DEVELOPMENT OF AN AGENT BASED MODELLING AND SIMULATION TOOL FOR ANTICIPATORY CHANGE PLANNING FOR CELLULAR TRANSPORT SYSTEMS

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Abstract

The dissertation focuses on the specific intralogistics system called Cellular Transport System (CTS) to develop an integrated simulation tool in order to systematically anticipate change drivers and select optimization measures for CTS.

To achieve this, firstly, CTS and it constituents are defined and introduced.

Secondly, the Anticipatory Change Planning (ACP) as an applicable systematic experimentation approach is developed. That is especially required for CTS because of its flexibility and adaptability. Thus, each significant change driver which has influence on the CTS can be tested, and the conditions of the warehouse, with or without measured effects can be assessed under favour of the holistic ACP framework.

Lastly, the CTS is simulated based on the agent-based simulation methodology within the scope of this research. Based on several usual and extreme case studies the behaviour of CTS is analyzed and effective adaptation measures are tested and evaluated.

The dissertation proves the applicability and usefulness of agent-based simulation for the anticipatory change planning of Cellular Transport Systems.

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I dedicate my PhD study to my beloved parents, Yasar and Perihan Karakaya, my brothers Tuncay and Gencay, and my sisters Emine, Duygu, Gizem who pray for me and whose lovely support, trust in me and endless patience have made possible the completion of this dissertation.

Lastly, I thank Allah for giving me strength, health and the ability to complete this work and for endowing me with patience while working on this study.

Contents

Abbreviation

ABC	Activity Based Costing
ABM	Agent Based Modelling
ABS	Agent Based Simulation
ABSP	Agent-Based Simulation Packages
ACP	Anticipatory Change Planning
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AS/RS	Automated Storage and Retrieval System
AVS/RS	Autonomous Vehicle Storage and Retrieval System
CPS	Change Planning Simulation
CTS	Cellular Transport System
DCs	Distribution Centers
ERM	Experimental Research Methodology
FCFS	First Come First Serve
FLM	Fuzzy Logic Method
MIS	Manufacturing Information System
MSM	Multi-Shuttle Move
PCM	Process Chain Model
PLC	Programmable Logic Controller
PRS	Pure Random Storage
RFID	Radio Frequency Identification Device
ROP	Re-order Point
SSC	Statistical Control Chart
SSP	Six Steps Planning
TA	Traditional Accounting
TQM	Total Quality Management
WAM	Weighted Average Method

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Chapter 1

Introduction

1.1 Initial Statement

Recent developments in the field of intralogistics have resulted in fully automated warehouses. Thus, many industries automate their warehouse facilities in order to obtain high throughput levels and improve accuracy in the most efficient way. However, intralogistics systems currently lack sufficient flexibility, due to bulk conveyor systems and huge sorters which are unable to react fast enough when needed. Also, their equipment and installation costs are very high. Hence, the automated system causes operating costs to increase. Currently, the most well-known automated systems are the Automated Storage and Retrieval Systems (AS/RS) and the Autonomous Vehicle Storage and Retrieval Systems (AVR/RS). Besides, although warehouses are the essential contact point between manufacturer-customer and supplier-manufacturer, they add no value to the product itself. Because of this trade off, it would be expedient to reduce operation costs. With this objective in mind, the Cellular Transport System (CTS) was developed as an alternative intralogistics system by the Fraunhofer Institute for Material Flow and Logistics.

The CTS is based on autonomous transportation entities (ten Hompel, et al., 2011) which are able to pick, pack and ship movable storage shelves. An increase in the use of autonomous vehicles can be seen in any kind of field. The research on robotics and on multi-agent systems was combined in order to provide a new type of autonomous vehicle for intralogistics applications which is called a Multi-Shuttle Move (MSM). However, current autonomous vehicle applications such as AVS/RS are relatively inflexible (Ekren, et al., 2010). In other words, autonomous vehicles are neither self-controlled nor fully autonomous. For instance, they are not able to communicate with each other in order to find the shortest way, nor negotiate to fulfil the customer requirements in a minimum time. In contrast to previous studies, the proposed MSMs will have the following technical features: 1) they will be autonomously intelligent and self-oriented. 2) They will be able to move, not only on the floor, but also inside the rack storage. 3) They will have the ability to communicate with other vehicles and their surrounding environment. 4) They will have a decentralized architecture with an autonomous and a swarm intelligent system.

Changeability in dynamic markets needs not only flexible warehouse systems with autonomous vehicles, but also anticipatory systems which should facilitate planning for various future scenarios. The purpose of anticipating possible future scenarios by using the aforementioned technique, is to be able to determine the option which best effectuates the set requirements. In order to manage an intralogistics system, companies need to know the effects of their decisions and they need to be aware of which appropriate action to take next. At this point, Anticipatory Change Planning (ACP) allows the system to identify new opportunities, predict market requirements and to make future plans. Hence, when using ACP, Method Engineers should be able to plan faster and better. The compact form of this aimed study is represented visually in the following Figure 1.1.

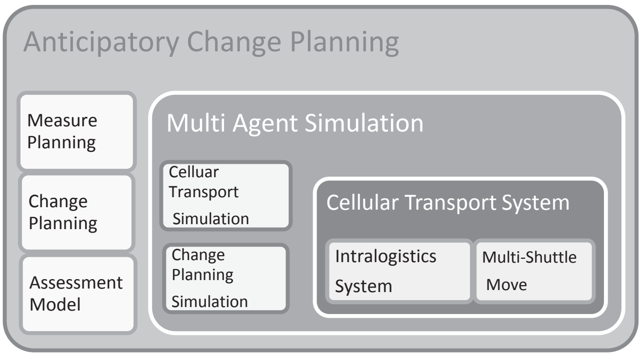


Figure 1.1 Fundamental Structure of the Research Study

1.2 Problem Definition

Until now, some research has been carried out regarding the technical aspects of the CTS e.g. avoidance of collision or writing embedded software into the shuttles' computer systems in order to create autonomously mobile robots. However, this thesis will discuss the examination of the CTS as a whole by focusing on the main operations of warehousing such as receiving, storage, picking and shipping. Even though (Kamagaew, et al., 2011) compared the CTS with conventional conveyor systems, partly to show its flexibility, no research has been carried out yet regarding the efficiency and effectiveness of the CTS.

Furthermore, AS/RS has been successfully used for many years in various applications, making use of both analytical and simulation models (Eldemir, et al., 2003). AVS/RS has also been implemented at numerous facilities in Europe (Ekren, et al., 2011). As a result, setting up new warehouses with current intralogistics systems is very well known. On the other hand, the CTS is a novel intralogistics method. As companies lack both experience and know-how in this field, they are not able to implement CTS in their warehouses

Although, in recent years, Agent-Based Simulation has become more popular in a broad range of areas and disciplines, the simulation model of warehouse systems designed based on agent architecture is limited. Besides this fact, there are no studies available in the literature concerned with CTS simulation due to its novelty. Hereby, the essential question to be examined in this study is how to simulate the structural design of Multi Shuttle Move (MSM) thinking together with conventional warehouse activities.

It is certain that all kinds of businesses have confronted many difficulties in order to reconfigure their organizations economically, and with the least effort because of continuously changing factors on a strategic, tactical or operational level. One reason behind this challenge is the deficiency of knowledge about change types and the drivers of these changes. Even though some methods exist to fill this deficiency i.e. Risk Management, and Disruption Management, there should be a particular planning model that could be defined as a continuous process which supports the assessment of changes, increases the awareness of these changes and improves the management of changes efficiently.

In addition, no research has been found that surveyed a compact framework for the intralogistics system, especially based on autonomous architecture which is capable of applying and anticipating changes, finding appropriate measures in case of necessity after putting changes into practice and evaluating the whole system with the help of what-if scenarios.

1.3 Research Questions

The aim of this Ph.D. thesis is to first develop a simulation model of a complete CTS with a Multi-Shuttle Move System. In addition, the model should comprise a procedure of the simulation structure in order to ensure that it could be beneficial for the practitioners throughout the installation or the construction of the CTS. As a second step, the thesis seeks to anticipate any occurrence, which could be any type of expected and unexpected event, and to proactively find its effect on the intralogistics system. The Anticipatory Change Planning approach, which should be composed of three fundamental parts; change planning, measure setting up, as well as an assessment model will be designed. The key role of this dissertation, in addition to the above mentioned aims, will be to make sure that a better decision is made before, during, and after change implementation, by using a systematic experimentation tool. To achieve the aforementioned aim, this thesis seeks to answer the following questions:

1. How can the CTS thematically be explained and classified in the Intralogistic Systems?

A Cellular Transport System (CTS) is a novel method for material storage and handling. That is why little research has been carried out on the CTS so far. For this reason, a comprehensive overview of the CTS and its specifications will be given. Besides this, the basic characteristic features of existing intralogistics systems will be supplied in an attempt to clarify the differences and similarities of the CTS.

2. How can the CTS be modelled technically and simulated by agent architecture?

In the first place, for technical CTS modelling, not only well-known operations such as shipping, order picking etc., but also original properties like Multi-Shuttle-Move architecture will be designed by means of process chain methodology. Secondly, the agent based modelling approach will be built to simulate systems.

3. How can an ACP framework be modelled and implemented?

To find an adequate answer for this research question, it should be first known which change drivers exist and how their effects on demand and supply could be reflected, and secondly, which measures could be available and if required, how could the optimum measure be chosen methodically.

4. How can the efficiency and performance of the CTS be assessed and which methodologies should be improved?

After ensuring the available change drivers and their impacts on different performance keys, it is necessary to assess the efficiency of CTS statistically after change implementation. Therefore, an assessment model enhanced by providing performance availability analyses and scenario planning methods will be generated.

5. How and by which means can the integrated ACP with CTS be validated?

In order to assure the validation and verification of proposed system, systematic experimentation method in a real case scenarios will be structured and the anticipatory change planning will also be utilized to test different what if scenarios.

1.4 Thesis Structure

The remaining content of the dissertation is organized as follows:

Chapter 2 aims to support essential knowledge and provide a comprehensive literature review of three main parts of study. Firstly background information about intralogistics systems and conventional intralogistics methodologies to introduce the Cellular Transport System (CTS) will be provided. Secondly, the literature and structure of Agent Based Simulation (ABS) are explained to describe the reason behind the selection of ABS as a part of the dissertation. Lastly, the Anticipatory Change Planning (ACP) concept, which contains necessary definitions and a literature review about previous studies, will be represented.

Chapter 3 introduces an essential structure of study for creating an ACP by putting forward three planning steps. First, the Change Planning topic comprises an extensive study about collecting all kinds of change and changeability to build up a basic structure for the simulation. Second, in the Measure Planning section the Process Chain Method, to decide an appropriate measure in case of necessity, and Six Steps Planning, to assure a systematic approach for experimentation, will be introduced. Third, Assessment Model planning aims to evaluate the productivity of intralogistics systems using different methods.

Chapter 4 begins with some analyses for simulation software selection particularly for Agent Based Simulation. It incorporates the construction of the CTS, and involves both modeling analysis with the help of process chain methodology and the simulation model. All warehouse activities such as, order picking, replenishment etc. which should become available in any intralogistics system, is included in the proceeding sections of Chapter 4.

Chapter 5 provides the statistical analyses and assessment charts acquired from both the simulation and analytical model. Firstly, Change Planning Simulation (CPS) is established along with all logic algorithms behind the CPS such as, market conditions, customer behaviors etc. Secondly, the result graphs concerned with flexibility corridors, and two proposed methods to evaluate limits of flexibility corridors, will be explained. Not only pre-determined performance indicators such as, throughput rate, on time delivery etc. but also costing analysis embedded to reflect reality into the simulation will be clarified. Thirdly, the considerable analyses related to performance availability found using three different methods will be demonstrated in detail with a specific example. Lastly, The Systematic Experimentation model, which includes measure analyses, will be proved by using scenario analyses. Also validation and verification of proposed system accuracy will be ensured with five scenarios.

Chapter 6 offers the main findings after completing the present research study and conclusions. The second phase of Chapter 6 provides possible recommendations and future research.

Chapter 2

Theoretical Background

This chapter is aimed to support essential knowledge and provide a comprehensive literature review of three main parts of the study. These are; 1) the intralogistics system concept in which the concept of intralogistics will be examined in depth. After providing background information about the intralogistics system, the existing major intralogistics methodology examples; namely the Automated Storage and Retrieval System (AS/RS), and the Autonomous Vehicle Storage and Retrieval System (AVS/RS) will be explained. Then, the new intralogistics technology called the Cellular Transport System (CTS) will be introduced. 2) The Agent- Based Simulation Concept, which involves general information about simulation and modelling, in particular the literature and structure of Agent Based Simulation (ABS) will be explained to provide a better understanding of why ABS is selected as part of the study. 3) The last heading is related to the introduction of the Anticipatory Change Planning concept, which contains fundamental definitions and a literature review with regard to previous studies.

2.1 Intralogistics System Concept

There is no doubt that in the time of globalization, competition is increasing, whilst borders are getting smaller. This has resulted in a rise in customer demand and more analysis about how it can be dealt with. Companies have proposed some solutions, which are mostly included in the field of supply chain management or logistics management, in order to manage this improvement and to find the best possible cost reductions, especially in the intralogistics processes. Although the intralogistics cost percentage varies from application to application, its cost may explain 10% to 50% of the total manufacturing costs (Heragu, 1997). As a result, due to the fact that intralogistics is a crucial cost driver at a large number of companies, intralogistics is t considered to be at the heart of the operational supply chain and not just an ‘assistant’ to supply chain management.

2.1.1 Definition and Specifications of Intralogistics Systems

Although, in recent years, the term intralogistics has become more commonly used, it has not been defined sufficiently in literature as yet. The term intralogistics is generally used in English literature as a warehousing system, material handling system or material flow system whose definitions will firstly in order to provide a better understanding of the term ‘intralogistics’.

Material flow analysis is a systematic assessment of the flow of materials within a defined space and time (Brunner, et al., 2003). Material handling systems integrate data flows and physical material flows for the handling and storage process.

Material handling is the movement of materials (raw materials, scrap, semi-finished and finished products) to, through, and from the productive process, in warehouses and storage, and in receiving and shipping areas (Frazelle, 1992). The meaning of the materials handling system can be simplified as an integrated system which includes main warehousing activities; namely handling, storing, transporting and controlling of materials.

Warehousing concerns material handling activities, i.e., the receiving of goods, storage, order-picking, accumulation, sorting and shipping that take place within the storage area, receiving and shipping areas (Van den Berg, et al., 1999).

'Intralogistics' can be thought of as a term which replaces the concept of the material flow system or the material handling system. However, it is much more than that. It could be defined as "the part of logistics concerned with warehousing and movement of raw materials and goods within the premises of a factory or company site" (CeMat, 2011). It is necessary here to clarify exactly what 'intralogistics' means by giving Arnold's comprehensive definition; "intralogistics comprises organization, controlling, execution and optimization of the in-house material flow, information flow as well as handling in industry and trade companies as well as public facilities" (Arnold, 2006).

2.1.2 Classification of Intralogistics Systems

Intralogistics systems can be categorized based on particular features. Basically two types are distinguished in terms of warehouse functionality: Distribution Warehouse and Production Warehouse (Rouwenhorst, et al., 2000). In addition to the distribution and the production warehouse, the contract warehouse is also introduced by (Van den Berg, 1999) as a third type of warehouse.

The Distribution Warehouse (Distribution Centre) is a warehouse in which products from different suppliers are collected (and sometimes assembled) for delivery to a number of customers (Van den Berg, 1999). The quantity of different products in a distribution warehouse is most large and the major objective is to obtain the maximum throughput rate within a reasonable time. Therefore, this results in a complex and relatively high-priced warehousing process. In recent years, at DCs, one of the prominent practices is cross docking, in which products are received at the receiving dock and are moved directly to the shipping dock where they are uploaded onto outbound vehicles for distribution (Wang, et al., 2010).

The Production Warehouse is used for the storage of raw materials, semi-finished products and finished products in a production facility (Van den Berg, 1999). Raw materials and finished products may be stored for long periods. This type of warehouse occurs when the procurement batch of incoming parts is much larger than the production batch, or when the production batch exceeds the customer order quantity of finished products. Therefore, the prominent design criterion is the storage capacity (Rouwenhorst, et al., 2000).

The Contract Warehouse is a facility that performs the warehousing operations on behalf of one or more customers (Van den Berg, 1999). Contract warehousing is an outsourcing strategy to obtain warehousing expertise and the services of a third party. The warehousing service provider serves an exclusive user over a long term. Depending on this contract, the user/owner and the third party service provider share the risk of cost (Wang, et al., 2010).

With regard to the level of automation, the intralogistics system is distinguished between manual, automated and automatic intralogistics systems; explained below in depth.

Manuel Intralogistics Systems

Manual systems are characterized by the fact that they require a human being for horizontal and vertical transport of a pallet from a given point in the warehouse to another location. Pallets are moved by a worker using a forklift truck to do the vertical and horizontal transporting (Segerlund, et al., 1996). The manual system is a classic intralogistics model of picker-to-part, which means that the order pickers either walk or drive with their vehicle to the storage locations. For storage/retrieval operations, forklift trucks and a variety of trucks are frequently used in the manual system. Pick-to-light and Pick-to-voice systems could be an example of the manual intralogistics systems.

Automated Intralogistics Systems

The main characteristic of this system is to operate according to the parts-to-picker principle. Hence, the order pickers work and wait at a fixed workstation. Such systems are designed for the warehouses which have high automation and cannot be operated manually in everyday operations. Thus, the forklift truck and driver are replaced by conveyors and cranes. Besides the fact that less manpower is required, the two major advantages of automated intralogistics systems are high speed and the high throughput rate. In spite of this increase in performance and vertical space utilization, these systems resulted in reduced flexibility and high maintenance and installation costs (Segerlund, et al., 1996).Horizontal or vertical carousels, the automated storage/retrieval system (AS/RS) and pallet racking with automated replenishment fall into this intralogistics category.

Automatic Intralogistics Systems

Automation, the third alternative, further increases picking performance by incorporating automatic order pickers such as dispensers or order-picking robots. Automatic order-picking systems perform high speed picking of small or medium-sized non-fragile items of uniform size and shape, e.g., pharmaceuticals. If the order picker of an automated intralogistics system is replaced by a robot, then an automatic intralogistics system is obtained. An A-frame automatic dispenser machine is another automatic intralogistics system without order pickers (Van den Berg, 1999).

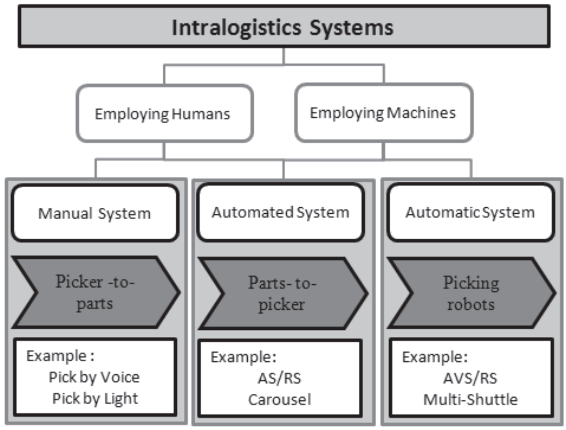


Figure 2-1: Classification of Intralogistics Systems in terms of order-picking methods (based on (De Koster, 2004)).

There is a particular case in the above category shown in Figure 2-1; the intralogistics system with multi-shuttle storage. This intralogistics methodology is involved in manual intralogistics logic, yet some part of the pallet or bin transport is executed by a machine. In shuttle systems, the bins are transported into the depth of each aisle through a shuttle machine. This system is therefore a first, though very small, step into the automatic intralogistics category.

2.1.3 Main Activities of the Intralogistics System

The flow of products through the intralogistics is divided into several distinct phases, or processes. At this point, Van den Berg (1999) subdivides the activities in a warehouse into four categories: receiving, storage, order-picking and shipping. However, De Koster, et al., (2007) state that the main warehouse activities include: receiving, transfer and put away, order picking/selection, accumulation/sortation, cross-docking, and shipping. In order to gain a better understanding about the main activities of the warehouse, the comprehensive explanations for each one are provided below.

The Receiving Process

The receiving process consists of unloading the trucks, recording and verifying the quantity of products and quality control to establish whether or not there is any amount or quality incompatibility. Delivered loads by transport carriers are encountered firstly in the receiving area and then the products are checked and transported, or held in the buffer area awaiting the next process.

The Storage Process

Subsequently, the products are made ready, for instance, by labelling or attaching a barcode for transportation to the storage area. Rouwenhorst et al. (2000) define the storage area by distinguishing it into two parts: the reserve area, where products are stored in the most economical way (bulk storage area) and the forward area, where products are stored for easy retrieval by an order picker. In the forward area, products are stored in smaller amounts in for example, bins, totes or shelves, in order for them to be easily picked, while the reserve area consists of pallets.

The Replenishment Process (Transfer and Put away)

The replenishment process can be defined as the quick transportation of products from the reserve storage to the forward storage. The arriving loads are often delivered on pallets, then the loads are repackaged e.g. full pallets are redistributed to small bins. These products are then carried from the replenishment area to a specific location in the storage zone.

