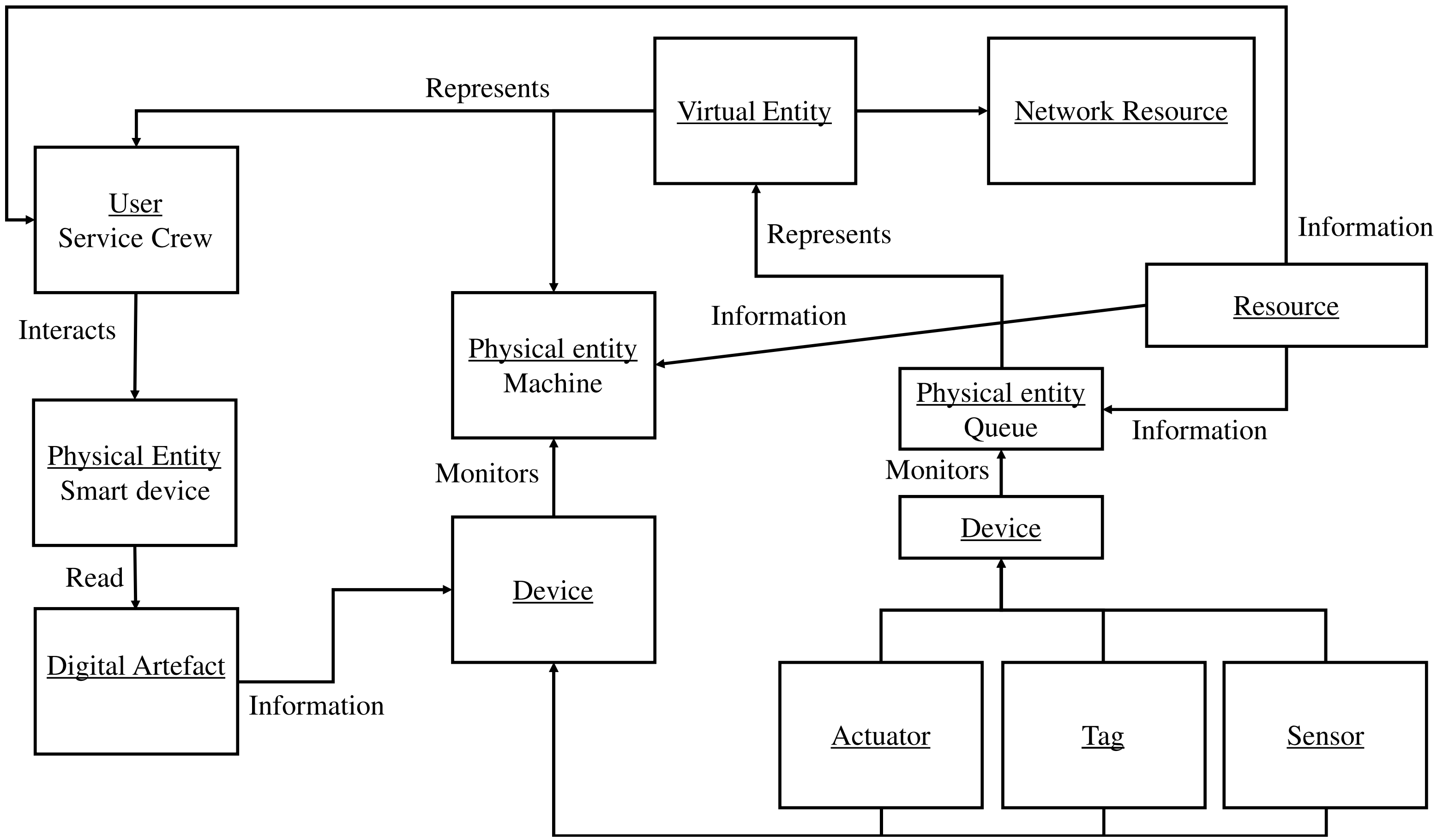


Figure 5-46: Representation of the IoT Domain Mode

1

The proposed representation of the IoT domain model for the case study includes different elements. Starting with the physical entities that can take the form of any physical object in the environment. Various representations of these entities are available including but not limited to 3D models, avatars, database, and objects. In the simulation model of this research, objects are considered to mimic the systems. Then we have the devices that are the connection between the physical world and the virtual ones. The concern of the domain model is to concentrate on the capabilities to provide observations. Therefore, the capabilities include the ability of the device to communicate, store, and store information. Capabilities depend on the system requirements in terms of exchanging data and communicational messages between resources. The selection of these devices is indirectly affecting other sub-models in the IoT architecture reference model. It will define how the relation takes a place from a device to another as well as the security and privacy side.

Resources are main element in the model in this case it is referred to the software that handles all complex big data analysis and hence share the valuable information with the environment through communicational messaging. Resources can be installed in a device and hence called on device resources.

From this sub-model the modeler moves to the information model where all required information about entities and their relationships are identified. Figure 5-74 shows how this information are captured through the initial definition of each machine along with it parameter.

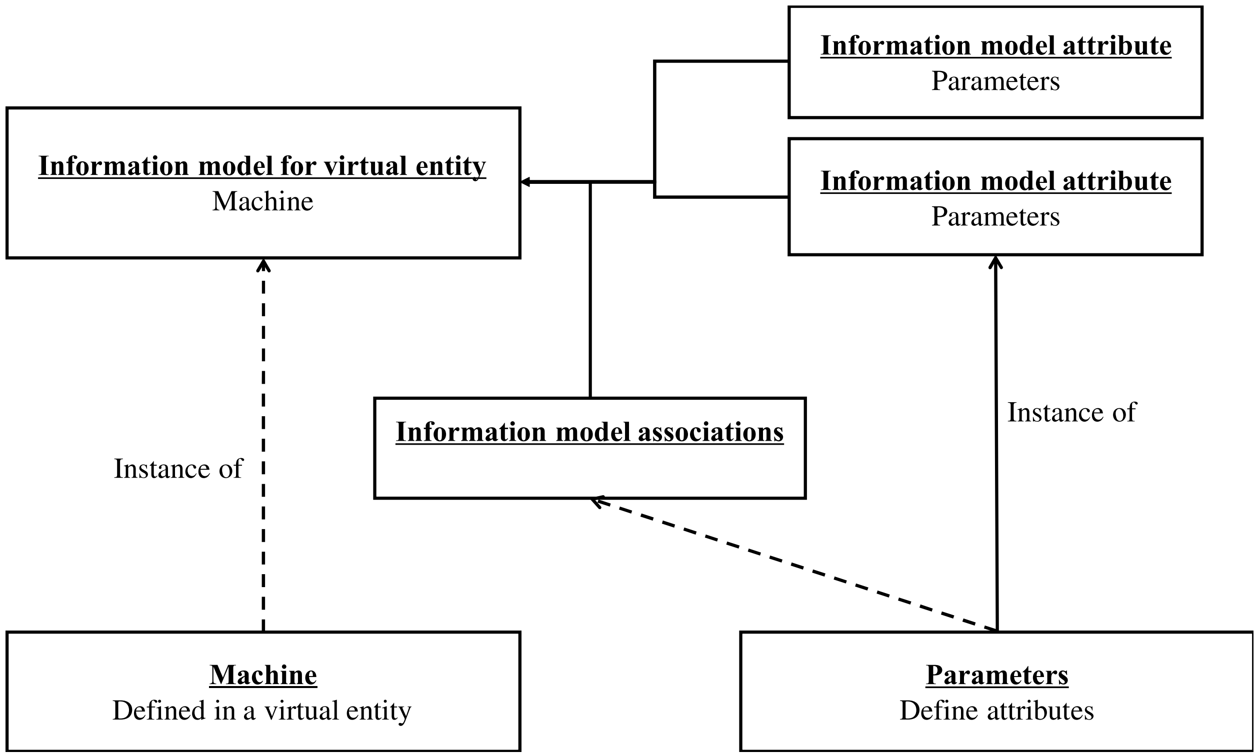


Figure 5-47: IoT information model

The functional model is the next stage after the informational model is completed. The main purpose is to understand the relationship between different entities. Moreover, breakdown complicated and complex systems into controllable functions. Rules are identified in this sub-model as well as policies of how entities interact and communicate. For example, rules like FIFO in the queue can be advanced to different prioritized rules. These polices are defined in this stage.