The Order Picking Process

Order picking/selection is the most important activity in most warehouses (De Koster, et al., 2007). Order picking refers to the retrieval process, which means obtaining the correct amounts of the products as requested by the customer. It is executed manually, or is automated or carried out by autonomous vehicles. In the zone picking approach, products are collected in a random way. Therefore, these products are transferred to the sorting process in order to classify orders according to the product type and amount.

Research in the United Kingdom, found out that order-picking is the most costly activity among the main activities of warehouses. More than 60% of all operating costs in a typical warehouse can be attributed to the order-picking process (Drury, 1988).

The Accumulation and Sortation Process

When an order includes multiple product items, these items must be accumulated. While the orders are accumulated in a warehouse, the products arrive to the shipment area in a mixed way, with the products of other orders. Before delivering to the customers, the orders have to be sorted, in other words, the products that belong to the same order have to be put together. Accumulation and sorting may either be performed during or after the order-picking process (Van den Berg, 1999). These two processes are called the accumulation/ sortation process.

The Shipping Process

After sortation based on customer requirements, at the shipping area orders are packed, accumulated on mostly a pallet and ultimately loaded on to transport carriers i.e. trucks, trains.

The Cross-Docking Process

Products which do not require order picking or long stays in the warehouse are transported directly to the shipping area. This process is called the cross-docking process. Figure 2-2 below shows the characteristic functional areas and flows within warehouses.

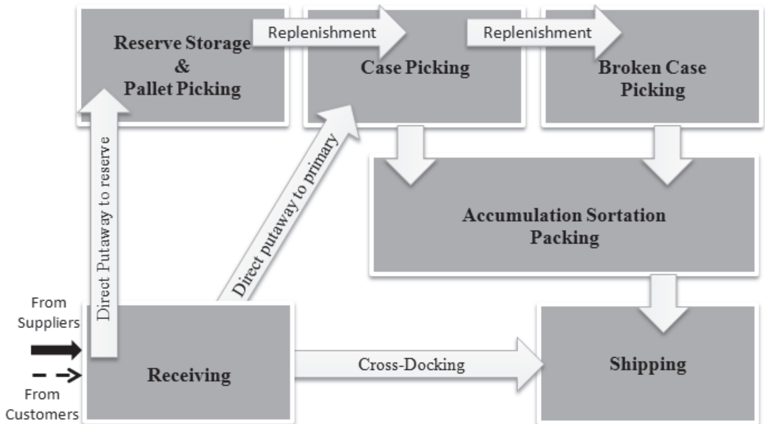


Figure 2-2: Typical warehouse functions and flows (Tompkins, et al., 2010).

2.1.4 Major Intralogistics Systems

2.1.4.1 Automated Storage and Retrieval Systems (AS/RS)

ASRSs have been widely used in the distribution and production environment since their introduction in the 1950s. Between 1994 and 2004, there has been a significant increase in the number of ASRSs used in the distribution environment according to the Automated Storage and Retrieval Systems Production Section of the Material Handling Industry of America in 2005 (Roodbergen, et al., 2009).

AS/RS is mostly used in distribution centres and production environments in order to put raw materials or (semi-) finished products in storage racks and to pick products requested by the customer from storage to complete an order. AS/RS is fully automated, in other words it can store or retrieve products without the help of a worker. These systems have certain advantages over manual intralogistics systems i.e. providing fast, accurate and effective handling of products all day long, saving in labour costs and space and resulting in high reliability with low failure rates. However, high installation and maintenance costs and less flexibility due to huge storage racks and cranes can be given as examples of obvious disadvantages. In its most basic form, an AS/RS usually consists of storage racks which are served by cranes, running through aisles between two racks where products are stored and retrieved automatically. Figure 1-3 represents an AS/RS and its components.

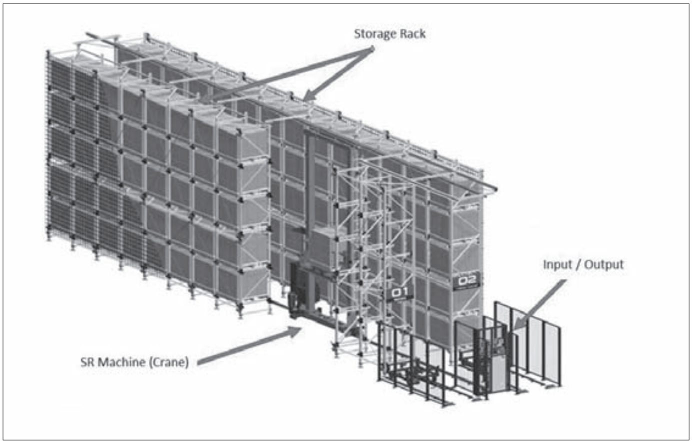


Figure 2-3: AS/RS and its components

2.1.4.2 Autonomous Vehicle Storage and Retrieval Systems (AVS/RS)

AVS/RS is a comparatively novel intralogistics methodology for automated handling which has been implemented at scores of facilities, primarily in Europe (Malmborg, 2002). Furthermore, this intralogistics system has been carried out in a French distribution centre.

AVS/RS is within Ekren's and Heragu's area of interest, and has helped intralogistics systems by using autonomous vehicles which transport products, not only within the same aisle, but also from one tier to another, using lifts (Ekren, et al., 2011). In other words, autonomous vehicles travel horizontally over rails, through aisles and vertically by utilizing an elevator. In addition, the main advantage of this methodology is that autonomous vehicles are capable of travelling to other aisles if necessary. Thus, they do not have to be bound to a specific aisle.

Gagliardi, et al., (2011) said that an AVS/RS study which was carried out in a French distribution centre was based on strict assumptions, for instance: the Application of Pure Random Storage (PRS) assignment policy, completing orders according to the First Come First Served (FCFS) rule and practising the dwell-point policy, which means that autonomous vehicles remain in place after completion of each transaction.

Figure 2-4 shows an AVS/RS and its components. The system is composed of autonomous vehicles, lifts, conveyors and storage racks. AVS/RS utilises a rail system performing in orthogonal directions within the high-rise, high-density storage area. The storage area is divided into multiple tiers and each tier has the rail system. (Ekren, et al., 2011).

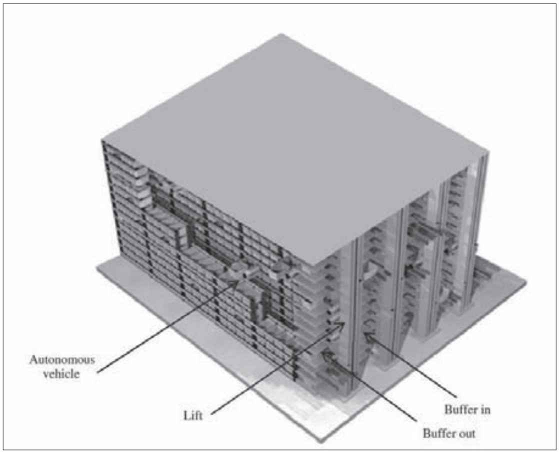


Figure 2-4: AVS/RS and its components (Marchet, et al., 2012).

2.1.5 Proposed Intralogistics Systems: the Cellular Transport System

Today, rapidly changing customer demands, small online order quantities, tight delivery schedules with high customer service level requirements and high competition make it increasingly difficult for companies to maintain a good performance by using existing intralogistics techniques. Even well-structured intralogistics systems do not meet the huge challenge of changing and adapting requirements which arise from competitiveness and dynamics in global markets, nor are they simultaneously capable of enhancing the level of flexibility, and changeability as well as levels of automation.

The reason why intralogistics systems play an ever more important role in companies includes many crucial operational points, such as on time delivery of ordered goods, service and good quality in the right quantity with the right sequence, and completing orders by using the right method in the right position. Therefore, the alternative intralogistics methodology should be appropriate for the value added chain concept of companies, have enough flexibility to adapt to market solutions, and be strongly agile in order to overcome the late or no delivery risk. At this point, the Cellular Transport System (CTS) has been developed as an alternative intralogistics system by the Fraunhofer Institute for Material Flow and Logistics.

In the proceeding parts, alternative autonomous systems are broadly explained, and the main logic behind the autonomous vehicles called the 'Internet of Things' is introduced comprehensively in order to set up a strong background for the concept of the Cellular Transport System (CTS).

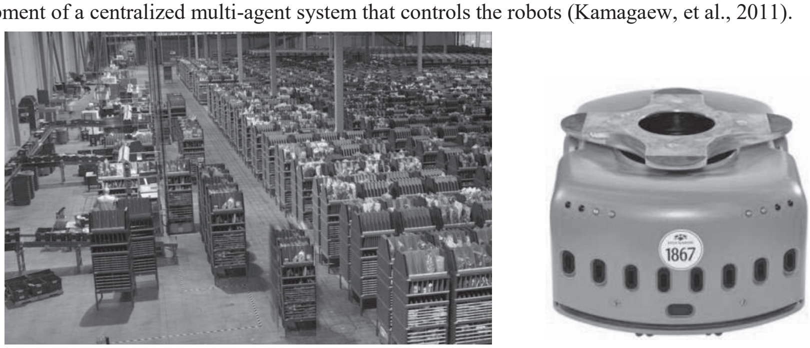
2.1.5.1 Introduction of Autonomous Vehicles

Short production cycles and just-in-time inventory management require flexible intralogistics systems in terms of material flow, with the usage of small autonomous transport vehicles which perform as a swarm of mobile robots (Röhrig, et al., 2012). Up to the present, several autonomous vehicle applications have been implemented in the practical intralogistics environment. Subsequently, the most popular applications by groups of autonomous vehicles are explained in depth as follows:

The KIVA Mobile Fulfilment System

The KIVA system includes hundreds of autonomous mobile robots which are able to lift and carry storage blocks in a warehouse. The largest installation at the moment consists of five hundred KIVA robots handlings products in the STAPLES, USA Company (Wurman, et al., 2008).

In existing storage concepts, products are stored in a specific fixed location of storage racks. However, with KIVA, inventory is not bound to physical location constraints. As a result of the fact that products in movable storage racks can be delivered to any operator, the KIVA Mobile-Robotic Fulfilment System provides extremely fast cycle times with reduced labour requirements from receiving, to picking and shipping. The maximum speed is limited to 1.3 m/sc. The focus of the KIVA project is on the development of a centralized multi-agent system that controls the robots (Kamagaew, et al., 2011).



(a) **(b)**

Figure 2-5: a) A Kiva warehouse implementation Flipse 2011 b) A Kiva robot Flipse 2011.

The KARIS Kleinskaliges (Small-scale) Autonomes Redundantes Intralogistics System

The KARIS system was developed at the Karlsruhe Institute of Technology in order to create a flexible intralogistics system using an autonomous vehicle with roller conveyor mounted on top. These vehicles are capable of adapting themselves to meet continuously changing requirements, i.e. forming a compound to transport big pallet loads, or forming a conventional conveyor belt to transfer products over a roller conveyor located over each vehicle (Kamagaew, et al., 2011).This project aims at generating a relatively low cost transportation platform instead of a long system of conveyor belts, and a low flow of products based on goals.

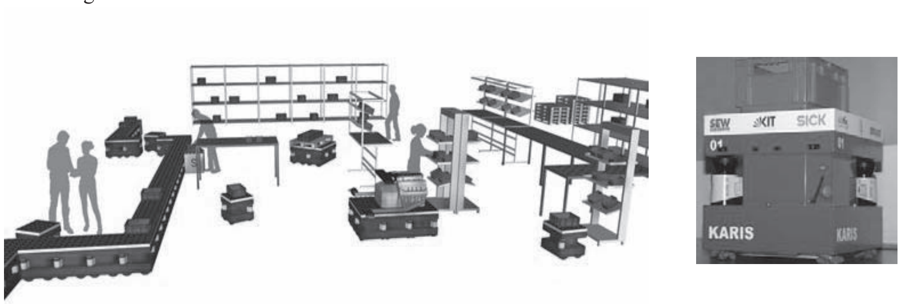
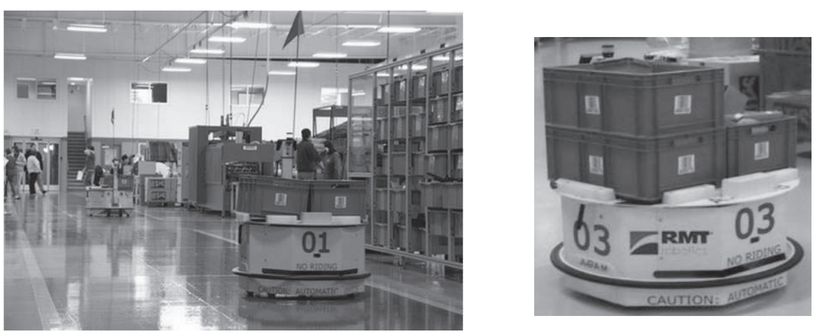


Figure 2-6: The KARIS warehouse implementation © Karlsruhe Institute of Technology (KIT).

ADAMTM (Autonomous Delivery and Manipulation)

The ADAM^{TM} system was introduced by the RMTE Robotics Company to the autonomous mobile robot market in 2005. It is based on Automated Guided Vehicle logic, yet it uses the open path navigation as opposed to steering using a rails path. ADAM^{TM} is projected for any intralogistics application that demands transportation of products in unplanned situations, and aims to maximize operational efficiency by robotically transporting. Although the ADAM^{TM} concept is not able to offer a complete solution, including a material handling device (Kamagaew, et al., 2011), in recent years, its compact size, controllable speed and dynamic movement features make it an exemplar for the company that requires spontaneous changes.



(a) **(b)**

Figure 2-7: a) An ADAM^{TM} warehouse implementation b) An ADAMTH robot © RMT robotics.

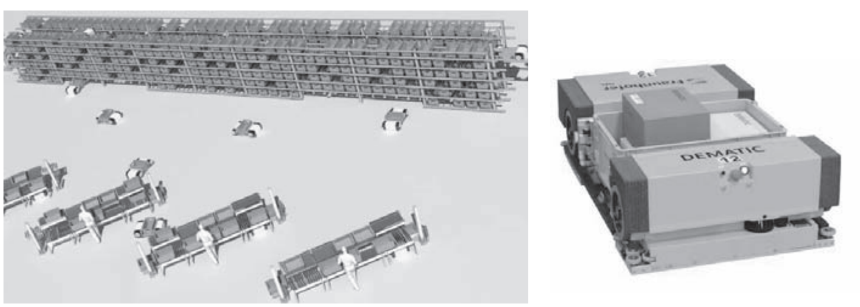
The Multi-Shuttle Move (MSM)

The Multi- Shuttle Move is an integration of the standard shuttles principle and an Automated Guided Vehicle (AGV) principle, and has been implemented by scientists from Germany's Fraunhofer Institute for Material Flow and Logistics in an attempt to create a novel and effective kind of intralogistics system. The Multi- Shuttle Move is not only capable of moving on the rail which is mounted in the storage rack, but also it is able to leave the storage rack and to work as an AGV by using open path navigation.

The MSM provides various drive options and has a maximum speed of 1.1 m/s on the floor, and 2.1 m/s in the rail-guided racking system which is located between two storage blocks - the higher velocity in the rail is obtained by a gear. The acceleration limit is a maximum of 2 m/sc (Kamagaew, et al., 2011).

The novel MSM system provides certain characteristic advantages compared to conventional technologies as follows:

- No necessity of huge installation cost and time.
- Direct transportation from the destination point to the arrival point e.g. in the distribution centre from the storage zone to the workstation zone without any transfer process.
- Flexible adaptation by increasing and decreasing the number of vehicles in the case of fluctuating transhipment demand.
- Capable of transporting on an inadequate layout or construction.



(a) **(b)**

Figure 2-8: a) A trial hall of the Cellular Transport System© Fraunhofer IML b) A Multi- Shuttle Move.

2.1.5.2 The Internet of Things

The 'Internet of Things' was lexicalized by Kevin Ashton, he explains that "I could be wrong, but I'm fairly sure the phrase 'Internet of Things' started life as the title of a presentation I made at Procter & Gamble (P&G) in 1999. Linking the new idea of the Radio Frequency Identification Device (RFID) in P&G's supply chain to the then-red-hot topic of the Internet was more than just a good way to get executive attention. It summed up an important insight which is still often misunderstood" (Kevin, 2009). Miorandi, et al., (2012), however, proposes an explanatory meaning as an umbrella keyword for covering various aspects related to the extension of the Internet and the Web into the physical realm, by means of the widespread deployment of spatially distributed devices with embedded identification, sensing and/or actuation capabilities.

The concept of the Internet of Things, which has a vision of creating a link between digital and physical entities through efficient information and communication technologies, enables a new class of applications and services. For instance, RFID technology, one of the technological mainstays of the Internet of Things allows original solutions for intralogistics systems. Hence, it is possible to change conventional central material flow systems by a decentral material control system. Decentralized intralogistics systems by means of Internet of Things logic is described in the following Figure 2-9.

In the right side of the figure, existing centralized material flow methodology is depicted. Technical equipment such as conveyors and products are located at the bottom of this control pyramid. Then, a programmable logic controller (PLC) is situated in the middle, while the control of centralized material flow takes part at the top. Whereas this hierarchical structure possesses a large bottom with much technical equipment, the top of the structure contains one or a few controls of centralized systems. The fundamental principal of the Internet of Things is to use the smaller self-autonomous control units as a substitute for a centralized structure. These units are, in the left side of the figure, represented as logistical objects, i.e. conveyors, RFID readers and all layers are identified in a hierarchical structure. For instance, the transported products can find their way through the system independently by communicating and negotiating with other material handling units during all period of handling (Nettsträter, et al., 2010).

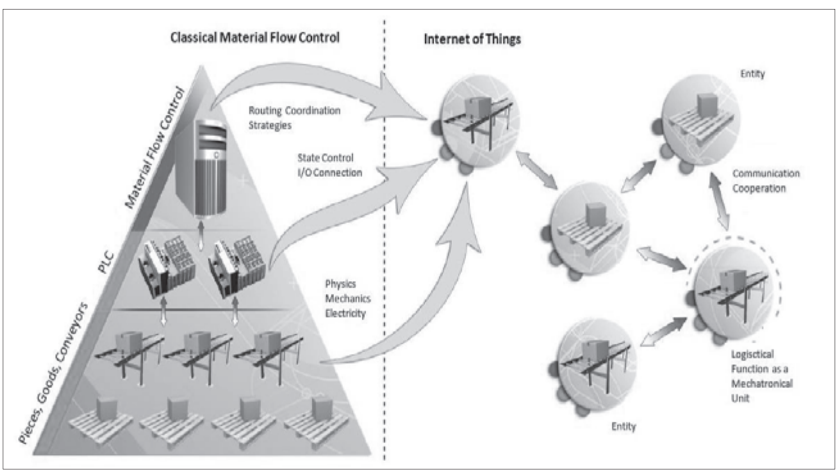


Figure 2-9: The Hierarchical Material Flow system and the Internet of Things (Günthner, et al., 2010).

2.1.5.3 Definition and Specifications of CTS

In recent years, research activities in decentralized control systems by means of the Internet of Things architecture in intralogistics systems have been growing (Günthner, et al., 2010). The Cellular Transport System (CTS) is accepted as an example of a decentralized intralogistics system as well in the vision for the 'Internet of Things' in logistics.

According to a comprehensive definition provided by (ten Hompel, et al., 2011), "Cellular Transport Systems are based on material handling entities. These entities could be autonomous transport vehicles or autonomous conveying modules. The control and the communication between these autonomous entities are executed by Software Agents. Cellular Transport Systems are flexible in their topology, for this reason they are able to adapt to environmental changes. Finally, this ensures the overall transport systems' performance due the interaction between the material handling entities."

The main principle behind the CTS concept is that decisions are made by the self- governing units which depend on some gathered information or probabilistic calculation. Generally speaking, centralized control systems lose their importance towards decentralized control systems. Kamagaew, et al., (2011) state this reality that "hierarchical structures are dissolved towards a mesh-like structure with self-containing entities." In intralogistics systems, autonomous units consist of a variety of functions i.e. consistent communication and negotiation ability, high sensor/actuator properties to gather local information to ensure advanced flexibility, collision avoidance and task assignment.

A currently experimental hall containing the CTS was built on an area of 1000 m^2 with a 65 meter long test area in Dortmund Fraunhofer IML to analysis its exact performance (Kirks, et al., 2012). The entire system, including fifty Multishuttle Move® units, five order picking stations and storage racks with elevators located at two sides of the storage racks, was implemented to examine the performance of the CTS by comparing it to other conventional intralogistics systems. The experimental hall is depicted in Figure 2-10 below.

Figure 2-10: The experimental area of Cellular Transport System.

2.2 The Agent-Based Simulation Concept

Firstly, the concept of modelling and classification of simulation will be presented to distinguish Agent-Based Simulation (ABS), which is a different kind of simulation from other types of simulation methodology. Then Agent-Based Simulation will be introduced in depth by categorising the term "agent" according to its different characteristics. Finally, the structure of agent-based modelling and the necessity of agent-based simulation will be explained.

2.2.1 The Modelling and Simulation Concept

System

In literature, numerous definitions of a system can be found. Gordon offers a good definition of 'system' i.e. "assemblage of entities joined in some regular interaction of interdependence" (Gordon, 1978). In other words, a system is a set of related components which interact with each other on the basis of system rules and principles.

Model

A model is an abstraction to represent an existing or proposed system such as a project, a business, an environment or a company warehouse. It attempts to simulate a system in the real world through simplification. Naturally, the reasons for the usage of models are efficiency, ease of analysis and the ability to predict future scenarios.

System Modelling

It is possible to conduct the study of a system by testing different methods. One possibility is to conduct an experiment with the system itself without using a model. This is, however, for technical reasons, almost impossible. For instance, testing the new layout of the warehouse while daily operation is in progress in the ongoing system can be gruelling for the whole company.

Also, the cost of such an experiment can be very expensive. Additionally, the system might not yet exist or is only partially completed. In such cases, analysing a system by using a model is a far better option. Due to the substitution and simplification of the system, a model is much more economical than the creation of the whole system.

Obviously, a system can be simulated using various models. As explained by Gordon, "a model of a system is not unique, because it directly depends on the aim of the study" (Gordon, 1978). In fact, a model is based on information gathered for the purpose and on assumptions made to simplify the view of the system.

Gordon classifies the different types of models as shown in the Figure 2-11 below and further explanations about each class are provided as follows.

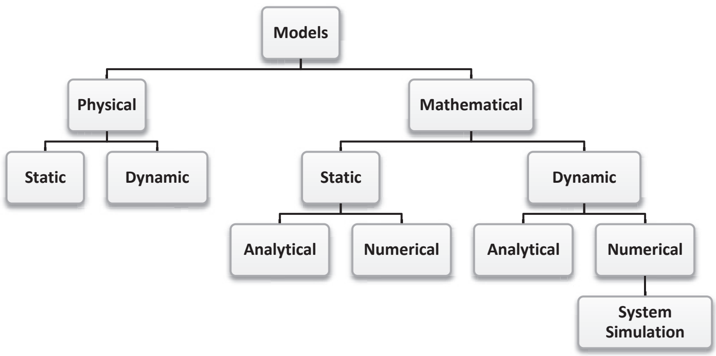


Figure 2-11: Types of models (Gordon, 1978).

The Physical and Mathematical Model

Physical models are concrete systems based on the same features as the original system. For example, a small-scale model has similar properties as the real system that it is based on. Mathematical models, on the other hand, use symbolic notations, as well as mathematical equations and formulations which are provided from design and analysis of the real system.

The Static and Dynamic Model

In a static model, the time factor is not considered. Static models focus on the state of the system, while the dynamic model modifies the state of the variables as time passes. When using dynamic modelling, in order to determine which quantity of a product should be produced, it is important to take into consideration the time of year, as customer demand varies each month.

The Analytical and Numerical Model

Analytical methods are mathematical models that use a mathematical theory to solve a set of equations and provide an exact solution, whereas numerical methods use a kind of numerical procedure to obtain the behaviour of models. Numerical methods try to find solutions by using computational procedures. Simulation models are regarded as a numerical model.

2.2.2 System Simulation and Classification

While a variety of definitions of the term simulation have been made, this study will use the definition first suggested by Shannon, (1998) who stated that a simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system. Banks offered another definition of simulation: "Simulation means imitating the operation of the real system through a model" (Banks, 1998). As a result, simulation can be defined as the process of creating a model of an available or proposed system in order to identify and understand which factors affect the system and to predict the future behaviour of the system. Moreover, there exist different types of simulations which can be categorised as follows:

2.2.2.1 According to the type of variables used to define the model

Stochastic Simulation

Naturally, when the unknown factors and their influence are considerable, simulation is almost impossible. However, it is possible to estimate a specific value- interval or the probability of a certain value at a specific time. This is called a stochastic (or probabilistic) simulation.

Deterministic Simulation

Deterministic models explain the behaviour of the system based on some physical law. This means that the behaviour of a system is fully known. For example, the planets move around the sun according to Newton's laws and their position can be predicted with great accuracy into the future.

2.2.2.2 According to modification of the interest variables over time

Discrete-Event Simulation

A discrete system is a popular simulation methodology in which the state variables change only at a discrete set of points in time (Banks, et al., 2005). The discrete-event system simulation models the process of a system as discrete points in time at which changes happen. A call centre simulation is an example of a discrete simulation. In call centre simulations, the state variables correspond to the number of calls. Thus, a change occurs each time an incoming call is received, based on specific distribution.

Continuous Event Simulation

A continuous system is another simulation technique in which the state variables change continuously over time (Banks, et al., 2005). Continuous simulations are the most appropriate if the state variables change continuously, rather than in infrequent discrete steps. A simulation of the amount of water in a barrage is a good example of a continuous simulation. The level of water continuously increases during rainy weather, while it continuously decreases during the hot summer because of on-going evaporation.

Hybrid Simulation (Combined Discrete/ Continuous Simulation)

This type of simulation combines the features of continuous and discrete simulations. It solves differential equations by applying discrete events to a continuously changing system.

Monte Carlo Simulation

The Monte Carlo methods provide approximate solutions to a variety of mathematical problems by performing statistical sampling. This type of simulation uses random numbers to vary input parameters for a set of calculations. It gives a range of results rather than a single value.

2.2.2.3 According to modelling technique

Object-Oriented Simulations

An object-oriented simulation consists of a set of object classes which can be used to create simulation models and packages. The simulations built with these tools possess the benefits of an object-oriented design, including the use of encapsulation, inheritance, polymorphism, run-time binding and parameterized typing. These concepts could be explained by creating a set of object frames which encapsulate simulation requirements.

Agent-Based Simulations

This is a special class of discrete event simulation in which the mobile entities are known as agents. Whereas in traditional discrete event modelling the entities only have attributes (properties that may control how they interact with various resources or control elements), agents have both attributes and methods (e.g., rules for interacting with other agents). An agent-based model could, for example, simulate the behaviour of a population of customers who are interacting with each other. In the proceeding section, the specifications of ABS are explained in detail as follows.

2.2.3 Agent- Based Simulation

Agent-Based Simulation (ABS) is a novel simulation methodology. Until the early 2000s, the term 'agent' was only used within the computer science field. Recently, Agent-based modelling has become more popular in a broad range of areas and disciplines. Axelrod claims that an agent is a third way of doing science (Axelrod, 1997). Bonabeau defines any type of independent component to be an agent (Bonabeau, 2001). A comprehensive analysis regarding the term 'agent' is provided by (Maes, 1997) who explains that an agent is a computational study which is long lived, has goals, sensors and efforts and decides autonomously which actions to take in the current situation to maximize progress towards its time varying goals. Taking all the above definitions into account, it can be said that an agent is a physical or virtual entity which has certain abilities, in particular, communication abilities, autonomous abilities and decision making abilities.

Wooldridge, et al., (1995) divides agents based on the execution of their task into the three classes listed below:

1. **Rule Determined**: Agents are responsible to fulfil the task according to specific pre-defined rules.
2. **User Determined:** Agents execute the entire task with the direct intervention of humans.
3. **Volunteer Determined:** Agents are able to perform the task themselves when it is believed suitable, without external intervention.

The main characteristics of agents, introduced by (Wooldridge, et al., 1995) are:

1. **Autonomy:** Agents should be capable of completing their duties without any interference from humans and should regulate their own behaviour and their own movements.
2. **Social Ability**: Agents should have the communication ability to interact with other components that are located in the same environment.
3. **Responsiveness**: Agents should be able to recognize and identify their environment in order to react and decide the next action at the appropriate time.
4. **Pro-activity**: Agents should possess the ability to represent some alternative behaviour to reach the well-defined goal when needed.

5. **Adaptability**: Agents should arrange their actions and movements in a timely manner and with reasonable effort when facing any kind of change.
6. **Mobility**: Agents should be able to change their position in order to convey knowledge, perceive the problem and generate the solution explicitly.
7. **Rationality**: Agents should be aware of their goals and avoid certain actions and behaviours that are not relevant to their particular aim.

Furthermore, (Nwana, 1996) provides another classification of agents with respect to their task-assignment as follows:

1. **Collaborative agents** are able to communicate and negotiate with humans and other agents in their environment to achieve a common purpose, by using their individual autonomy and cooperation skills.
2. **Interface agents** are specific agents responsible for setting up a connection with users by collecting and conveying information.
3. **Mobile agents** are defined as software agents that can change location to collect useful information requested by users, and subsequently present this information to the users.
4. **Information agents** are special software agents identified to control and handle the information using vast amounts of data from networks or internet flow.
5. **Reactive agents** are responsible for predicting certain events before they happen, using signals or predetermined algorithms. These agents do not perform goal-directed tasks like other types of agents.
6. **Hybrid agents,** as (Nwana, 1996) points out, are agents who exhibit two or more agent characteristics inside one single agent, in order to accomplish multiple assignments simultaneously.
7. **Heterogeneous agents** are two or more agents that are joined together in a different agent structure in order to overcome complex difficulties.

In the manufacturing and warehousing field, as Paolucci, et al., (2005) argue agents can actively support information management and specifically, agents can be applied to enhance existing Manufacturing Information Systems (MISs). In other words, over the years, the agent technology has been used to support industry in the area of information management as a software agent. Moreover, the authors claimed that although it should be evident that agents could be useful tools to support the manufacturing industry, it is not quite so clear how to implement agent technology. In the following shape, Figure 2-12, different agent types and architecture established for MISs are demonstrated as an example.

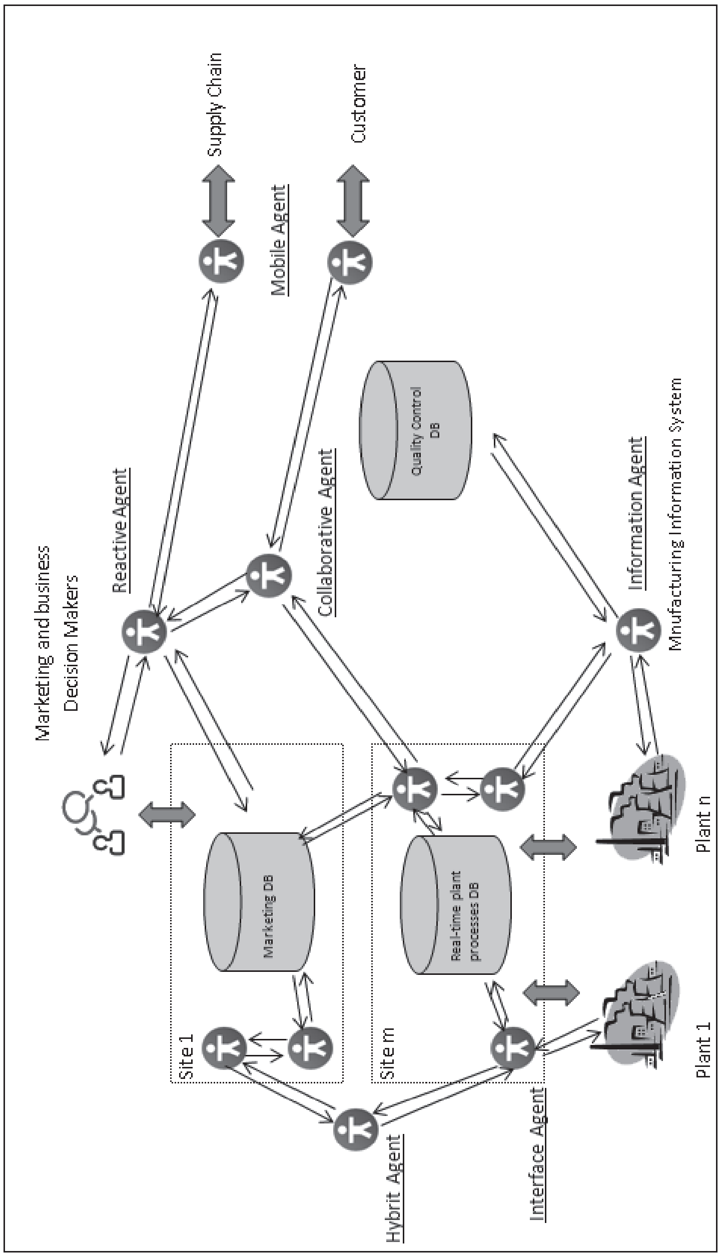


Figure 2-12: Agent Types and Architecture for Manufacturing Information Systems (Paolucci, et al., 2005).

2.2.4 Literature Review of Agent-Based Simulation

Agent-Based Simulation has been applied in a huge variety of fields, and is also triggered by simulation practitioners who need to simulate detail features that could not be simulated by conventional simulation methodologies.

Applications can be seen, especially in the biological, ecological, social, business and manufacturing fields. In the field of biology, for instance, an agent offers a considerable opportunity to measure the spread of the cancer virus (Preziosi, 2003) in a virtual environment. Moreover, the application areas vary from modelling ancient cultures to modelling customer behaviour in the market condition. The Table 2-1 below lists several Agent-based simulation applications according to their fields and provides a short explanation and reference to relevant articles.

Table 2-1: Literature of Agent-based simulation

Field	Explanation	Articles
Biological Science	Molecular Behaviour	(Troisi, et al., 2005)
	Cell Behaviour and Interactions	(Alber, et al., 2003)
	Mobile Cell for Immune System	(Folcik, et al., 2007)
Ecology & Health	Speed of Cancer	(Preziosi, 2003)
	Space Interactions	(Testa, 2007)
	Spread of Infections	(Carley, et al., 2006)
Economics	Relaxing Classic Economics	(Arthur, et al., 1997)
	Interest Behaviour	(Tesfatsion, 2002)
Business & Market	Tourisms	(Charania, et al., 2006)
	Market Dynamic	(Lo´ pez-Sa´nchez, et al., 2005)
	Economics and Market Condition	(Tonmukayakul, 2007)
	Supply Chain	(Macal, 2004a)
Society & Culture	Archaeological Evidence	(Kohler, et al., 2005)
	Ancient Civilization	(Wilkinson TJ, et al., 2007)

2.2.5 Structure of Agent Based Simulation

Jennings (1996) stated that the use of agent technology is justified when the applications are modular, decentralized, changeable, ill- structured and complex. One of the main differences between ABS and other simulation methodologies is that ABS is a decentralized system. Agents hold individual local information in order to accomplish a predefined task without any central power, neither allocating duties and necessary information to all agents, nor controlling their performance to maintain consistency. Instead of central authority, agents meet the user requirements by interacting, not with all agents, as in a real-life scenario, but by sending and receiving messages to inform each other in order to find the best solution.

Agent-based modelling focuses on systems that include the number of active objects such as people, customers, and vehicles that have specific behaviours. Agent-based modelling differs from other types of modelling with regard to how it approaches such systems and how easily it can be further improved to simulate more complicated situations. Agent-based modelling cannot be a substitution for Discrete Event or System Dynamics modelling, but it is a useful model that can be used effectively in combination with other modelling methods.

The structure of agents could be created using different techniques based on types of simulation software, such as programming language or graphical editors. Agent-based modelling should always be composed of many active objects especially humans, all of which must communicate with each other. However, any physical or non-physical object might be an agent, such as a vehicle, a building, a plan, a city, an illness, a company, etc. For example, the model of a warehouse where each workstation is modelled as an active object is an agent based simulation. Additionally, even a passive, immobile object can be an agent. In the same warehouse, for instance, every workstation can be modelled as an agent. Each workstation could be modelled according to its state of busy, idle, breakdown or maintenance. On the other hand, the agent-based model might consist of very few agents, and these agents could be identical or completely different from each other. Also, some agents can interact with all other agents, while others can be isolated from their environment. In short, many dissimilar agent-based model structures are available.

Most agent-based models work in discrete time i.e. interaction, decision making and changes of state are instant. In this respect, agent-based modelling is quite similar to discrete event modelling; what is different the types of the agents states. The states represent the agents' behaviour in response to varying times or conditions.

A state chart or state diagram is a graphical method which can be used instead of programming language. Such a diagram facilitates the simple and efficient expression of events and the behaviour of agents. State charts are mainly composed of states and transitions. In order to provide a better understanding of state charts and their components, a *Customer Behaviour State Chart* is used below in Figure2-13 as an illustrative example. The Customer Behaviour State Chart consists of three states, namely the Initial State, Ordering State, and Order Completion State, and of three transitions, i.e. Order Transition, Preparing Transition, and Finished Transition.

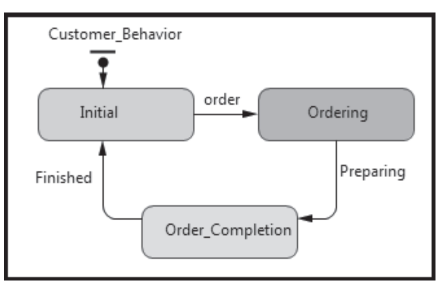


Figure 2-13: Customer Behaviour State chart

At the beginning of the simulation, each customer is at the "*Initial State*", waiting for the "*Create Order*" message which is inside the "*Order*" transition. After receiving the "*Create Order*" message, agents move their current state to the "*Ordering State*", which could involve some specific Java Code, in order to extend the agents' property in response to user requirements. For instance, different types of order-items belong to a specific customer, and their pending distribution can be defined during the "*Ordering State*". At the "*Ordering State*" point, agents wait for the message "*Preparing*" to be written during the "*Preparing*" transition, until the agents jump to the "*Order Completion*" state. At the last step, agents return to their first state once they are triggered by the "*Complete*" message inside the "*Finished*" transition.

2.2.6 The Need for Agent Based Modelling

The reason for using models is to solve real-world problems in order to optimize systems without having to construct real prototypes or to experiment with real systems, as this might be expensive or impossible. Modelling could be explained as a process of abstraction of real world problems, using analytical or simulation techniques. Borschev, et al., (2004) show a range of problems arranged on the scale according to the typical level of abstraction of the corresponding models. Figure 2-14 illustrates the level of abstraction of certain simulation applications. According to Borschev's and Filippov's definition below, warehouse and automotive control systems could be found on the low abstraction level in other words on the micro level or operational level. Agent-based simulation approaches possess the ability to handle and simulate all details in warehouse logistics, such as exact sizes, distances, velocities and timing.

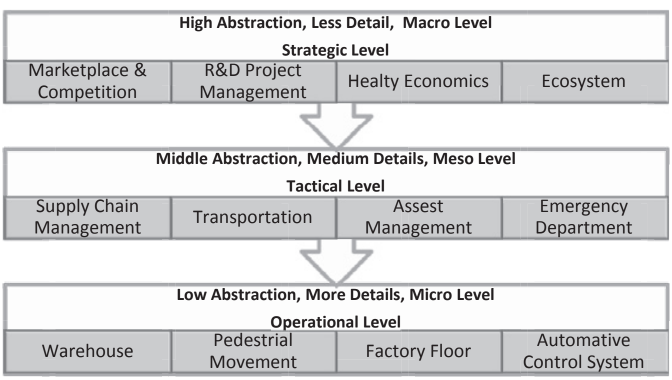


Figure 2-14: Application of Simulation Modelling based on Abstraction Level (Borschev, et al., 2004)

Moreover, (Borschev, et al., 2004) define three major simulation paradigms according to the level of abstraction, as shown in Figure1-15 below. These are: System Dynamics, Agent-Based and Discrete Event simulation. System Dynamics, for instance, deals with high abstraction level modelling, while Discrete Event modelling is positioned at the low to middle abstraction level. Agent-based modelling, however, can be used for all levels of abstraction. Hence, the application of agent-based models is very versatile. Cellular Transport Systems (CTS) are recognized as being located on the low abstraction level, while Anticipatory Change Planning which corresponds to supply chain and market competition issues are accepted to be locates on the high abstraction level. However, both CTS and Anticipatory

Change Planning should be simulated simultaneously. Agent-based simulation paradigms are able to handle both high and low abstraction levels at the same time. Thus, throughout this study, the agent based approach is chosen as a simulation methodology.

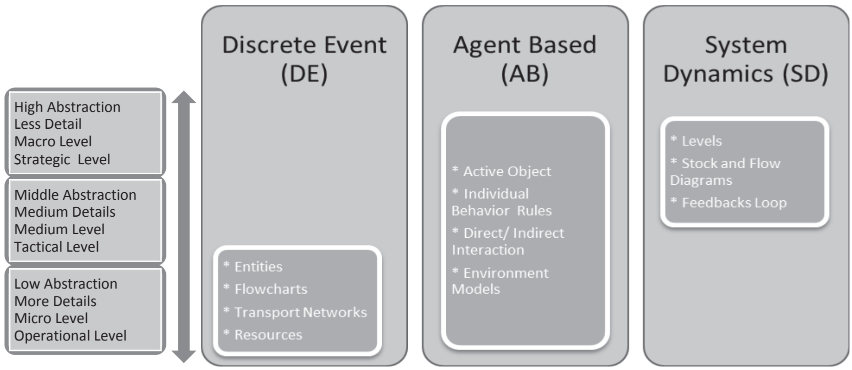


Figure 2-15: Simulation Approaches based on Abstraction Levels (Borschev, et al., 2004)

2.3 Anticipatory Change Planning Concept

The last main part of the present study, Anticipatory Change Planning, will be explained firstly by giving various definitions from scientific researches. In the second part, the previous studies such as Risk Management and Disruption Management, which can be accepted to show some similarities with proposed ACP, are introduced in order to lay emphasis on the importance and difference of ACP.