The mentioned sub-models are foundation for the IoT communicational model. Within the manufacturing facility; machines, queues, and service crew are the defined entities that will be connected and communicate to share and exchange information. Different messaging and communicating protocol is required to in the facility and has to be defined.

5.6 Conclusion

Based on the current performance of the production line, the manufacturing facility is losing potential customers. This is due to the underperformance of the machines that comes from the frequent and sudden failures. Table 5-21 shows the utilizations at the end of the simulation run. According to the policy of the facility machines should perform between 70%-80%. Only machine 2 is working as per the policy. Rest of the machines are underperforming due to the high failure rate.

Table 5-19: Machines' Utilizations

Machine	Utilization
Machine 1	60.44%
Machine 2	80.74%
Machine 3	50.37%
Machine 4	55.85%
Machine 5	58.14%
Machine 6	59.67%
Machine 7	61.95%

Based on the definition of SMS, a data driven solution has to be applied to prevent these failures. The use of real-time data and technology offer the right information to predict events such as failures in machines (McKewen 2015).

In SMS sensors are attached to each machine, readings are captured and analyzed to prevent future failures. These analyses enable manufacturing facilities to establish a trouble shooting guide. The importance of this guide relies on the required time it takes for the service team to identify the root cause of the problem/failure as well as prevent future failures. An example has been provided to illustrate the benefit of messaging in ABM.

The hybrid simulation model was verified using different methods. According to Sargent (2013). These methods are as follow:

Animation: although there was no animated design. Yet queue numbers or flow of material from machine to another is depicted. Moreover, charts were provided and it reflects that state of each machine.

Degenerate tests: this is clearly shown while number of queues are declining when the machines are active and in a working state. While the opposite happens when it is in failure or maintenance state.

Event Validity: utilization rates were compared to the actual ones and the facility confirm that they get the same rate.

Face Validity: AnyLogic and Java expert was asked to validate the model. The result was positive after few code changes. Also, a manufacturing engineer was asked to validate the behavior of the system and it was positive as well.

Operational Graphics: throughput rate and other parameters in the system ere reflected on the model.

Parameter Variability (sensitivity analysis): different inputs were considered and same data trend were appearing.

CHAPTER 6 SUMMARY

6.1 Conclusion

The focus of this study is to advance the research on SMSs. McKewen (2015) summarizes the definition of SMS by stating that it is a combination of real-time data and technology. It offers the right information to the right people and machines at the right time with the needed format. The system is smart because it offers a real-time data for planning and managing manufacturing and the whole supply chain. This also allows different devices to share messaging and communicate with each other independently.

The excessive cost of establishing an information technology infrastructure today makes it infeasible to embrace SMS with its cohesive definition. Consequently, this makes modeling and simulation primary area to augment the design of SMS.

In fact, several motives are behind this study. First, the dynamic changes in the market force manufacturers to meet customers' expectations in terms of higher quality, lower prices, and minimal lead-time. Second, emergence of the technological capabilities today opens a new era of SMSs to meet these expectations. Moreover, the difficult budgetary and trade climate that the nation is facing today needs a prompt research response to aid the most valuable economic sector (Newsroom 2016) (States 2011). Finally, a report was submitted to the president of United States to accelerate the U.S. advance manufacturing; that makes it one of the technological priority in the nation (States 2014).

Difficulties and challenges facing top management in their decisions towards SMS establishment are recognized. One of those decisions is the configuration of the system that will result in better machines' utilizations and shorter lead time. The configuration includes the required machines and their quantities. Initially, the direction was finding ways to assess top management to decide from vast alternatives the type and number of machines required to meet customers' expectations.