2.3.1 Definition of Anticipatory Systems

Most of the scientific studies about anticipatory systems are not included within the scope of intralogistics environment. They are generally connected with theoretical biology i.e. "*Anticipatory Systems"* by (Rosen, 1985), semiotics i.e. "*Anticipation"* by (Nadin, 2003) or artificial intelligence i.e. "*The Challenge of Anticipation"* by (Pezzulo, et al., 2008). Below, three main definitions of anticipatory systems from different scientific fields are listed.

Robert Rosen defines anticipation in artificial systems as; "An anticipatory system is a system containing a predictive model of itself and/or of its environment that allows it to change its current state at an instant in accord with the model predictions pertaining to a later instant" (Rosen, 1985).

According to Mihai Nadin's definition, anticipation is a recursive process described through the functioning of a mechanism whose past, present, and future states allow it to evolve from an initial to a final state that is implicitly embedded in the mechanism. (Nadin, 2003). Besides, his introductory explanation of anticipation, Nadin offers twelve brief definitions of anticipation in order to facilitate a better understanding of its importance. For instance, anticipation is a realization within the domain of possibilities or anticipation is an attractor within dynamic systems.

Anticipatory systems, as defined by (Pezzulo, et al., 2008) are systems that generally use their predictive capabilities to optimize behaviour and learning to the best of their knowledge.

Also, they make a clear distinction between prediction and anticipation by providing the following statement: Prediction is a representation of a particular future event. Anticipation is a future-oriented action, decision, or behaviour based on a (implicit or explicit) prediction (Pezzulo, et al., 2008).

On the basis of the definition above, the term 'anticipation' might be summed up in terms of the intralogistics systems concept, as an identification and prediction of potential-changes in order to respond in appropriate time, and to minimize the negative effects and maximize the positive effects of such changes.

2.3.2 Literature Review of Anticipatory Systems

2.3.2.1 Risk Management

There is a large volume of published studies describing the risk definition and the role of risk management, even in the field of both business and science. For instance, Sitkin, et al., (1992) defines risk as "the extent to which there is hesitation, whether potentially desired or insignificant/unwanted outcomes of decision will be realised". In other respects, Ritchie, et al., (2007) formulates a principle of risk to assess (1) the probability of occurrence of certain outcomes (2) severity from the occurrence of the event (3) the ability to detect the risk. It is put together in the notation below.

$$Risk = Likelihood \times Severity \times Detection$$

'Risk Management' is defined as "an organised process to identify what can go wrong, to quantify and assess associated risks, and to implement/control the appropriate approach for preventing or handling each risk identified" (INCOSE, 2002).

The risk management process generally is composed of four main steps shown in Figure 2-16, which can be repeated until the risks are kept within the acceptable corridors. These steps are:

Risk Identification; the phase in which the risks are determined. All possible risks are collected in a list. Not only risk identification, but also identifying the source or drivers of potential risks is carried out in this step.

Risk Assessment; this phase comes after the risks analysis in order to measure the likelihood and the expected impact on the defined system. In other words, this assessment essentially deals with two main questions; first, "how likely a risk is" (i.e., the frequency of risk) and second, "how terrible the risk can be" (i.e., the severity of risk).

Risk Evaluation; the phase in which mitigation decisions are taken to stop, or at least reduce the effect of risk. Thus, it is also called the risk mitigation phase. . This phase is composed of many mitigation strategies and new implementation plans when the unwanted event occurs.

Risk Monitoring; the phase in which the impact of mitigation plans is followed up. For many reasons, an organization should have a dynamic check system on managing risks in organizations, and a frequent updates system, by applying some other changes within the system or in the environment.

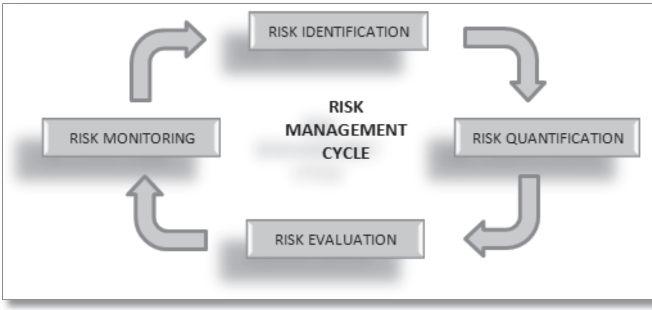


Figure 2-16: Risk Management Steps

2.3.2.2 Disruption Management

The term 'Disruption' is defined by (Behdani, 2013) inside the concept of the supply chain and it can be revised according to the concept of intralogistics, as an event that might happen in any part of the intralogistics system and, if it happens, it causes undesired impacts on the (achievement of) objective and the performance of intralogistics.

According to a definition provided by (Behdani, 2013), Disruption Management is a structured and continuous process to analyze the impact of disruption across an intralogistics system on the predefined objectives, and to handle these disruptions in their whole lifecycle.

The difference between risk management and disruption management can be simply shown with the help of the following Figure 2-17 . All activities are divided into two classes in terms of time; Pre-Disruption or Post-Disruption. Pre-Disruption actions are also called 'Prevention' actions and fall within the area of Risk Management, whereas Post- Disruption actions are also called 'Response' activities, and are being dealt with by Disruption Management. For this reason, all activities and measures are taken by organizations in order to reduce the negative impact of possible disruption; some of them before unwanted action, some of them after.

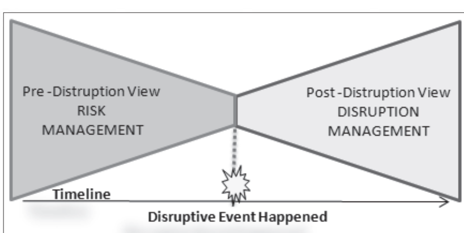


Figure 2-17: The relationship between Risk Management and Disruption Management

Behdani (2013) combines disruption management with risk management by creating another cycle inside the risk management cycle. In spite of all required and preventive measures, unfortunately, the unwanted disruption can take place. In case of disruption, the first action should become aware of the event immediately. The next phase is the disruption reaction phase, in which predefined mitigation plans should be applied. If these plans are not enough to overcome the negative effect of disruption, the existing strategies should be extended with alternative solutions. The last phase is the disruption learning phase, in which lessons should be taken from recovered disruption in order to use in similar situations in the future. Disruption management steps are illustrated in detail with the help of following Figure 1-18.

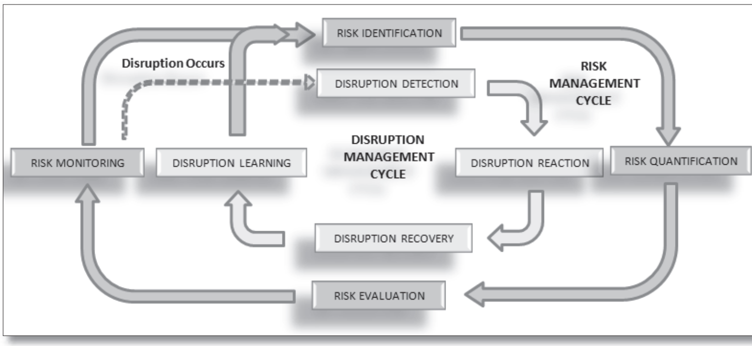


Figure 2-18: The overall structure of an Integrated Framework (Behdani, 2013)

2.3.2.3 Anticipatory Management

Nadin (2009) proposes an explanatory sentence to point out the link between the anticipatory concept and risk. He states that successful anticipation mitigates risk. Also, he suggests the anticipation-based risk management method, in which an experimental setting for the quantification of anticipation and structural measurements are located. Therefore, Anticipation Change Planning (ACP) is put into the Risk Management side, as can be seen from the following Figure 2-19.

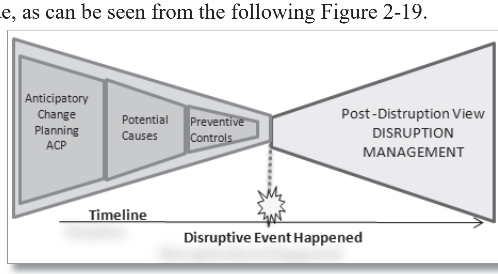


Figure 2-19: Relationship between Anticipatory Change Plan and Risk Management

An estimation or prediction of the future is not sufficient for this study. It is necessary to take available information from the forecast techniques and integrate them with the decision making procedure, in order to both respond on time and improve existing systems. This is the goal of ACP, which is under the remit of this dissertation research.

ACP could be defined as a continuous process that supports efficient and effective assessment of changes (or potential risks), increases the awareness of these changes, and improves the management of changes. In reviewing the literature, the anticipatory term is used in many scientific areas, for instance, in the Artificial Intelligence (AI) field, as an anticipatory agent. Anticipation can be performed by agents depending on some predictions, pre-defined rules, or some statistical equations.

Dubois (1998) introduces computing anticipatory systems that are able to anticipate with computing power. He also claims that computation is not only related to artificial computers, like a personal computer, but also to natural systems which perform computations. Therefore, the anticipatory planning concept is carried out by the U.S. Military as a new approach, called anticipatory planning and adaptive execution, in order to execute planning, performing and monitoring processes simultaneously, by merging useful information and artificial intelligence methodologies.

Ashley and Morrison (1997) provide a flow chart model given in Figure 2-20, to recognize and manage threats and opportunities; this is called the Anticipatory Management Decision Process Model. It aims to make use of knowledge and experience that are obtained from outside the organizations, to lead the way for them.

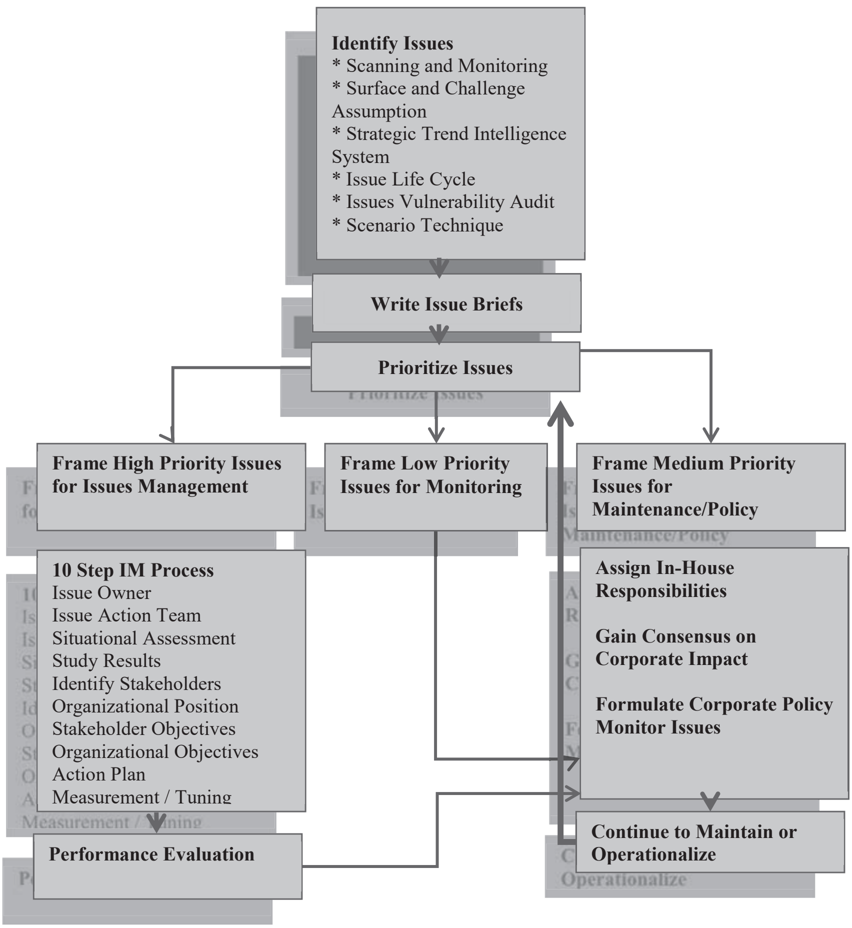


Figure 2-20: Anticipatory Management Decision Process Model, (Ashley, et al., 1997)

Chapter 3

Conceptualizing and Research Methodology Development

This chapter aims to structure a systematic approach for anticipatory change planning, (ACP) which is an essential level of study, by introducing three planning phases which are; 1) the change planning topic, which comprises comprehensive investigations about any kind of change and changeability, in order to offer a better understanding of other chapters. In addition, possible change drivers are aggregated and represented in a compact way. 2) The measure planning section, in which the process chain method is introduced for measure identification, and also Six Steps Planning, to assure a systematic approach for experimentation. Finally, 3) Assessment model planning is mainly composed of methods to evaluate the productivity of the intralogistics system. Before explaining the components of ACP in more detail, Chapter 3 supports background information for other systematic planning methods, to anticipate changes which have already taken place in literature.

3.1 Systematic Approach for Anticipatory Change Planning

In order to increase the power to take decisions accurately and quickly, a systematic decision support system is required. Until now, very little was found in literature on the concept of systematic anticipatory change planning. Ashley and Morrison (1997) created a flow chart to identify and supervise potential threats, risks or changes; they called it the Anticipatory Management Decision Process Model. For the visualization of the flow chart, see Chapter 2. The logic behind this anticipatory design is firstly to identify possible issues using different techniques such as scenario planning, strategic trends or continuously scanning and monitoring. Secondly, these determined issues are prioritized on the basis of maintenance and management levels. Then, feasible actions to take after change happens are listed. This anticipatory model is envisioned for strategic level planning, by taking into account enterprise objectives as a whole, rather than the field of intralogistics specifically.

The first evaluable anticipatory change system is provided by (Uygun, et al., 2009), which is more convenient for the projected model within the concept of this study. The purpose of this study is to create a utilization-based simulation tool that enables us to manage the intralogistics systems in a changeable and challenging business environment more effectively and efficiently (Kuhn, et al., 2008). The proposed anticipatory change model, illustrated below in Figure 3-1, is generated, and three main segments are included in this structure. 1) 'Phase Segments' refers to the main parts of the model which continue iteratively. 2) The 'Task Segment' is a second segment in which the responsibilities are allocated and assigned. 3) The 'Tool' segment shows the required models needed to accomplish the above tasks. The sub segments can be explained as flows in brief. The anticipatory change system is firstly based on system load determination. To find an accurate and reliable system load, expected and unexpected orders should be taken into consideration by using a particular simulation model. The next step is about identification of possible change requirements, as well as determining bottleneck or deficiencies that might have occurred during applied changes. For this step, a simulation tool is needed to simulate the existing or proposed intralogistics system. After the required changes are implemented, some measures could be necessary to regulate the ongoing system. At this point, measures and precautions are specified. Besides that, a measure selection model should be on hand in order to evaluate all measures, to choose the most suitable one. In the last steps, the selected measures, or a combination of measures, are implemented, and an evaluation or assessments system is responsible for reporting several statistical analyses about new situations.

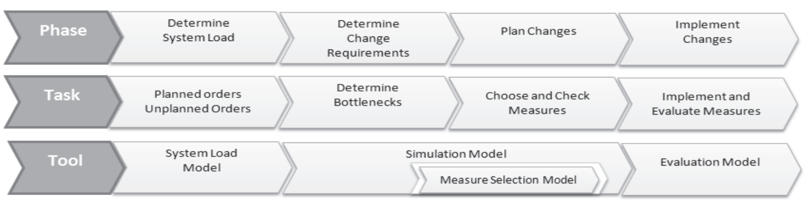


Figure 3-1: Phase and tools for Anticipatory Change Planning (Uygun, et al., 2009).

In order to increase the power to make decisions accurately and quickly, a systematic decision support system is required. Kuhn and et al., (2011) suggest a systematized planning process example to make better decisions, which is explained in detail in Figure 3-2 as follows.

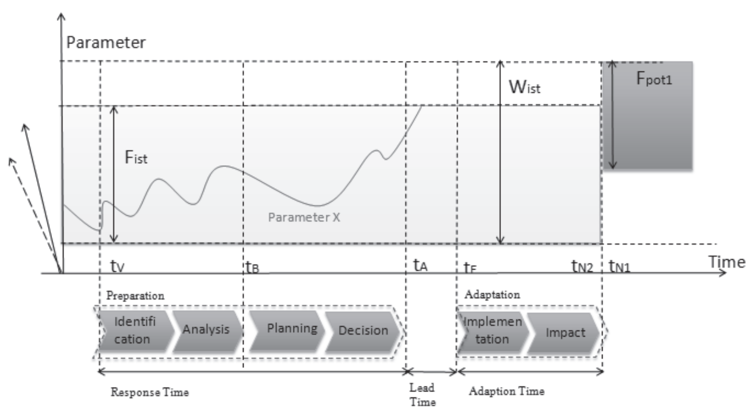


Figure 3-2: The systematized planning process (Kuhn, et al., 2011).

The proposed planning process is, firstly, divided into main phases; the preparation phase, which deals with before change happens, and the adaptation phase which is more related to after measure implementation. There exist four levels, which are included in the preparation phase. When the influencing of change is detected, the planning process begins. In the identification phase, which is the initial phase, the specification of change event is determined and conveyed through into the analysis phase. Assessments of the flexibility corridors are carried out to find out whether the existing system is capable of implementing this change or not. If a decision is taken to apply a measure, the appropriate scenarios about measure type and duration are generated, and other assessments concerning scenarios are performed in the planning phase. In the subsequent decision phase, the selected change scenarios are carried out. Toth et al., (2012) argue that these four steps should be completed in a short span of time to provide enough time for the adaptation phase. Besides that, a reliable and quick decision plays a key role if available flexibility corridors are not sufficient for the change that will be implemented, since moving to the new flexibility corridors also needs additional time.

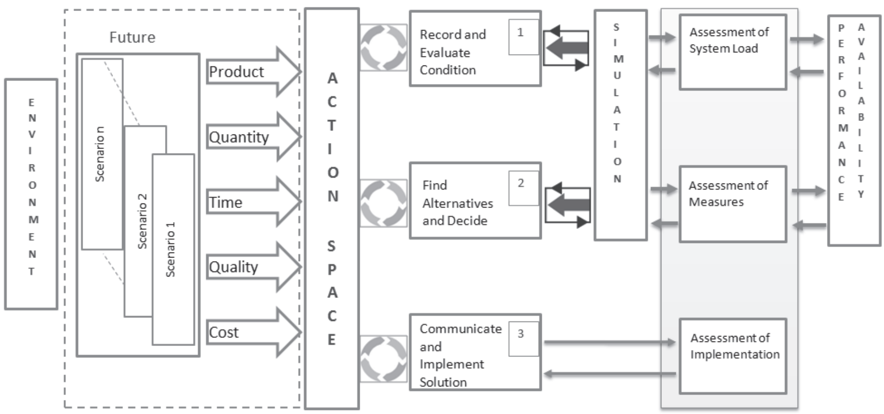


Figure 3-3: The simulation-based anticipatory change planning framework (Güller, et al., 2014).

Simulation base anticipatory change planning is an extension of the study that belongs to (Uygun, et al., 2009), by integrating simulation techniques to create case studies, and performance availability to make assessments (Güller, et al., 2014). The model is composed of several repetitive parts which might be discussed under three headings: 1) Scenario generating is the initial part of a model, in that various future case scenarios are produced by taking into consideration possible change drivers, uncertainty situations or potential risk types. In order to examine these scenarios, product type, quantity, quality, cost and delivery time are entered into the simulation. 2) Simulation running is the main part of the planning model to simulate the future case in order to enable assessment. The simulation tool, firstly, runs the existing situation of the intralogistics system without any change implementation. Within this framework, the flexibility corridors are constructed to recognize whether the existing system is able to handle the changes located in the future scenario. If it is not, the appropriate measures are chosen to overcome the deficiency occurred change execution. 3) The measurement part includes flexibility corridors and performance availability methodology to compute the quantitative value of measures. The performance availability is a novel quantifies method to evaluate the degree of fulfilment of the system and customer requirements. The introduced simulation based anticipatory change planning is demonstrated in Figure 3-3 above.

Within the scope of this study, Anticipatory Change Planning could be discussed under three headings which are: 1) Change Planning, which includes a particular simulation model called Change Planning

Simulation, which is generated based on agent based thinking. 2) Measure Planning, which is designed using Six Step Planning emerged from process chain methodology and 3) Assessment Planning, which is composed of flexibility corridors to monitor the system behaviour and performance availability, to measure the entire system efficiency. Cellular Transport System simulation is created as a basic framework to choose and implement measures and evaluate the performance of the whole system. The following Figure 3-4 summarizes the Anticipatory Change Planning as a visual.

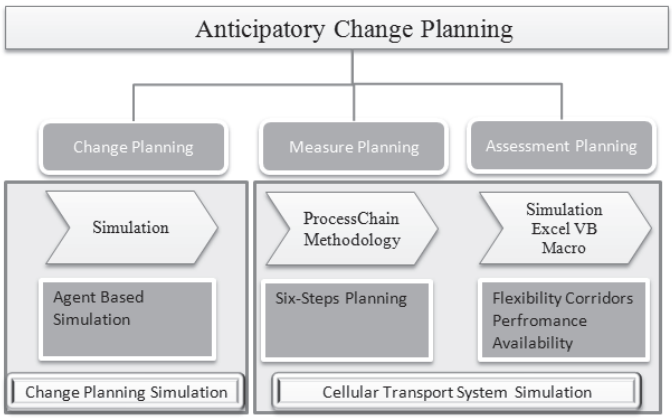


Figure 3-4: The general view of Anticipatory Change Planning.

3.2 Construction of Change Planning

These days, all kinds of businesses have confronted many difficulties when reconfiguring their organizations economically, and with the least effort, because of continuously changing factors on a strategic, tactical or operational level. One reason behind this challenge is the deficiency of knowledge about change types and the drivers of these changes. In order to provide all kinds of change drivers as a whole, for the proposed Anticipatory Change Planning, previous studies will be examined and a comprehensive table is provided in the following section.

3.2.1 Definition of Change and Changeability

Wiendahl (2007) provides the following Figure 3-5 in order to understand what the main change drivers are and to define the appropriate degree of changeability of them. Change objects are described and classified on the basis of its driver, strategy, extension, focus and type. More explanations for each step are given in detail as follows:

Change drivers trigger a probable change in three different ways; by demand volatility, variety in product range, size, model, some further properties, and modified company strategy for the price, competition or target of the marketing plan. The second step which is able to change focus can be categorized into two areas; internal and external. Internal change objects deal with disruptions caused by company-internal factors, such as machine breakdowns or manpower uncertainty, whereas changeability of external change objects deal with environmental factors that can directly or indirectly lead to disturbances within the supply chain, such as natural disasters or political instability. The next step is available for describing the strategy of change in terms of its necessity, sufficiency and whether it could be competitive or not. To measure the extension of change, firstly, the level of impact area, secondly, the pre-assigned frequency and time allocation for each change and lastly, the required effort, must be specified in the form of equipment, labour, time, area, experience and knowledge. The above determinations are carried out for a particular product, process, facility or whole organizations, which are called change objects. At the end of all steps, the Performance Measurement System collects all features of determinant of change, in order to assess the impact of the changeability by looking at some parameters i.e., throughput rate, on time delivery performance, the amount of inventory etc.

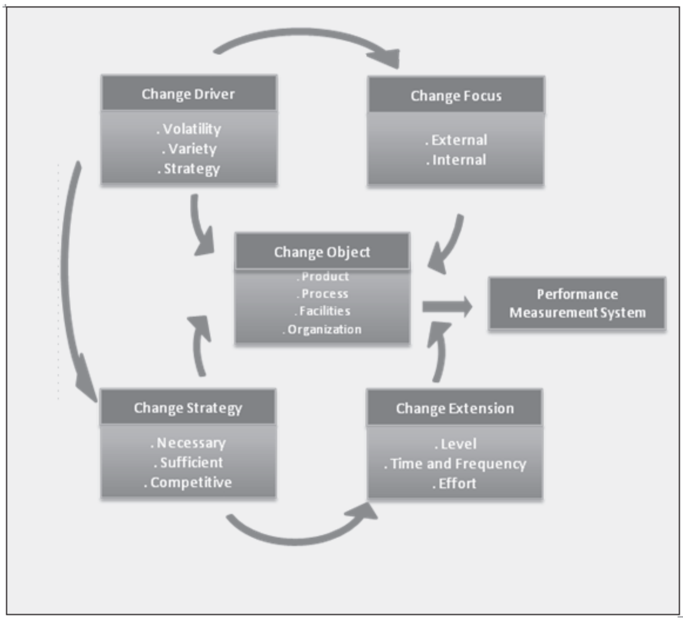


Figure 3-5: Change drivers and their fundamental properties (Wiendahl, et al., 2007)

The term ‘changeability’ is most commonly used in German literature, and can be defined as the ability to change when companies need to adopt their systems to a new state of affairs (Zaeh, et al., 2005). Although the meaning of changeability is clear enough, , in order to distinguish it from some similar terms such as flexibility, re-configurability and agility, the detailed definitions for each term are provided below:

Re-configurability

The main concern of the re-configurability issue is to rearrange existing equipment, workstations and machines by eliminating or combining some specific hardware or software in order to adjust the manufacturing system to desired capacity (Koren, et al., 1999). Despite the fact that re-configurability can provide the potential to modify the dimensions based on requirements, its concept deals exclusively with the technical aspect of organization.

Agility

The principle behind 'Agile' manufacturing systems thinking is to match dynamic market requirements with commercial partnerships. An agile manufacturing system intends to provide agility, not only for the manufacturing department, but also for the whole company, using lean manufacturing techniques, total quality management (TQM), and business process engineering methods all together (Yusuf, et al., 1999).

Flexibility

There is a large volume of published studies describing the definition of flexibility; however, there is an ambiguity which can obviously be seen. Slack, (1983), who proposed an explanatory definition, stated that the series of accessible states, and the time and cost required for moving from one point to another, are measures variables to assess whether a system is flexible enough or not. A configured flexible system can give organizations the freedom to enable modifications within specified limits. In other words, flexibility is the option to change in pre-defined dimensions. Thus, while the system components remain constant, the connections and interactions between these components can be rearranged.

Changeability

A considerable amount of literature has commonly featured the term 'changeability', which may be defined as a result of flexibility, mobility and a very fast conversion in connection with high integration (Wirth, et al., 2000). According to the definition provided by (Wiendahl, et al., 2007), changeability is an ability of a factory to react effectively and efficiently on planned and unplanned changes. Comparing changeability with other terms mentioned above, Zaeh, et al., (2005) states that it is more than re-configurability because it is not restricted to hardware or software elements. Despite having the same objectives of agile manufacturing, changeability is not able to utilize well known techniques and methods which could outweigh the cost. Contrary to the flexible system, changeability includes ability to vary its own structure. Changeability makes the switch from one corridor to another corridor possible for the company in a short span of time. Whereas flexibility is capable of adapting existing systems inside certain corridors, changeability can ensure the company is flexible in originating new corridors. The difference between flexibility and changeability can be realized from the following Figure 3-6.

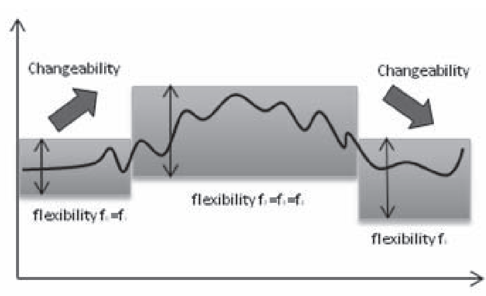


Figure 3-6: The difference between Changeability and Flexibility.

3.2.2 Identification of Change Drivers

In early literature, the difference between uncertainty and risk is put forward by Luce, et al., (1957) who states that a probability can be given for the risk issue, whereas the probability of uncertainty cannot be known. However, Covello, et al., (1993) clarified the risk term as "a characteristic of a situation or action wherein a number of outcomes are possible, the particular one that will occur is uncertain, and at least one of the possibilities is undesirable". They distinguished the uncertainty term from risk by stating that, uncertainty is a situation where a number of possibilities exist and one does not know which one of them has occurred or will occur. More recent studies, for instance; Simpson, et al., (2000) specified that risk is an assured, unwanted effect that will happen in the near/far future with a probability, while uncertainty is a term that can include a variety of possible wanted and unwanted events with many possibilities. Although the above mentioned difference between uncertainty and risk appears throughout this thesis, the term 'risk' or 'uncertainty' will refer to the change driver.

In recent years, there has been an increasing amount of literature on uncertainty classification in terms of different aspects. Christopher and Peck (2004) offer a fundamental framework in which uncertainty is categorized based upon the location of the source. These are: 1) internal uncertainty with causes inside the company, 2) internal uncertainty proceeding from outside the company, and even inside the supply chain, and 3) external uncertainty which is rooted outside the supply chain structure.

Gong (2009) improves this framework shown in Figure 3-7 by inserting the expectation and impact of uncertainty parameters. Firstly, from the point of the uncertainty source, he adds an extra location that is inside the company, and related to the warehouse control system. According to the variance structure of uncertainty, three classes have emerged; first, the unpredictable event whose probability of occurrence is very low, such as natural loss, disease, war, flood and explosions, second, predictable events that are likely, for example, labor dispute and demand seasonality, third, internal variability which can happen accidently because of warehouse daily operations such as variance in routing or variance in order picking. Additionally, the third dimension of the following graph is concerned with the uncertainty impact on three levels; strategic, tactical and operational. Strategic level uncertainty has a long term impact on the warehouse as a whole, for example, terrorism, natural damage or pandemic illness. Although the occurrence of this kind of uncertainty source has a low probability, they could have a strong influence over all supply chain operations. Labor dispute and facility cost change trends can be given as an example for tactical level uncertainty which could have emerged from inside and outside the warehouse, as well as within the supply chain. Operational level uncertainty that is directly connected to daily operations has a short term effect on labor, equipment and internal control parameters.

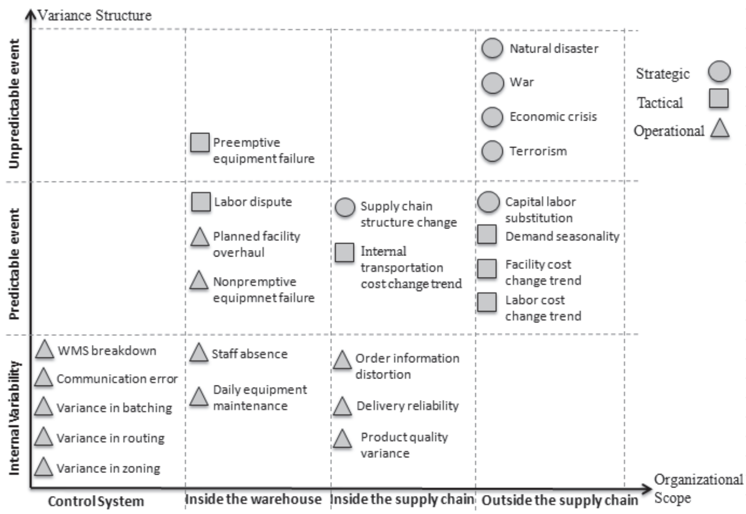


Figure 3-7: Change drivers of warehouse operations (Gong, 2009).

Although Gong, (2009) improves classification of change drivers by putting the aspect of impact and expectation into the above graph, he only takes the uncertainty source of warehouse operations into consideration. However, the uncertainties have been looked at in a broad perspective. Additionally, in the following graph, the locations of source have been enlarged with the combination of (Christopher, et al., 2004)'s study. Inside the supply chain class, for example, is divided into two groups: Demand and Supply. In other words, cubical Figure 3-8 is capable of showing four different aspects of each change driver in a compact form. For instance, natural loss or catastrophic loss is accepted under and outside of the supply chain, and the strategic decision category as an environmental and unpredictable change. Besides that, the graph below is elaborated by giving many examples.

To provide more understanding about the cubical figure below, even if the main categories of change driver has already been explained, a comprehensive explanation will be given about the location of the source category as follows:

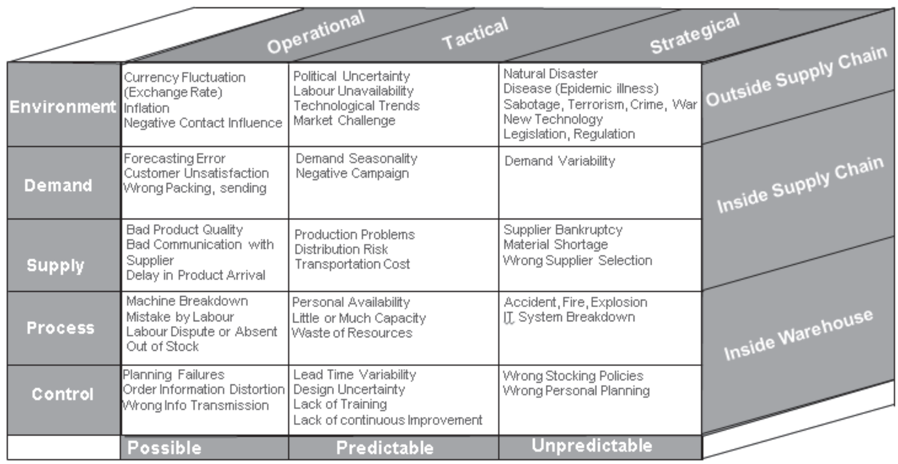


Figure 3-8: All change drivers (extended version of (Gong, 2009) and (Christopher, et al., 2004))

Environmental uncertainty stems from any disruptions and failures outside the supply chain, e.g. catastrophic loss, social crisis (protest, sabotage, war), financial crisis, and technological incompatibility etc.

Demand uncertainty represents incompatibility between, not only predicted demand by the company and the amount required by the customer, but also information and money between the local company and the market, e.g. forecasting errors, demand fluctuations, unstable markets etc.

Supply uncertainty is concerned with any unpredictable disruptions or failures of product and/or service flow from suppliers, e.g. wrong supplier chosen, supplier strike, quality problems in raw material etc.

Process uncertainty is related to any disruptions and failures of resources. If any maintenance is required, all repair operations are carried out within the individual company, e.g. breakdown in IT systems, industrial accidents etc.

Control uncertainty develops from some misapplied rules, procedures or strategies which are established to control and regulate internal processes, e.g. picking strategy, order policy, inventory management etc.

3.3 Construction of Measure Planning

Mitigation strategies are used as a measure to identify how to prevent a problem or decrease the negative effect of the problem after it occurs within the risk management concept. However, measure planning is different from mitigation. Firstly, a number of articles address these strategies which will be highlighted as follows. Secondly, the Process Chain Methodology will be introduced in order to measure determination. Lastly, more explanation about Six Steps Planning is given in order to put forward a systematic approach to searching for the appropriate measure.

3.3.1 Identification of Measures

Chopra, et al., (2004) describe how organizations could mitigate possible risk and uncertainties by using the following strategies, namely; add capacity, acquire redundant suppliers, increase responsiveness, add inventory, increase flexibility, pool or aggregate demand and increase capability. These strategies are concerned primarily with the source of demand-side and supply-side risk. For (Tang, 2006), the risk response approach is in four stages: 1) Supply management, in which by having multiple suppliers, extra inventory options can be applied to eliminate or at least reduce the unfavourable supply effects. 2) Product management mitigation strategies could be used to increase the variety of product ranges, differentiate possible product groups or to integrate dynamic assortment planning. 3) Demand management aims to cope with the uncertainty of demand, which contains forecasting, and dynamic pricing mitigation techniques. 4) Information management is available to overcome technological or related problems by using information security, transparency or collaboration methods.

One area that deserves more explanation is the distinction between ‘mitigation strategies’ and ‘measures’. The difference between these two terms exhibit that mitigation strategies focus mainly on how to lessen the undesired influence of risk and uncertainty, such as damage, hazard, crisis or incompatibility. Contrary to the described mitigation strategies, within the scope of this study, the term ‘measure’ has come to be used to refer to any precautionary behaviour in response to the perceived need of changeability.

Through the following Table 3-1, which contains some possible measure alternatives provided from the process chain methodology, the companies should be able to identify the measures for the short term, middle term and long term duration. Also, they can have an absolute idea of what measures might have an influence on capacity, cost or even throughput rate.

Table 3-1: Measure tables on the basis of planning term.

Short Term Measures	Medium Term Measures	Long Term Measures
Resources	**Resources**	**Resources**
Number of workers - **Personnel**	Quantity of machines - **Means of Production**	Layout and function-allocation- **Space**
Quantity of machines - **Means of Production**	Quantity of working Material- **Auxiliary Means of Production**	Rent, leasing, hiring ,selling, buying area - **Space**
Quantity of working material- **Auxiliary Means of Production**	Use of area (shape and large)- **Space**	Physical rebuild- **Means of Production**
Shift, changing working time - **Personnel**	Qualifications training - **Personnel**	Worker selection -**Personnel**
Over or short time, weekend working - **Personnel**		
Use of area (shape and large)- **Space**		
Quantity of vehicles (forklift, shuttle)- **Means of Production**		
Speed of vehicles, machines - **Means of Production**		
Control	**Control**	**Control**
Synchronisation -**Network Level**	Transport concept (milk run. cross dock)- **Planning Level**	Company strategy about budget -**Normative Level**
Retrieval time- **Network Level**	Supply concept(JIT, JIS, Kanban, Pearl Chain) -**Planning Level**	Environment protection -**Normative Level**
Vehicle disposition -**Network Level**	Capacity allocation based on production, distribution -**Planning Level**	Extension of market fields -**Normative Level**
Technical controlling - **Control Level**	Stock strategy - **Planning Level**	Product portfolio adjustment -**Normative Level**
Order picking lists - **Network Level**	Delivery strategy -**Planning Level**	Setting up and ending Customer - **Administration Level**
	Order picking, accumulation strategy -**Planning Level**	Setting up supplier relations- **Administration Level**
		Out and in sourcing rule - **Administrative Level**
		Pull- push system - **Administrative Level**
		Material handling system - **Administrative Level**
Structure	**Structure**	**Structure**
Transport network - **Layout**	Transport network- **Layout**	Steps of distribution network -**Layout**
	Contents of the responsibilities- **Organizational Structure**	Number of and geographic location of warehouse -**Layout**
	Routing rules -**Organizational Structure**	EDP system **Communication Structure**
	Call protocol- **Communication Structure**	Pick by light, pick by voice -**Layout**
	Collision avoidance- **Layout**	

The Measure-Filter Model

Uygun and Luft (2010) have developed a model to choose the most appropriate measure, systematically called the measure filter model. It is composed of three parts; measures store, flexibility matrix and rating system. In the measure store part, all possible measures are divided into four groups, according to the relevance of process chain components, which are control measures, structure measures, process measures and resource measures.

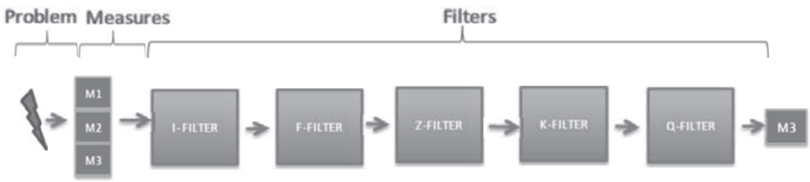


Figure 3-9: Systematic Measure Filter model (Uygun, et al., 2010).

The flexibility matrix includes five filters, and is used to show how to reach the optimum measure; see the above Figure 3-9. 1) I-Filter is available to understand the degree of interdependency among measures. 2) F-Filter is designed to test how easy the implementation of the above mentioned measure is by looking at legal requirements, physical conditions, physical adjustment etc. 3) Z-Filter quantifies the required time duration which consists of acquisition time, implementation time and resolution time. 4) K-Filter evaluates the possible measures based on financial aspects caused by setup costs, resolution costs and application costs. Lastly, 5) Q-Filter is inserted in the model to strengthen and evaluate the level of contribution, in terms of quality, and considers process management, social integration and load capacity parameters in order to decide on which measure is more suitable. . The final part of the model is a rating system that accumulates all numeric values which are assigned during measure assessment, and represents the most appropriate measure for the encountered problem. An example of a measure filter model with numerical values is demonstrated in Table 3-2.

Table 3-2: An example of the filter analysis of alternative measures.

Problem	Bottleneck on Workstation								
Problem Source	Resources	**X**							
	Process								
	Structure								
	Control								
Process	Urgent	**X**							
	Chronic								
Measure	Add new workstation			-1	-1	-1	1	1	**I Filter**
	Decrease # of orders per workstation				1	1	-1	-1	
	Increase speed of the worker					-1	-1	-1	
	Add new worker						-1	-1	
	Distance between storage and workstation							-1	
	Move shuttles on to another way								
Solution	Move shuttles on to another way		Add new workstation	Decrease # of orders per workstation	Increase speed of the worker	Add new worker	Distance btwn storage and station	Move shuttles on to another way	
Flexible	Qualification		1	1	0,5	0,5	1	1	**F Filter**
	Legal requirement		1	1	0	1	1	1	
	Physical condition		1	1	1	1	0,1	1	
	Physical adjustment		0,1	1	1	0,5	0,1	1	
	Specific flexibility		**0,1**	**1**	**0**	**0,25**	**0,01**	**1**	
Target Triangle	**Short implementation period**	**50**							**Z Filter**
	Acquisition time	30	2	6	6	5	1	9	
	Implementation time	15	1	5	5	2	1	8	
	Resolution time	5	1	5	5	3	1	5	
	Low Cost	**10**							**K Filter**
	Setup cost	6	1	6	6	2	1	5	
	Resolution cost	3	1	5	5	6	2	7	
	Application cost	1	2	5	5	1	7	7	
	High achievement contribution	**40**							**Q Filter**
	Process management	30	8	2	3	1	5	5	
	Social integration	5	5	2	3	3	5	5	
	Load capacity	5	2	3	3	5	3	3	
	Total target triangle		**366**	**421**	**456**	**296**	**259**	**663**	**Total**
Importance	Absolutely		36,6	421	0	74	2,59	663	**1197,19**
	Relative		0,03	0,35	0,00	0,06	0,00	0,55	
	Ranking		0	0	0	0	0	1	

Due to the presence of a high number of parameters, and relations that should be taken into account consecutively, this measure-filter model is not capable of providing the required performance. Even though selecting the most suitable measure concept is included within the scope of this dissertation, the measure-filter model will not be used along with this study.