Then, questions have been formed including: how SMS can be analyzed? How to model SMS in terms of messaging and communication utilizing today's advanced capabilities in software engineering? What are the suitable components of a framework that will lead to optimize the configuration of SMS? According to Samvedi, Jain et al. (2012) failing to select the suitable configuration to perform the job will negatively affect the company's productivity, flexibility, and responsiveness. It is important to use the reference models available.

Therefore, the objective is to develop a framework to generate the configuration. The framework serves as a guide to determine the required machines and their quantities. A hybrid simulation model is used to enhance the design phase and hence, optimize the system's configuration. Accomplishing this framework is the contribution to the body of knowledge.

In order to investigate the mentioned problem, a research methodology has been created. It starts by the literature review, literature gap analysis, framework development, preliminary simulation framework, case study refine framework, and finally conclusion and future studies.

The previous research work in the literature, cover multiple areas including: 1) SMS to understand the current stage of the research. 2) Design FMSs: this is main feature in the SMSs. It covers techniques used to model, evaluate, and configure FMSs. 3) Agent based-models in manufacturing: agent technology has become one of the most efficient technologies in designing manufacturing systems. 4) Agent based-simulation models: researchers attempt to use new technologies and method to design manufacturing facilities. ABM is one of those tools. 5) Multi criteria decision making: different tools are tested to configure manufacturing systems.

The literature denotes that in machine tool selection, queuing and AHP models are the most utilized tools to determine the configuration of the systems. While optimization models, particularly GA are used in FMS to solve the problem of machine loading and scheduling. Also, agents are used in solving the scheduling problem and the control of the job-shop.

Based on the literature analysis, a conclusion has been drawn about generating a SMS configuration. Messaging and communication between devices are part of the main features of the system. These features are ultimately modeled via ABM. However, to ensure the reflection of the customers' requirements a comprehensive framework is developed.

6.2 Summary of the Framework

Upon reviewing the literature, it appears that there is a lack in the research arena of integrated dynamic models that can assess and evaluate systems based on the number of specified factors that will aid decision makers to determine the SMS configuration. Apparently, innovative processes and products have to be introduced to close the gap between consumers' expectations and producers' outcomes. Hence, the adoption of the unconventional manufacturing system is crucial.

Therefore, an integrated framework has been proposed to resolve the SMS configuration problem. To implement it, expert manufacturing engineers have to contribute to the work along with needed data to achieve the desired outcome. This section summarizes the framework (Figure 6-1).

The first phase results in the types of machines and the other three phases gives the required number of machines. Initially, system components are identified through the use of expert machine selection matrix. Different inputs are combined and merged to identify the required machines to perform the job. Subject matter experts provide the detailed information about the products to fulfill the matrix. Parts to be produced are given by the management where the products' details such as: parts' components and operational requirements are given by the subject experts (manufacturing engineers). The outcome here is the type of machines. The second tool is the machine parameter matrix. Experts selects the required parameters that will affect the system and then provide limits (minimum and maximum values) for each parameter.

More details about the machining process is also given to understand the sequence of the operations. This is an essential information to build the DES model. BPMN is used to reflect the process plan of each produced part. Since FMS is part form the SMS, it could happen that each product has its own sequence processing. Therefore, capturing such information is important to build the model efficiently.

Then, system behavioral analysis is considered to understand the interaction between the different components of the system. This phase is crucial to capture the behavior of each the agent and the interaction of the agents with its environment. Two main tools are used based on AUML. The first is the message sequence diagram: a graphical representation to the message sequencing between agents or between agents and the system. In the case of this research, agents interact with the environment. Particularly, each machine communicates with its own queue. Each time and event happens, agents in this case machines are either communicating with their queues or it is the opposite. This is the behavior of the hybrid model (agents and discrete model). Now, it is the time to determine the behavior of each agent using statecharts that is also based on AUML.

Finally, building the hybrid simulation model. The model is build using “AnyLogic”; a simulation software that can handles multiple simulation types in one model. The DES is built initially, and then agents are developed. Between the three manufacturing performance measures: cost, quality, and utilization. Machine utilizations are considered to be the focus of the work.

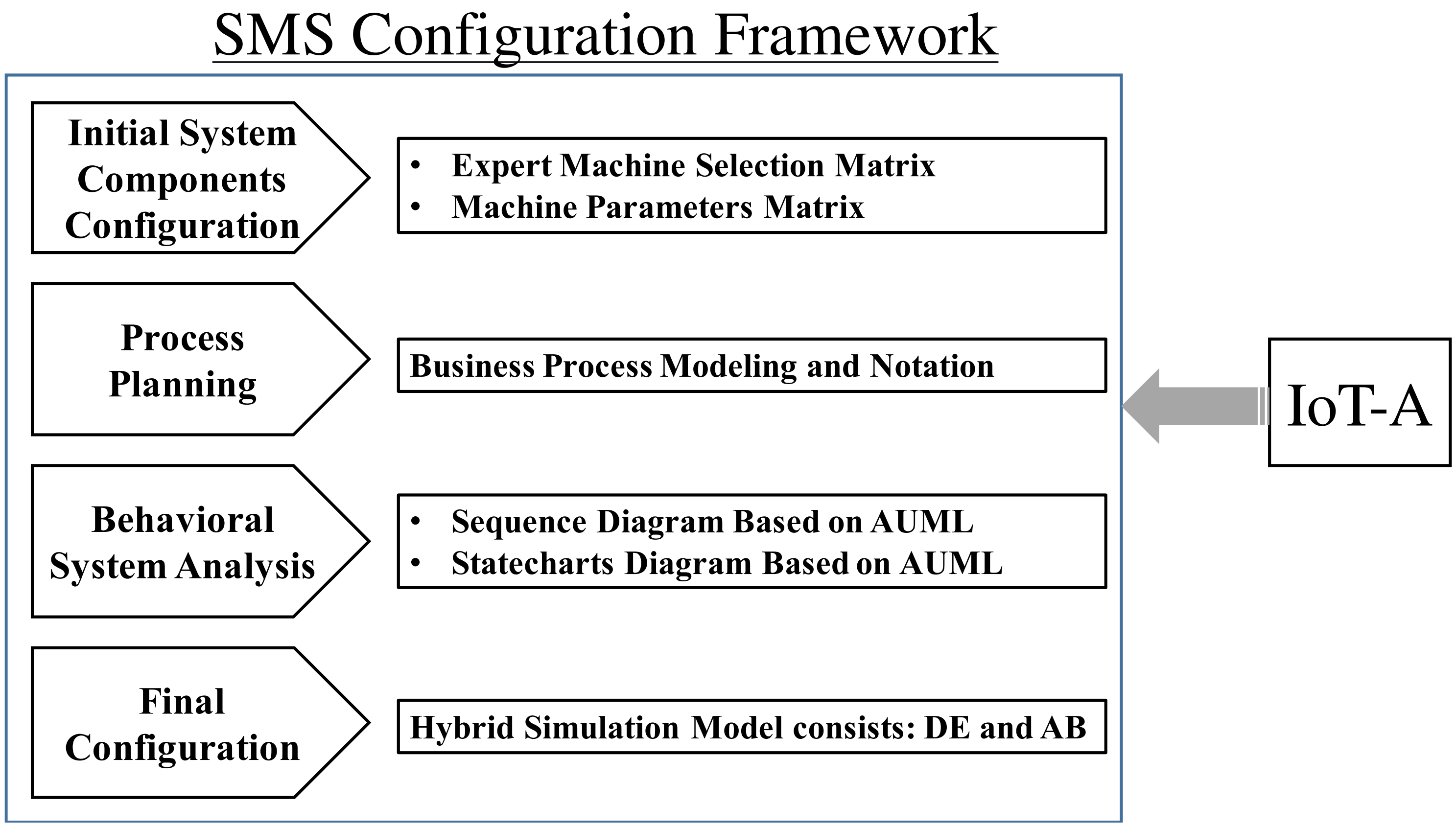


Figure 6-1: Framework to generate SMS Configuration

Upon the framework development, an actual manufacturing facility is used to examine its effectiveness. Also most importantly illustrates the implementation of the hybrid simulation model. A manufacturing facility in north America has been chosen to test the framework. the facility specialized in producing aluminum hydraulic pumps. Pumps are divided into three sections: front, body, and back plates. The case study is built based on the back plate.