3.3.2 The Process Chain Model for Measures Determination

The process chain approach is rooted in Porter's notion of the value chain (Blecken, 2009); however, Kuhn (1995) has made it widely known. He also points out that the initial point of this model is that the well-known process chain elements display system behaviour from the point of transformation logic (Kuhn, 1995). The process chain model is crated based on a purely process-oriented perspective. Besides that, Nyhuis, et al., (2009) claim that the process chain model is a model which is developed especially to illustrate and design merely for the logistics process. Moreover, the process chain model approach has a number of attractive features as follows:

Logical and sequential features construct a configuration from individual processes to describe companies in a well- structured and controllable method. This feature provides one way to understand all variety of operations, without any complexity, and this understanding can be used to manage the whole system.

Preferable visualization ability enables you to obtain a preferable visualization and analysis of the entire system. In any case, the fundamental idea of the process chain is to offer a combined representation with processes and their relations all together.

The time- oriented view means that all processes and sub- processes are arranged in time order. It facilitates following the system load, material or information flow in an easy way.

The integrated system approach makes available a holistic illustration of each process, which consists of related resources, pre-determined rules, input /output information and its structure.

Self-similarity property means that all company operations are described through the same parameters, which are also called potential classes. Because of this, it is possible to expand on the process chain by breaking a particular process into its sub-processes.

Until now, the process chain approach has been effectively implemented, with success, for a large number of application areas, such as logistics, supply chain, manufacturing and production fields, which in turn can be utilized by users, who are either familiar with it directly, or alternatively, who do not have any experience in their previous activities (Blecken, 2009).

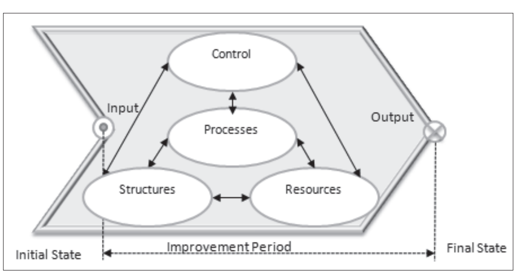


Figure 3-10: The process chain element.

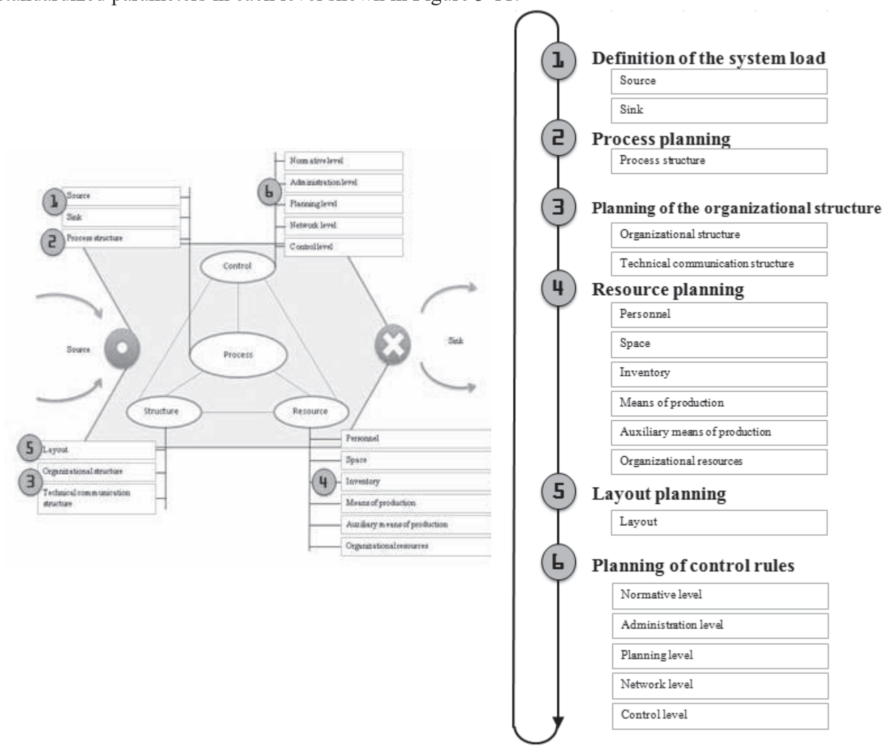
The properties of each process can be discussed under four elements as shown in Figure 3-10. These are process, structure, resource and control. In addition, every single element contains sub-components, and one process is totally composed of seventeen different sub-components; also called potential classes. In the below Table 3-3, elaborative explanations are provided for all potential classes on the basis of the following studies: (Jungmann, et al., 2009), (Blecken, 2009) and (Güller, et al., 2014).

Table 3-3: Potential classes of the process chain model.

#	Parameter	Description
Processes		
1	Process structure	Defines sub- processes which are generated to show small tasks systematically and shows the flow between processes.
2	Source	Creates performance objects (input) that flow through the processes of the system. The attributes of the source are object type, the amount of object, cost and quality of object.
3	Sink	Delivers the converted performance object into either; inside of another process, or as a source or end process such as customer, and supplier.
Structure		
4	Layout	Defines the layout of the enterprise and sets up different types of the topology structure.
5	Organizational structure	Assigns the responsibility for each process.
6	Communication structure	Describes the infrastructure of information flows and their components.
Resources		
7	Personnel	Refers to all labourers or workers who are working directly in order to fulfil the assigned task.
8	Space	Identifies special areas and fields for each process and measures the flow amount within these areas.
9	Inventory	Quantifies the amount of stocks, which includes temporary and permanent products as well as raw materials, and semi-/finished products.
10	Means of production	The performance objects which are used directly during product transformation (e.g. workstations).
11	Auxiliary means of production	Means performance objects in which the performance objects are carried or transported (e.g. pallets, bins).
12	Organizational resources	Means equipment that is utilized for information services (e.g. computer, printer).
Controlling		
13	Normative level	Includes strategic rules, values and the philosophy of the company. The mission and goals are defined clearly to reflect the other level.
14	Administration level	Establishes an interface for customers and suppliers and collects all orders in a pool to convey the list of orders to the sublevel control stage.
15	Planning level	Makes a plan to deliver the confirmed orders on a pre-determined date and optimizes all procedures.
16	Network level	Deals with all the arrangement and coordination of resources to maintain processes and to find alternative solutions if needed.
17	Control level	Observes the processing period to analyse whether the rules are applied or not and reports confirmation of completion.

3.3.3 The Six Steps Planning Method

The process chain approach does not merely imply that the company can take advantage of its high visualization feature, or holistic structure to improve understanding. Besides, it has been used to build up a planning methodology, which performs iteratively with the help of the above-mentioned seventeen process chain subcomponents. It would be easier to make an analysis and find solutions for all companies when they face an unexpected event, knowing a logical link between those subcomponents and identifying the priorities for the first response strategy. At this point, the process chain model offers the Six Steps Planning (SSP) method, which provides a repetitive cycle with the standardized parameters in each level shown in Figure 3-11.



a) ***b)***

Figure 3-11: a) The components of the process chain b) through the process chain, the Six Steps Planning (SSP).

To provide a better understanding of SSP, each main class and sub-class is explained systematically, in detail, from the point of measure planning and identification, as follows:

Definition of the system load

The system load can be defined as an object which transforms between the source and sink of process. There are five, separable features of the system load, which are: product type, the quantity of the product, the quality of the product, and cost and time parameters. A confirmed order is an example of the system load which contains within itself the amount of items inside the order and the demanded item type, the quality level of each item, total cost and the delivery time of the order.

Process planning

The second phase of the six-step planning method is to generate all main and sub processes. A main requirement is to determine the right connection between processes and arrange them in chronological order. As mentioned above, every process has a source parameter which creates performance objects, and a sink parameter which conveys the transformed performance objects into another process. However, the performance object is different for each process. For example, in an unloading process chain, pallets are unloaded from trucks in order to transport to the de-palletizing area. Within this unloading time period, the pallets are accepted as a performance object. Hence, the performance object should be defined for each process to create product and material flow. Different from pallet, empty/ full/ half-full-bin, order, box, and truck might be given as an example for the performance object.

Planning of the organizational structure

In this step, the design of the organization chart is established by allocating responsibility to each process. To maintain better performance from this model, each operation should be under one's charge. Moreover, it is obvious that the assignment of responsibility makes responding easy during failure or any change that happens.

Resource planning

The resource planning step is the fourth step in which the necessary resources are allocated for each process. All kinds of resources can be collected under five classes, these are: personnel, space, inventory, means of production, auxiliary means of production and organizational resources, which are explained in detail in Table 1 above. Having a comprehensive knowledge of resources for the concerning process provides an ability to find a suitable measure strategy for the encountered changes. In order to obtain a better understanding, the order picking process can be discussed as an example. The order picking process is executed by five workers, who are working on each workstation in workstation zones, using half/empty bins and pallets. In addition, forklifts and transportation vehicles give help to them simultaneously. Hence, all the above written resources, such as five employees, workstation machines and bins should be defined as a resource attribute for every process.

Layout planning

The next step refers to not only layout planning, but also to some topology of the above-mentioned resources. In this step, the arrangement of the enterprise structure is generated both within the sub-processes, and for the entire system.

Planning of control rules

The final step is the planning of control rules, which aims firstly to strengthen the company structure with technical or non- technical rules and principles. Secondly, it enables monitoring of the behaviour of the system load, or other parameter indicators, thus raising awareness of whether they are inside the control corridors or not. Thirdly, identification of the regulation strategy also includes respond specifications when any unexpected situations happen. In order to gain consistency between processes, the planning control level is discussed under five control layers, as shown in Figure 3-12, which are listed respectively as follows: normative, administration, planning, network and control level (Kuhn, 1995). For a detailed description of control layers, see Table 3-3.

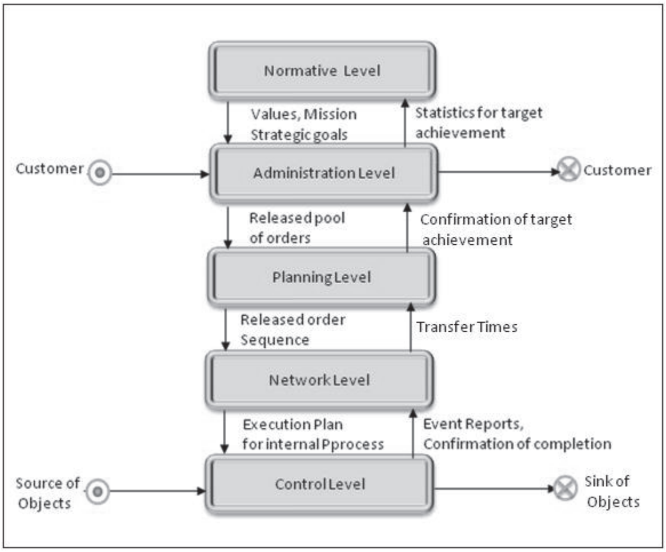


Figure 3-12: General Interface model for control levels.

3.4 Construction of Assessment Planning

In an attempt to evaluate the performance of existing systems or improved systems, an assessment model is developed which is composed of mainly two parts: 1) flexibility corridors are established to determine the upper and lower boundaries of control parameters and 2) performance availability is developed to calculate the efficiency of the overall system.

3.4.1 Flexibility Corridors

The flexibility corridors concept is not well-known in English literature. Although the origin of this concept is known to be Germany, there is still not enough published studies available describing specification of the flexibility corridors. When a company wants to implement any changeability on manufacturing or logistic systems as a strategic level decision, the key of ability is to adjust the existing system on the basis of predetermined corridors of flexibility, in a short time, and with reasonable installation costs (Baudzus, et al., 2013). The principle behind flexibility corridors thinking is to ensure whether or not the changes are located within the acceptable upper and lower limits. Quantity, quality, time, product and cost parameters could be one lengthwise measurement of the flexibility corridors. In addition to this, customer-oriented, e.g. on time delivery performance, product availability and company-oriented, e.g. throughput rate, capacity utilization parameters can be monitored under favour of the flexibility corridors. The typical flexibility corridors are provided in Figure 3-13, with its particular notation of time duration. Moreover, the procedure during change and measure implementation, such as a shift from one corridor to another after selected measures, might be understood with the help of the following figure:

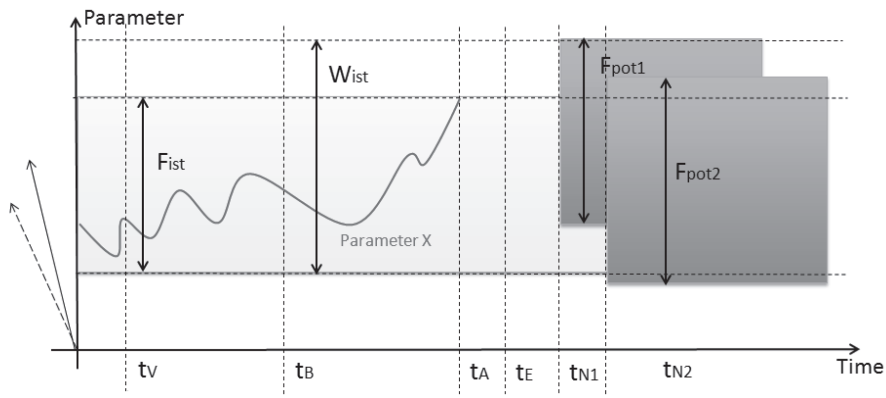


Figure 3-13: Changeability and Flexibility (Nyhuis, 2008)

t_V : Influential factor of change

t_B : Recognizing a measure requirement

t_A : Decision on measures

t_E : Time at which the existing flexibility corridor is not valid, after completion of measures

t_{N1} : Time at which the effect of decided measure N1 begins

t_{N2} : Time at which the effect of decided measure N2 begins

F_{IST} : Current flexibility corridor

W_{IST} : Current change corridor

F_{POT1} : Potential of flexibility corridor 1

F_{POT2} : Potential of flexibility corridor 2

3.4.2 Performance Availability

According to a definition provided by VDI guideline 4486, performance availability is a "Degree of fulfilment of processes agreed between contract parties (manufacturer and user) in accordance with the requirements and deadlines, and in compliance with the agreed basic conditions". Because this is a novel concept, studies to find the calculation of performance ability have not yet been completed. Up to this point, two simple ways are determined to calculate performance availability, in terms of summation of waiting times or running times. The following equations are provided on the basis of the VDI guideline 4486 report.

3.4.2.1 Conventional Model

Waiting Times:

In order to measure the performance availability by taking account into waiting times that are caused by breakdowns, worker failures or unexpected events, the following formula is used:

T_W : The total waiting time

T_B : The total observational time

η_w : Performance availability

$$\eta_w = \frac{T_B - T_W}{T_B} \qquad 3\text{-}1$$

Running Times:

If the waiting time calculation is not successful, another alternative method can be used that is based on delayed load in proportion to the total order:

N : The total amount of total load

n : The total amount of delayed loads

η_L : Performance availability

$$\eta_L = \frac{N - n}{N} \qquad 3\text{-}2$$

Nevertheless, current intralogistics systems are becoming more challenging in order to measure the situations, due to performing various operations simultaneously. Hence, the above equations are not sufficient enough to quantify the performance availability of a whole enterprise, as well as to overcome this challenge. Due to this, within the structure of this dissertation, two methods will be utilized to recognize a good way for solving this complex problem; in other words, to compute performance availability. One of them is the weighted average method, the other one is the fuzzy logic method. Both are explained briefly as follows:

3.4.2.2 The Weighted Average Method (WAM)

The average means that all the items are weighted equally. An average calculation in which each item to be averaged is assigned a weight, is called the Weighted Average Method. The weighting coefficient defines the proportion of the importance of each item on the average. The weighted average formula and notations are given below.

$$WAM = \sum_{i=1}^{n} W_i D_i \qquad 3\text{-}3$$

Where;

W_i : The weight for item i

D_i : The parameter which will be weighted

i : Item number+

n : The number of total items

3.4.2.3 Fuzzy Logic Method (FLM)

Recently, an increasing number of works use fuzzy logic for implementation in various fields, such as the description of human behaviour, demand forecasting, supply chain management etc. Fuzzy logic methodology is capable of working with both numeric and nonnumeric characters, and producing states in which to make better decisions (Sabeur, et al., 2007). In this study, the fuzzy logic approach is used to create a rule based model in order to find the degree of fulfilment of performance availability, by taking into account time performance dimensions, which are quality, quantity, product, and cost.

In the literature, there are numerous fuzzy models available: 1) the Mamdani model, 2) the Takagi-Sugeno model, and 3) Kosko's standard additive model (Sabeur, et al., 2007). Throughout this present study, the widely known Mamdani model, in which the following rules are applied iteratively, will be used.

- Fuzzification is the first step in which all input variables are converted in forms of fuzzy variables.
- The output determination step is applied to predetermined fuzzy rules with input values.
- The output aggregation step results in overall output by gathering all fuzzy rules.
- Defuzzification is the last step that matches the fuzzy output with the wanted form.

Chapter 4

Application of Simulation and Computational Study

Chapter 4 is structured to show how the Cellular Transport System (CTS) approach can be modelled and simulated gradually. In sub-section 4.2, all operations carried out in CTS are determined and depicted, both in compact and extensive levels, with the help of process chain methodology. Sub-section 4.3 comprises not only Agent-Based but also Discrete-Event simulation logic, which will be used while setting up the CTS. Design and simulation of every main warehouse activity available in intralogistics systems are explained in sub-section 4.4. In addition to the above headings, this chapter begins with an explanation of simulation software selection especially for Agent-Based simulation.

4.1 The Selection and Construction of Simulation Software

The software market offers multiple simulation software packages. Some are more expensive than some have more common features and can be used in a wide range of application areas, whereas others are more suited to only one field. Some also have a strong aspect of modelling, whereas others provide only essential features. In other words, there are too many properties that make each simulation package different. All simulation packages' particular strengths and weaknesses differ from one another. This makes it too hard to select and purchase a simulation package; and finding the appropriate simulation package is important as it can save a lot of money. On the other hand, a selection of inadequate packages can result in delayed and disrupted projects, and a loss of time and resources.

Due to the significance of the evaluation and selection of appropriate simulation software, both academics and simulation users in business are interested in research in this area. There are sufficient papers available that provide methods and strategies in order to evaluate the simulation packages for Agent- Based simulation. Examples of the studies related to simulation evaluation and selection are as follows:

Holder (1990) approaches the selection of simulation software structurally. In accordance with this approach, firstly the available resources within the organization are determined and then the simulation purpose is ascertained. This strategy facilitates the choosing of simulation software since the list of possible simulation software is reduced by evaluating priority.

Table 4-1: Literature Review on Agent-Bases Simulation Software Selection

Article	Year	Authors	Agent-Based Simulation Packages (ABSP)
Agent Toolkits: A General Overview of the Market and an Assessment of Instructor Satisfaction with Utilizing Toolkits in the Classroom (Serenko, et al., 2002).	2002	Alexander Serenko Brian Detlor	20 ABSP
Evaluation of Free Java-Libraries for Social-Scientific Agent Based Simulation (Tobias, et al., 2004).	2004	Robert Tobias Carole Hofmann	RePast, Swarm, Quicksilver, VSEit
Agent-Based Simulation Platforms: Review and Development Recommendations (Railsback, et al., 2006).	2006	Steven F. Railsback Steven L. Lytinen Stephen K. Jackson	NetLogo, Swarm, MASON, Repast, Java Swarm
Principles and Concepts of Agent-Based Modelling for Developing Geospatial Simulations (Castle, et al., 2006).	2006	Christian J. E. Castle Andrew T. Crooks	Swarm, MASON, Repast, StarLogo, NetLogo,OBEUS, AgentSheets, AnyLogic
Agent-Based Modelling (Getchell, 2008).	2008	Adam Getchell	RepastPy, Repast Simphony, and Breve
Environment Mediated Multi Agent Simulation Tools –A Comparison (Arunachalam, et al., 2008).	2008	S. Arunachalam, R. Zalila-Wenkstern, R. Steiner	NetLogo, MASON, Escape, RePastS, DIVAs
Tools of the Trade: A Survey of Various Agents Based Modelling Platforms (Nikolai, et al., 2009).	2009	Cynthia Nikolai Gregory Madey	53 ABSP
Survey of Agent Based Modelling and Simulation Tools (Allan, 2010).	2010	Rob Allan	44 ABSP
The Evolution of Agent-Based Simulation Platforms: A Review of NetLogo 5.0 and ReLogo (Lytinen, et al., 2012).	2011	Steven L. Lytinen Steven F. Railsback	NetLogo, Repast, (ReLogo)
Framework for Evaluation and Selection of the Software packages: A Hybrid Knowledge Based System Approach (Jadhav, et al., 2011).	2011	Anil S. Jadhava, Rajendra M. Sonarb	ActiveSMS, SMSDemon, GSMActive, SMSZyneo
Agent-Based Simulation Platforms: An Updated Review (Lytinen, et al., 2011).	2011	Steven L. Lytinen Steven F. Railsback	NetLogo, Repast, (ReLogo)
Introductory Tutorial: Agent-Based Modelling and Simulation (Macal, et al., 2006)	2011	Charles M. Macal Michael J. North	Repast, Swarm, MASON, Anylogic

Davis and Williams (1994) evaluate and select the best simulation software using the Analytical Hierarchy Process (AHP) model, which proves to be a good aid for structuring problems, evaluating alternatives and making good decisions.