Expert manufacturer engineers are interviewed to contribute in different phases of the framework. First the expert machine matrix was filled to find the required machines to perform the jobs. Then, based on the market demand, they identify the expected throughput rate that will satisfies customers. From there, machine parameter matrix is filled.

Then, the operational processes are captured to mimic the real system via BPMN. After that behavioral analysis was designed to know how the internal system components are interacting. Message sequence diagram as well as statecharts are developed. This is an essential foundation for modelers to build the simulation model. Different assumptions are taking into consideration while building the hybrid model.

The objective is calculating the current machines' utilization rate. Based on the company's policy their objective is to reach utilization rates that are equal to 70%-85%. The hybrid simulation model was built and verified. Different verification methods were used including: animation, degenerate tests, event validity, face validity, operational graphics, and parameter variability.

In fact, the manufacturing facility is underperforming due to the fact that the failure rates of the machines are very high. As result, the utilizations rates are very low based on their expectation.

6.3 Contribution to the Body of Knowledge

Manufacturing system configuration has been a wide area of research. Many researchers contributed to this area. The contribution is either by proposing an analytical model or a dynamic simulation model. However, this study contributed to the body of knowledge by proposing a framework to generate a SMS configuration. The substantial phase in the framework is modeling the messages between resources and show how they can communicate with each other.

The composition of the framework consists of qualitative and dynamic methods. It aids in the planning phase or evaluate an existing one. The framework, guides manufacturing experts to choose the right machines' types in a systematic way. A hybrid simulation model is built to determine the number of resources needed in the system. DES has been used to evaluate manufacturing systems. Yet agents served as a better way to mimic machines' behaviors. Resources are modeled autonomously and then connected to the system. Reference models of the IoT can support the developments of SMS.

6.4 Limitation and Future Research

This study filled a research gap with a framework that generates a SMS configuration using a hybrid simulation model. The scope of the research covers the interaction (messaging and communication) between machines (agents) and the system. While the objective is to determine the optimal configuration. The system performance measures are the machines' utilization rates and throughput of the system. To augment the research in this arena multiple future research work are proposed. Hence, different aspects are considered to amplify its applicability. The limitation of the current study as well as the proposed future research directions are outlined in this section.

The verification of the framework relies on an actual manufacturing facility. The facility has been chosen because it shares some of the attributes of SMS (such as fulfilling customized orders and satisfying medium volume and a high variety, flexible, agile, efficient, responsive etc.). Yet due to the lack of smart technological aspect in the facility, another case study with more advanced facility can demonstrate the advantage of ABM for SMS. Indeed, this could assist in determining features required in technological devices needed in each facility.

The machine selection matrix in the study neglects the fact that sensors have to be installed to a current machines and assumed that it is built-in the new ones. This is a major obstacle in the protocol of messaging. In order to evaluate an existing facility there should be a clear procedure of what type of technology that will be attached to the machines to enable the messaging that affects the state transitions.

Furthermore, the framework assumes the capabilities of a physical technology that can obtain real-data, analyze it, and share it. A better understanding about the existing capability of IoT and its potentials leads to a better modeling. Nevertheless, ABM can aid in the design phase of these technologies and support in determining the requirements for its features. Integrating the research of advancing the technology with ABM is a potential research area in this arena. In addition, ABM can be embedded in the IoT reference model; specifically, in the communication model. Merging the right information with proper functionalities can establish an ABM that is capable to simulate the system based on messaging and communication between concepts and events affecting the performance of the system –figure 6.2.