Hlupic and Paul (1997) represented approximately three hundred criteria for the evaluation and selection of simulation software. Not only the amount of criteria, but also their levels of importance are applied in the manufacturing environment. Hlupic et al. (2002) developed a software tool, SimSelect, which selects suitable simulation software based on the required features. Verma et al., (2008) presented a comprehensive framework which can be used for evaluation of a simulation software package. The evaluation criteria are divided into four main groups, which are further classified into subgroups according to their characters. These main groups include hardware and software considerations, modelling capabilities, simulation capabilities and input/output issues. Dias et al. (2011) dealt with discrete-event simulation selection in a different way. The authors claimed that simulation packages are selected by looking at the intensity of usage which they called popularity, instead of making specific judgments. Forty parameters are used to find the top ten 'most used' and 'best' contemporary tools.

Although, in the past few years, there has been an interest in using ABS, the survey of available ABS packages is limited. In addition, there are not sufficient papers that provide methods and strategy in order to evaluate the simulation packages for ABS. Significant papers with their explanations are listed in the above table. As can be seen, academics and simulation users in business are interested in research in this area, especially during recent years. For instance, Nikolai, et al., (2009) compared and classified approximately fifty three agent based simulation software packages based on system performance, and user interface.

4.1.1 Available Simulation Software Based on the Application Field

Simulation is used increasingly as an analysis and evaluation method by modelling complex, dynamic and stochastic behaviour of all types of systems, but especially manufacturing applications; see Figure 4-1. The main reason for this increase is competition within the industry and the enormous attention on the use of automated manufacturing systems. Additionally, visual and interactive features of simulation packages provide a better understanding and are easier to use when applied in industrial environments. Abu-Taieh and Sheikh (2007) represent another twenty one applications with their percentages as seen in the following Figure 4-1.

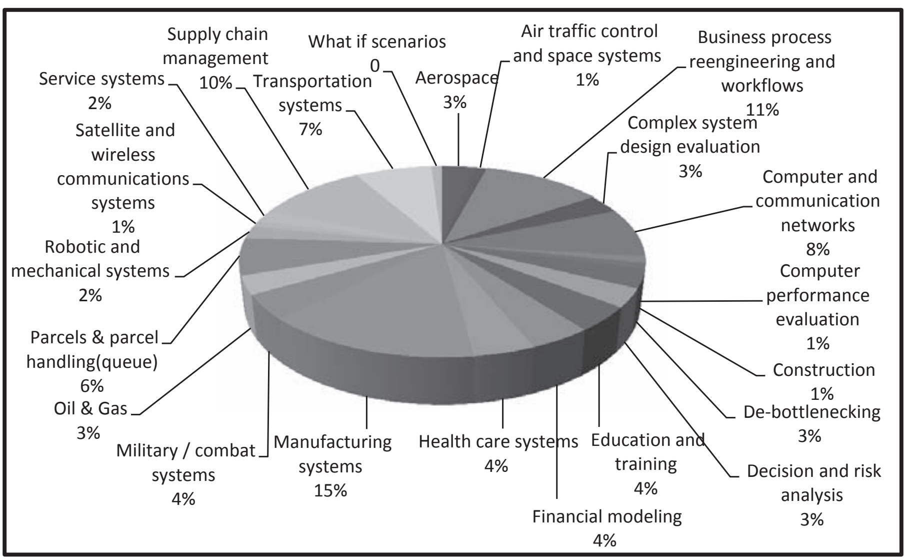


Figure 4-1: The Application Field of Simulation Packages

Four simulation tools that perform according to agent based principles are selected to decide which one could be more appropriate within the scope of this thesis. The choice is based on the importance of the environment in literature, and these packages are considered to be among the most effective platforms in the market: AnyLogic, MASON (Multi-Agent Simulation of Neighborhoods), RePast (Recursive Porous Agent Simulation Toolkit) and NetLogo. Some fundamental information about these most recognized packages, such as developers, date of inception, license type and programming language are summarized in the following Table 4-2.

Table 4-2: Technical Information of ABS software (Nikolai, et al., 2009)

ABSP	Developers	Date of Inception	License	Programming Language
AnyLogic	XJ Technologies, Russia	2009	Proprietary	Java; UML-RT (UML for real time)
MASON	George Mason University, USA	2003	Academic Free License (open source)	Java
NetLogo	North-western University, USA	1999	GPL General Public License	NetLogo
Repast	University of Chicago, USA	2000	BSD Berkley Software Distribution	Java; Python; Visual Basic, .Net, C++, J#, C#

4.1.2 Simulation Software Evaluation Criteria and Methodology

Law et al. (1991) distinguish the simulation tool from simulation languages and classified either as a simulation language, or simulator that has the same meaning as the simulation tool and simulation packages. When simulation language is employed, such as SIMAN, the simulation model is developed by writing a program. Although this technique supports much more flexibility, it is hard to learn and costly. On the other hand, the simulator enables users who have some previous experience in simulation to model the system with little or no programming experience. Due to this advantage, simulators have been preferred in business and manufacturing areas in recent years instead of simulation languages. AnyLogic can be given as an example of a simulator.

Although four simulation packages; AnyLogic, MASON, RePast and NetLogo can be applied in the intralogistics environment, and have some common features, like testability, analysis capability and visuality, there are many differences between these software packages. In the literature, Arunachalam et al. (2008) supported the following Figure 4-2 with main- and sub-criteria. While the top level represents the purpose of the study, which is selecting the best suitable software package, the second level consists of four main classes of assessment criteria which are namely, design criteria, model specification criteria, model execution criteria, and documentation. The third level consists of sub-classes of each main criterion. Finally, the bottom level represents available packages which will be chosen as a best tool.

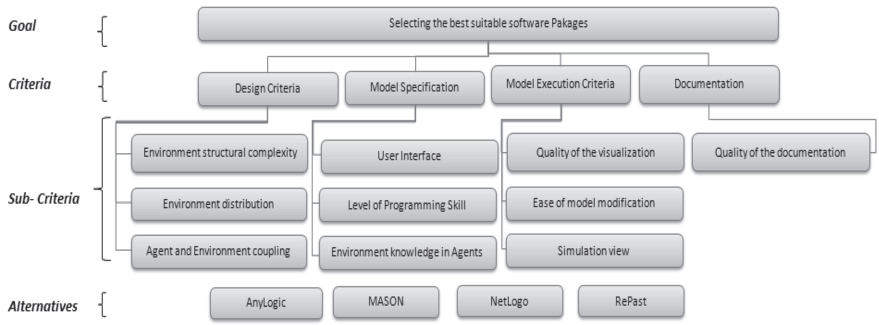


Figure 4-2: Evaluation Criteria for simulation Software Selection (Arunachalam, et al., 2008)

Four levels are determined, which are low, medium, high and very high, in order to evaluate the design criteria. To understand which case of the design criteria should be evaluated under which level, the following table is prepared based on the study of (Arunachalam, et al., 2008). With the help of Table 4-3 below, every kind of simulation software can be simply be assessed. . This process could be illustrated by giving an example. Evaluating the structure of the complexity of any kind of simulation tool is based on four different properties, namely grid, graph, continuous space or hybrid. If the simulation software provides only the continuous space feature, its structure complexity is scored as a high. All other assessments of each criterion are collected in the following Table 4-3.

Table 4-3: Evaluation Criteria for Simulation Software Selection Based on the (Arunachalam, et al., 2008) Study.

Design Criteria	Low	Medium	High	Very High
Structure complexity	Grid	Graph	Continuous Space	Hybrid
Environment distribution	No Distribution	Distributed processing	Distributed structure	Distributed structure& processing
Agent-Environment coupling	Very high coupling	High coupling	Average coupling	Low coupling
Quality of user interface (UI)	No feature can be specified	Simple environment model features can be specified	Most features can be specified using the UI	All features can be specified using the UI
Programming skill	Required very high programming skills	Required high programming skills	Required average programming skills	Required low programming skills
Environment knowledge in agents	Both the node and coordinate information are provided to agents	The existence of the node in the environment is specified and the location of the node is read at run time	The agent only has the knowledge of the node existence and does not know their location in the environment	Not pre-specified in agents
Visualization quality	Poor image rendering of agent movement and environment	Poor image rendering of agent movement, good for environment	Good image rendering of agent movement and environment	Excellent image rendering of agent movement and environment
Change of properties of a model	Cannot modify properties during simulation. Need to program the changes	Cannot modify properties during simulation. Make changes and re-run	Can modify properties without stopping simulation. Have to re-run simulation to see changes	Can modify properties without stopping simulation. Changes take effect immediately
Simulation view	2D, non- toroidal	Visual 2D programming for 3D programming for toroidal space	2D inspection programming for 3D, Toroidal space	Provide 2D, 3D, rotations, inspection, etc. Choice between toroidal and non-toroidal environment space
Quality of documentation	Provides low grade documentation quality	Provides sufficient documentation quality	Provides high documentation quality	Provides very high documentation quality

The rating process is composed of two stages. Firstly, the total rating values of MASON, NetLego, Repast simulation packages are obtained from the research of (Arunachalam, et al., 2008). Secondly, the rating values of AnyLogic simulation software have been acquired from the AnyLogic (former XJ Technologies) company. The overall values that belong to the four simulation softwares are given in Table 4-4, Table 4-5, Table 4-6 and Table 4-7.

Table 4-4: Rating for Design Criteria

Design Criteria			
Simulation Tool	**Structure Complexity**	**Distribution**	**Coupling**
NetLogo	Low	Very High	High
Mason	High	Low	Low
RePast	Very High	Medium	Low - Medium
AnyLogic	Very High	Very High	Very High

Table 4-5: Rating for Model Specification Criteria

Model Specification Criteria			
Simulation Tool	**User Interface**	**Programming Skill**	**Agent's Knowledge of Environment**
NetLogo	High	High	High
Mason	Low	Low	Low
RePast	High	Low	Very High
AnyLogic	Very High	High	Very High

Table 4-6: Rating for Model Execution Criteria

Model Execution Criteria			
Simulation Tool	**Visualization Quality**	**Modifying the Model**	**Simulation View**
NetLogo	Medium - High	Medium - High	High - Very High
Mason	Medium	Low	Medium
RePast	High	High	Very High
AnyLogic	Very High	High	Very High

Table 4-7: Rating for Documentation

Documentation	
Simulation Tool	**Quality of Documentation and Tutorials**
NetLogo	Very High
Mason	Very High
RePast	High
AnyLogic	High

Based on these results, it is concluded that the most preferred choice is clearly AnyLogic, which is also introduced in detail by giving general and specific features as follows:

AnyLogic, developed by XJ Technologies, is constructed as a multi-paradigm simulation modelling tool. Until recently, there were no commercial tools for agent-based modelling, t/here were just some small libraries which are coded in Java or C++. AnyLogic, however, is a tool that not only uses the historical simulation models like Discrete-Event, and Continuous-Event simulation, but also includes Agent-Based simulation to overcome complexity in the real case. Generally, simulation tools provide one or two simulation paradigms, while AnyLogic is probably the unique tool that enables the users to benefit from all the common simulation paradigms within the same visual environment: Discrete-Event, System Dynamics and Agent-Based simulations.

Moreover, it makes it possible to create different part of a model, by using different types of simulation methodologies to capture a more appropriate model. The Railway-Station Simulation illustrates this point clearly. The schedule of trains could be modelled as a discrete event model, whereas the passenger could be accepted as an agent when inserting their behaviour into the model. The AnyLogic simulation tool supports Object-Oriented design and could be extended by writing Java code inside the tool.

4.1.3 Reasons for Selecting the AnyLogic Simulation Package

There are more than two hundred different kinds of simulation software available in the market, including non-commercial tools. All software has some basic and specific features. However, they are different from each other in the sense that they have a certain built-in feature, which is suitable for a particular logistics application. Hence, the real system needs to be studied in all aspects and the desired result should be fully understood before the software can be selected. Additionally, it is obvious that neither of the simulation tools satisfies all criteria to the highest level nor can be appropriate for all objectives. However, one of the most important factors is to identify which software is more suitable than other packages according to planned purposes. Taking account all four of the other simulation packages' features and results obtained from selection analysis, in this study the AnyLogic Software is chosen. The main reasons are given as follows:

1. The majority of the existing simulation tools are specified for one or two particular simulation methodologies. For instance, Arena, AutoMod, ProModel and Extend, which are well known simulation tools in the market, are designed for discrete-event simulation. However, AnyLogic provides a common environment to generate not only stand-alone discrete-event, system dynamics or agent- based models, but ones that can be used in any combination. Integration of these models results in a more detailed simulation model which reflects reality more accurately.

2. Due to the Java environment, users are capable of obtaining great extensibility through the model they are creating. Uncommon or specific tasks and requirements could be fulfilled by writing java-code-functions inside the simulation program. Moreover, it is achievable to run the model without having a development program because of the significant benefits of the Java Applet application.

3. One certain strength of AnyLogic is the visual environment that accelerates the users' speed by dragging and dropping objects from the library to the development area. It is true to say that included object libraries enable one to build simulation in a quick and easy way.

4. Abu-Taieh and Sheikh (2007) recommend AnyLogic for the complex and more detailed models such as supply chain management or transportation systems. This study is supposed to be as complicated as the models mentioned above. It would have been concerned with both general warehouse activities and with the effects of some other external factor.

4.2 Design and Configuration of Cellular Transport Systems

The Cellular Transport System (CTS) is a novel methodology as an intralogistics system. Because of this, it is not known which operations should be included in the CTS. As mentioned previously, the CTS design totally differs from other alternative systems in terms of conveying items and storage rack structure, but still there exists basic operations which are contained within all kinds of intralogistics systems such as, order picking, storage, receiving shipping products etc. In the following section, all essential warehouse operations within the context of CTS are explained and illustrated through the process chain model.

4.2.1 Main Model

In this section, a major effort is made to determine how to structure the main model of CTS. The four main operations of warehousing, receiving, storage, picking and shipping are widely known. However, decisions about other main activities have a great importance, not only in determining process chain structure but also designing simulation programs. The major operations that are carried out in CTS can be discussed under eight headings. These are: customer order construction, warehouse management, order picking, order purchasing, receiving, replenishment, and storage and shipping, and are demonstrated in the following Figure 4-3.

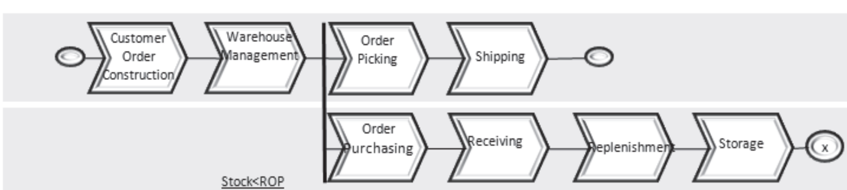


Figure 4-3: The main processes of the Cellular Transport System

In the above graph, the processes are arranged in time order. Hence, it is easy to follow the material or information flows, and the reason for changing direction from one process to another process. For instance, if the amount of stock is lower than the re-order point, the flow direction is shifted to the order purchasing process; except for when it cannot be known which process is under whose charge. At this point, the following Figure 4-4 is provided for matching the responsibilities of each process;

this is the third step of the process chain model. The order purchasing process, for instance, is carried out by the supplier, whereas order construction and order receiving is directly related to the customer.

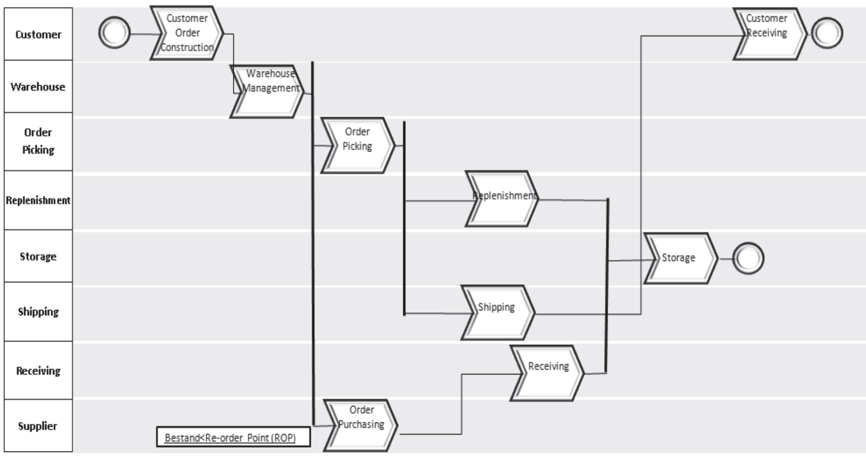


Figure 4-4: The main processes of the Cellular Transport System with their organization structure.

One way to understand what is going on within the organization, and to use that understanding to make better decisions and to plan, is to elaborate on the process chain model by adding sub processes. For example, the receiving process is grouped into five sub-processes, which are; unloading pallets from trucks, storing pallets in a high-bay storage rack, forklifts getting the pallet from storage to the de-palletizing area, the de-palletizing process and extracting products. Other processes associated with their sub processes are listed below, and Figure 4-5 shows the whole system comprehensively.

Customer: start order, get customer request, receive order and finish order

Order construction: construct order, accumulate orders, calculate required amount in terms of the product, calculate required bins, send message to shuttle and check the amount of storage.
Order Picking: bring required bins by shuttle, accept bins, allocate orders, carry bins by shuttle and complete the order.
Replenishment: receive empty bins, replenish bins, de-palletize and extract products into bins.
Storage: carry half-bins and full bins to storage by shuttle, and store bins.
Shipping: palletizing, take pallets by forklift, store pallets in a high- bay storage rack, loading into trucks.
Supplier: purchase items and prepare the order.

In addition to detailing features of the below in Figure 4-5, it is possible to observe performance objects that transform from one process to another process. Pallet, empty/ full/ half-full- bin, order, box and truck are defined as performance objects for the entire CTS.

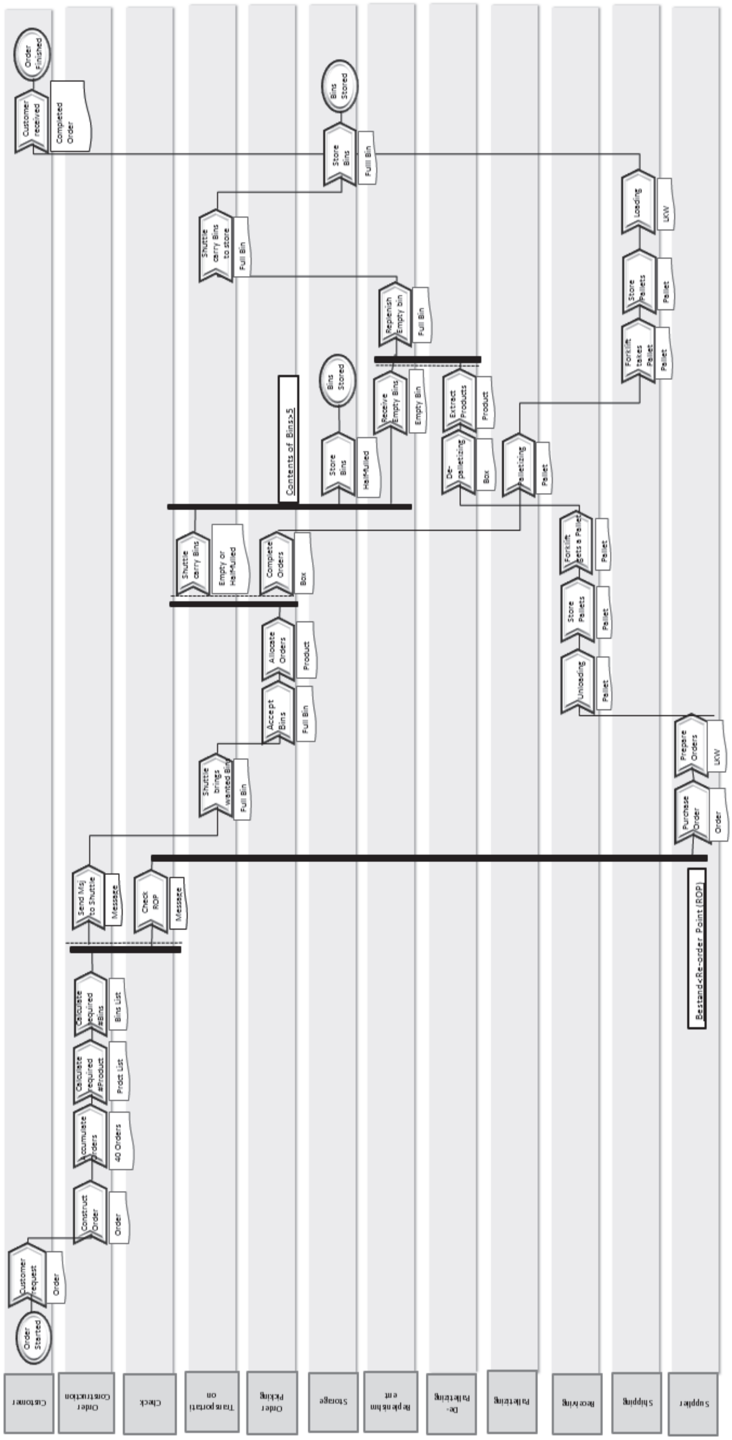


Figure 4-5: The sub- processes of the Cellular Transport System with their organization structure and specific system load

4.2.2 Process Control Levels

In order to make all processes work in order, various specific rules and strategies are determined for each process. Planning of control rules is the last step of the process chain and it is entrusted with managing and executing the task of these kinds of rules. The planning of control rules can be discussed under five headings; normative level, administrative level, planning level, network level and control level, and are designed to be in contact with each other by sending execution plans, order lists or scheduling information, and by receiving confirmation of plans, event reports or statistics for aim completion etc. To gain a better insight into these levels, comprehensive expressions and an example concerning the order picking operation are provided below.