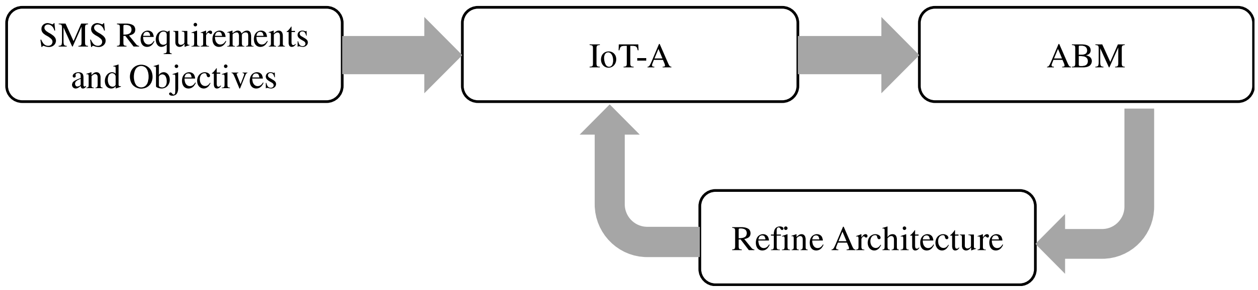


Figure 6-2: Potential Research Framework Integrating ABM

Initially, the framework attempt to use quality function deployment to determine the system's components. Instead, expert machine selection matrix has been developed. Quality function deployment has the potential to determine the specification of the technological devices needed in SMS.

A future research work could combine different perspectives coming from software engineering, manufacturing engineering, and computer science. Starting with conveying the experience and expertise of manufacturing engineers using different aspects knowledge acquisition to aid software engineers in designing a robust artificial intelligent system that will be integrated with an ABS model. Also, while designing the messaging and communication protocols between agents, lean manufacturing should be embedded in the design to optimize machines' utilizations. Kanban system can be considered during the transition states of the machines. For example, in the case study a machine can send an immediate message to preceding machines to stop producing in event of failure.

Absence of an integrated data warehouse that install the behavior of the machines within the facility and across the enterprise level, restricts the efficiency of the study in determine the final configuration. A future work should consider the integration of structuring data warehouse with the manufacturing facility. Developing a complete ABM for the entire enterprise will illustrate the picture of SMS. A model that shows the flow of messages and interaction between the different entities. An agent the serve as date warehouse, multiple agents that serve as different resources such machines, buffering areas, or material handling system.

Optimizing the buffering area through ABM is another potential for a future research work as well as optimize the use of AS/RS. Minimizing the buffering area leads to minimize the WIP and hence, lower operational cost. The manufacturing facility in the case study has almost no limitation in the queue lines or buffering areas between machines. This is because its never been a threat to the facility. Each machine has enough room but it is not the case in other facilities. However, a defined messaging protocol should be available to design this area.

Furthermore, material handling system and automated storage /retrieval systems (AS/RS) is part of the manufacturing facility. According to this research movement from and to MHS and AS/RS is neglected. The scope of the research can be extended to add these entities to the system. It will reflect more realistic cost figures and lead-time estimation. Raw material is considered available all times. SMS tend to optimize the concept of Just-In-Time (JIT). Therefore, an integrated informational technology platform with suppliers will lead to JIT and hence, reduce cost associated with inventories. All the mentioned elements should be combined in an integrated messaging protocol; that shows the consequences of each trigger. This will absolutely accelerate the creation of SMS.

Three main performance measures are considered when evaluating a performance of manufacturing system: cost, quality, and lead-time. This research uses the throughput rate that allows to find the lead-time. However, extending the scope by integrating different information from the supply chain will give a better lead-time estimate (i.e. delivery and shipment). In this case the manufacturing facility could serve as a single agent to deal and interact with its suppliers and customers where each one is an autonomous agent. Consequently, design ABM across the supply chain based on organizational levels.

With the emergence of IoT, organizations and companies will be able to trace all products through for example through RFID. The potential cost reduction is a potential research area as well as the impact of connecting sensors to equipment on the overall operating cost.

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