The Normative Level; the level is the first level in which top executives determine the values, missions and strategic goals directly related with the entire company For the order picking process, the goals could be the completion of all obtained orders on time, with perfect customer satisfaction, and without any failures or complaints. The previous sentence might be so general that it is acceptable for all types of company. It, thus, can be specified more by adding numbers or dates. For instance, the strategic purpose could be to deliver the customer order within three days, and the percentage of complaints should be under 5 %.

The Administration Level deals with customers, not only when orders are being entered in the system in the form of system load, but also after order completion, such as during the order delivery process. All orders are accumulated in a pool, and a vast number of analyses are made to evaluate whether the existing system is capable of handling the batch of the order or not. From the order picking process aspect, the order list which is rearranged based on product type is generated for each workstation. This level needs to obtain the conformation of target achievements from the subsequent level.

The Planning Level is in charge of arranging order sequence and matching the picking list with the workstation. In conventional intralogistics systems, the picking lists are allocated to pickers, whereas the picking lists are assigned to shuttles in the case of this study. On the other hand, planning levels needs to obtain the completion times of orders from the next level, namely the network level.

The Network Level is entrusted with all execution plans for internal process that are worked out. The other name of this level is 'workflow level', in which all kinds of information and material flows are supervised to complete the order accurately and efficiently. For the case of the order picking operation, the chief or foreman hands out the execution plan to the worker in the workstation. After order lists are filled out, event reports and confirmation of completion are demanded from the successive level, which is the control level.

The Control Level is the last level of the control procedure and is responsible for managing and checking the operation when it is taking place. This level is a connection between the source of objects and the sink of objects during the transformation of the system load. The speed of the shuttle, the number of shuttles, idle times for each worker, the total number of prepared orders, and the performance of workstations are reported after the operation is successfully achieved.

The rules concerned with all the essential operations of the cellular transport system are determined and given in the following Table 4 -8.

Table 4-8 Process Control Levels for the CTS model

Process	Potential Classes	Task	Link of Potential Classes	
Customer Order Construction	Normative	Register customer orders without any mistake and give a true and possible delivery date.	Aim. ↓	↑ Statistics
	Administrative	Get customer demands which include different items.	Customer demand. ↓	↑ Confirmation of delivery
	Planning	Check the availability of items, find the optimum date.	Data availability. ↓	↑ Confirmation of date
	Network	Create a new order. Enter customer information and generate a delivery date for the customer.	Registered info. ↓	↑ Accuracy of registration
	Control	Check whether delivery date is possible or not. Ensure the accuracy of customer info.		
Warehouse Management	Normative	Complete customer order on time without any failure. Provide customer satisfaction.	Aim. ↓	↑ Statistics
	Administrative	Collect customer orders in a pool. Decide whether to supply new items.	Orders' list, Supply Order. ↓	↑ Completion time
	Planning	Categorize orders ex. based on colour. Decide optimal number of supplied item.	Total Item List # of required item to purchase. ↓	↑ Confirmation list. ↑ Amount of supplied item.
	Network	Create purchasing order. Evaluate total quantity of bins required which are carried by shuttle. Prepare a list of bins for each item.	Total required bin list. Supplier Info. ↓	↑ Accuracy of list.
	Control	Check supplier information. Crosscheck for the calculation of the quantity of bins Ensure the accuracy of these lists.		
Order Picking	Normative	Complete order before determined delivery date.	Aim. ↓	↑ Statistics.
	Administrative	Obtain how many bins should be transferred. Make analysis about system load.	Amount of required items for picking process. ↓	↑ Total picked items list.
	Planning	Assign customer orders to the specific workstation. Find the quantity of optimum shuttle to complete whole order list.	Workstation-order assignment list. ↓	↑ Completion time.
	Network	Prepare order- workstation list. Prepare worker execution plan.	Execution plan. ↓	↑ Report of completion order.
Shipping	Normative	Complete order shipment properly and on time	Aim. ↓	↑ Statistics.
	Administrative	Get information on the total amount of prepared boxes and distinguish them according to features.	Total volume of shipment. ↓	↑ Completion time.
	Planning	Evaluate required number of pallets and resources (forklifts, pallet storage). Optimize the amount of trucks.	Available resource list. ↓	↑ Performance of resources.
	Network	Prepare resources schedule. Arrange palletizing-execution plan. Prepare shipment schedule.	Shipment schedule. ↓	↑ Shipment reports.

Purchasing	Normative	Receive necessary items from right supplier at right time and with right price.	Aim	Statistics.
	Administrative	Collect required products and categorize them and their features ex. urgency, price, lead time.	Required order item list.	Confirmation of supply delivery.
	Planning	Arrange the quantity of optimal product based on price and determine the right supplier between other alternatives.	Product- supplier list.	Performance of supplier.
	Network	Prepare product list to supply.	Purchasing list.	Purchasing report.
	Control	Total amount of purchased products. The lead time.		
Receiving	Normative	Receive and store new products regularly.	Aim	Statistics.
	Administrative	Get information on the total incoming pallets and analyze the storage and replenishment capacity.	Inbound pallets amount.	Completion time.
	Planning	Optimize the necessary resource usage e.g. forklift, pallet storage.	Available resource list.	Performance of resources.
	Network	Prepare the resource plan. Prepare de-palletizing execution plan.	Execution plan.	De-palletizing report.
	Control	The quantity of opened pallet. The throughput rate. The duration of forklift charging.		
Replenishment	Normative	Replenish the products timely and satisfy the warehouse needs.	Aim.	Statistics.
	Administrative	Obtain the total amount of empty bins and the available products which should be filled in a bin.	The list of empty bin. Items list which are placed in bins.	Completion time.
	Planning	Arrange shuttle and other resource needs. Optimize these resources' utilization.	Available resource list.	Performance of resources.
	Network	Prepare filling strategies.	Execution plan.	Replenishment report.
	Control	Total refilled bins. The speed of filling.		
Storage	Normative	Minimum storage, high circulation.	Aim.	Statistics.
	Administrative	Get information on the amount of product that should be stored and the amount of product to be received. Select storage strategies, choose storage strategies.	Strategies and methods.	Confirmation of storage efficiency.
	Planning	Determine the storage capacity. Organize the location for each product.	Capacity, location info.	Usage of capacity.
	Network	Generate storage plan. Keep products in a right condition.	Storage plan and rules.	Stored product info.
	Control	Total stored products for each category. Usage amount for each product category.		

4.3 The Simulation Approach for Cellular Transport Systems

Simulation methodology is generally based on one kind of paradigm, such as: Discrete-Event, Continuous-Event and Agent-Based Simulation. In contrast to the conventional simulation tools, AnyLogic is a single tool that gives freedom to users to utilize the all too common simulation paradigms within the same visual environment. In the current study, a hybrid model, which is combination of discrete event and agent based simulation, is used. For the purpose of further explanation, both simulation paradigms with an example are explained as follows. Then, the responsibilities of all agents, such as customer, shuttle or machine created on the basis of Agent Based Simulation under the concept of CTS simulation are introduced with their behaviour state diagrams.

4.3.1 The Logic of Discrete- Event Simulation

The main principal behind discrete- event simulation thinking is that the modellers investigate the system from the aspect of a process structure. In this methodology, the flow between entities plays a key role. In many cases, this kind of structure starts with a source entity which produces input into the system i.e. orders, finishes product etc., and ends with a sink entity in which the input variables are eliminated from the system. This kind of flowchart diagram is similar to the process chain paradigm explained in Chapter 3.

In the following Figure 4-6, a discrete event structure obtained from a CTS simulation, is given as an example. The main benefit of this kind of flowchart is that the following of streams between entities is simplified due to the sequential construction. It is constructed to insert initial stock principals into the simulation. The flowchart starts with a source, however, it does not finish with a sink, since this initial stock will be picked and delivered to the customer throughout the simulation period. After being product generated, the total amount of bins are put into storage. The model logic of unloading and replenishment Figure 0.1, the model logic of storage Figure 0.2, the model logic of loading and order picking Figure 0.3, and the model logic of workstations Figure 0-4 are shown in Appendix A.

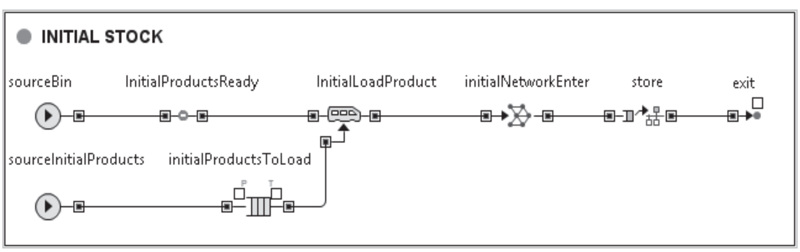


Figure 4-6: Discrete event structure screenshot from a CTS simulation.

4.3.2 The Logic of Agent - Based Simulation

As is comprehensively explained in Chapter 2, Agent-Based modelling is established based on autonomous and decentralized thinking. The agent-based model is composed of some active objects which are referred to as an agent. In the CTS simulation, customers, shuttle vehicles, charge machines, left/ right lifts, enter/ exit points and workstations are created as an agent. In this modelling technique, each single agent has several specific behaviours that are embedded into agents by using state charts. A state chart or state diagram is a graphical approach which can be used instead of writing programming code. Such a diagram facilitates the expression of events and the behaviour of agents efficiently and accurately. State charts are generally composed of states and transitions. All agents created are within the context of CTS simulation, and are explained comprehensively as follows.

4.3.2.1 Customer Behaviour

The Customer Behaviour state chart consists of four states, namely the Initial State, Ordering State, Order waiting and the Order Completion State, and of six transitions: Initial Order, Order Waiting, Order Start, Order Start-Again, Preparing and Finished Transition, which are shown in Figure 4-7.

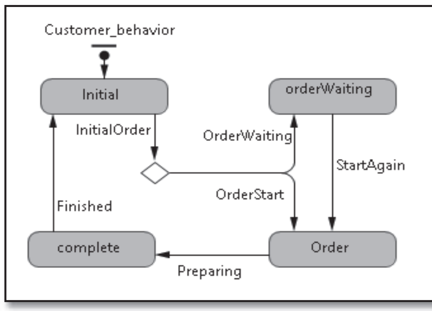


Figure 4-7: The state chart of customer behaviour.

At the beginning of the simulation each customer is at the '*Initial State'*. If any orders have not been entered into the system yet, the agent stays in the 'Order *Waiting State'*, to wait for the '*Create Order'* message which is inside the '*Order Start' and 'Start Again'* transitions. After receiving the '*Create Order'* message, agents move their current state to the '*Ordering State',* which could involve some specific Java Code, in order to extend the agents' property in response to user requirements. For instance, different types of order-items belong to a specific customer, and their pending distribution can be defined during the '*Ordering State'.* At the *'Ordering State'* point, agents wait for the message '*Preparing*' to be written during the '*Preparing'* transition, until the agents jump to the '*Order Completion'* state. At the last step, agents return to their first state once they are triggered by the '*Complete*' message inside the '*Finished'* transition.

4.3.2.2 Multi Shuttle Behaviour

The Multi Shuttle Move, an integration of the autonomous shuttle structure with the Automated Guided Vehicle (AGV) principle, has been implemented in an attempt to create a novel and effective intralogistics system. The main advantages of multi shuttles is not only that they are capable of moving on the rail which is mounted in the storage rack, but also that they are able to leave the storage rack and to work as an AGV by using open path navigation. Therefore, shuttles are charging both inside the storage and outside the storage. There are five main responsibilities embedded into each shuttle which are: retrieval responsibility, storage responsibility, collecting empty bins, charging, and collision avoidance. The entire responsibilities of shuttles generated using state-charts are provided as follows in Figure 4-8.

Retrieval Responsibility

The first task of shuttles under the retrieval responsibility is to arrive at the right level of storage in order to pick the requested retrieval process. Secondly, the shuttles move in an attempt to reach the workstation areas by using lifts. Generally, the retrieval process can be performed in a parts-to-picker or picker-to-parts method. In this simulation, the retrieval process is carried out based on the *'parts-to-picker'* method, which is also called 'materials-to-man'. This method means that pickers are waiting in front of workstations and the products are conveyed from storage to workstation by conveyors. The main benefit of this system is to reduce the total travel time of workers within the storage racks. Also, the parts-to-picker method is suggested for automated or autonomous intralogistics systems.

In the literature, the important methods for sequencing of retrieval process are determined under three headings: 1) First-come-first-served (FIFO) refers to retrieval requests that are listed based on the arrival sequence. 2) Shortest Completion Time means that the retrieval requests are ordered according to completion time and the shortest one is selected as being first. 3) The nearest neighbour method in which retrieval requests and storage requests are paired in order to find the minimum distance between two requests. In the proposed CTS simulation, the retrieval requests are fulfilled based on the FIFO method.

From the aspect of the sequencing problem of unit-load, the two cycle methods that feature in literature are: 1) the single command cycle, which states that merely a unit-load is transported, in other words, the command cycle could be either storage or retrieval. 2) The dual command cycle, which includes a combination of storage and retrieval requests which are performed sequentially. In the CTS simulation, the single cycle command is used because of the periodical arrival rate of storage requests.

Storage Responsibility

The storage process is divided into two types based on the fill rate of bins: 1) the storage of full bins process is related to the storage of products that are brought from the supplier. In order to accomplish this task, shuttles are responsible for arriving at the replenishment area to take full bins and move them to the storage area. 2) The storage of half bins process is concerned with the storage products that remain after being allocated at the order picking station. During this process, shuttles have to check the number of products in each bin after product sorting, based on customer requests. When the quantity of bins is higher than the re-fill-point that is predetermined as an operational decision, the bin should be conveyed to storage by shuttles again. Therefore, storage requests are not only in the current study but also in many cases stored with respect to the first-come-first-served principle.

Collect Empty Bins

If the number of products in one bin is lower than the re-fill-point, these bins are called empty bins. Within the context of the simulation, shuttles are also responsible for collecting empty bins to carry to the replenishment area to fill again.

Charging

A shuttle uses a kind of battery for obtaining energy which provides approximately four hours of travelling, both inside the storage and on the ground. When the state of battery is lower than a pre-specified limit, the shuttle is supposed to go to the charging area to recharge. The fill rate of the battery is continuously checked, every second, by a specific function which is embedded in the simulation.

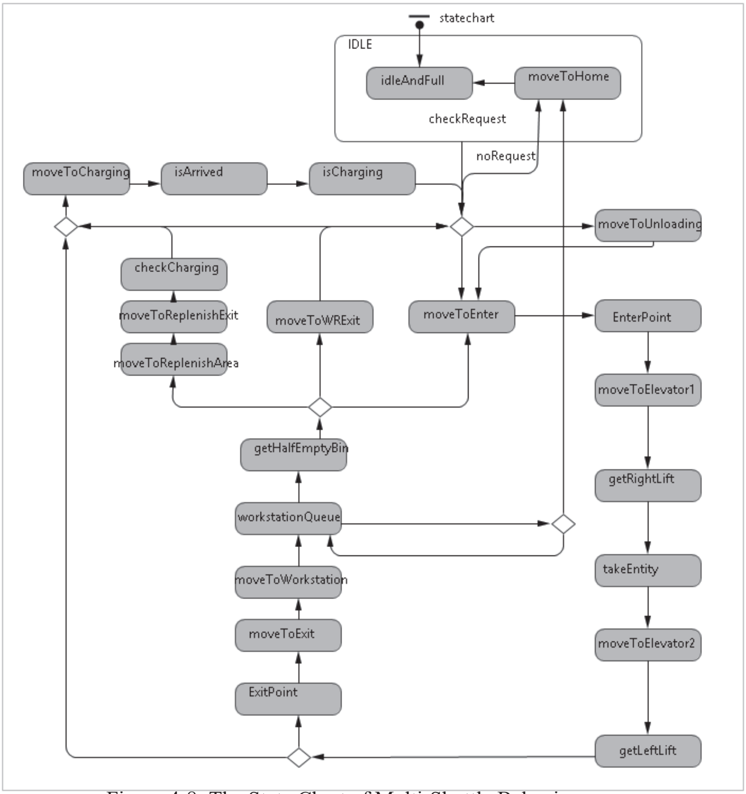


Figure 4-8: The State Chart of Multi-Shuttle Behaviour.

Collision Avoidance

In order to avoid collision between two or more shuttles, the following state diagram shown in Figure 4-9 is created which measures, firstly, the distance between all shuttles during travelling. When two shuttles are present within the collision range, first one stops and waits until the second shuttle leaves the predetermined range. In the meantime, the second shuttle makes an effort to run away immediately by accelerating its velocity.

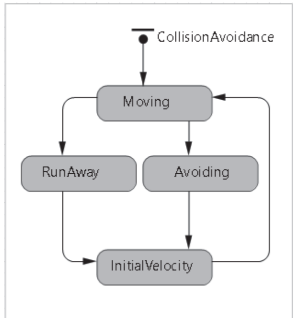


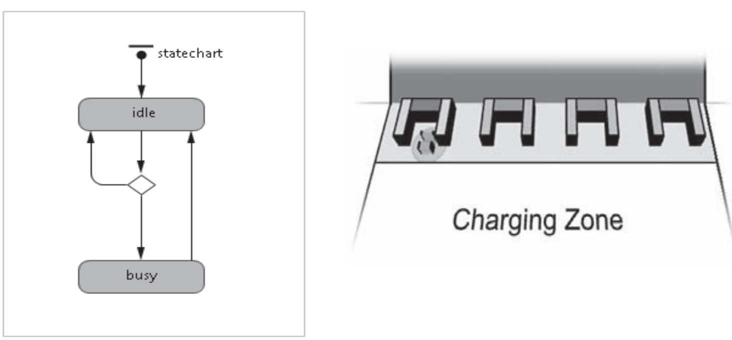
Figure 4-9: Collision Avoidance State Chart.

4.3.2.3 Machine Behaviour

Charging Machine

In the CTS simulation, four charging machines are located in the shuttle-home area in an attempt to recharge the empty batteries of shuttles. To answer the question as to which charging machine should be selected, three different strategies are established. These are: 1) *Random* Selection, which means that any machine is chosen arbitrary 2) *In Order which* means that all charging machines are enumerated and used in regular turn. 3) *Empty One, which* means that the shuttle can decide the machine only by considering whether it is idle or not.

The charging operation is made into a rule by using the following state diagram given in Figure 4-10. Usually, charging machines are waiting in the "*Idle"* state until any shuttle sends a message whose battery is getting close to empty. After charging is completed, the utilized machine returns to the initial point.

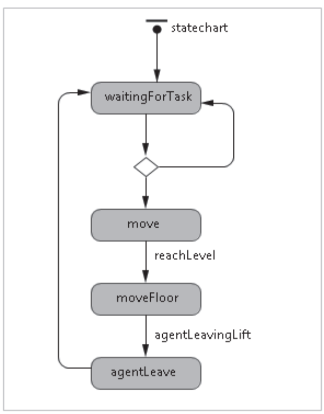


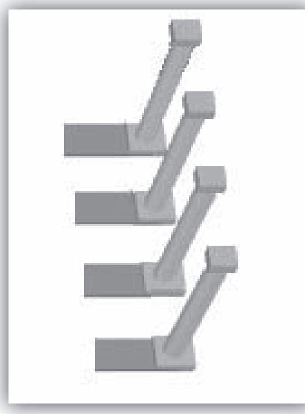
a) b)

Figure 4-10: a) Charging State Chart and b) Screenshot of Charging Zone.

Left/ Right Lift Behaviour

In contrast to the crane system, running through aisles to store and retrieval process in AS/RS, the elevators are used to provide vertical movement of the shuttle. Two lifts are located at the beginning and end of each aisle to ride the lift up and down respectively. In the literature, one considerable issue is to find dwell –the point location of crane. Various methods have been suggested to find out the answer to the question of where an idle crane should be positioned (Bozer, et al., 1984). The most popular methods are; 1) The *Input Station* method, which means that the lifts should be always at the input level. 2) The *Midpoint* method, which is used to ensure the level of lifts, is located in the middle of the racks. 3) The *Last Location* method which refers to positioning based on the last location of the lift. These methods have also been applied for the CTS simulation. For the right lift, which is in charge of going up, the input station rules are applied, while the midpoint rule is used for the left lift, which is responsible for going down. The state chart and screenshot of the lift system are given below in Figure 4-11.





a) b)

Figure 4-11: a) Left/ Right Lift State Chart, b) Screenshot of Left Lift

4.4 Construction of Cellular Transport System Simulations

Cellular Transport System (CTS) simulation has been simulated on the basis of distribution center principles, and refers to an intermediate place located in the middle of various sources, and customers, in order to merge different combinations of order requests and ship them to the particular customer. Mini load systems can be defined as a type of warehouse system where small items usually kept in small bins, totes, containers are handled. The CTS can be accepted as a typical mini load system, as all products are contained and stored in bins. Fundamental warehouse operations, which are order management, loading/unloading, palletizing/de-palletizing, purchasing, storage, order picking, and replenishment operations associated with CTS principles are explained in detail as follows. Other simulation parameters are given in Table 0-2.

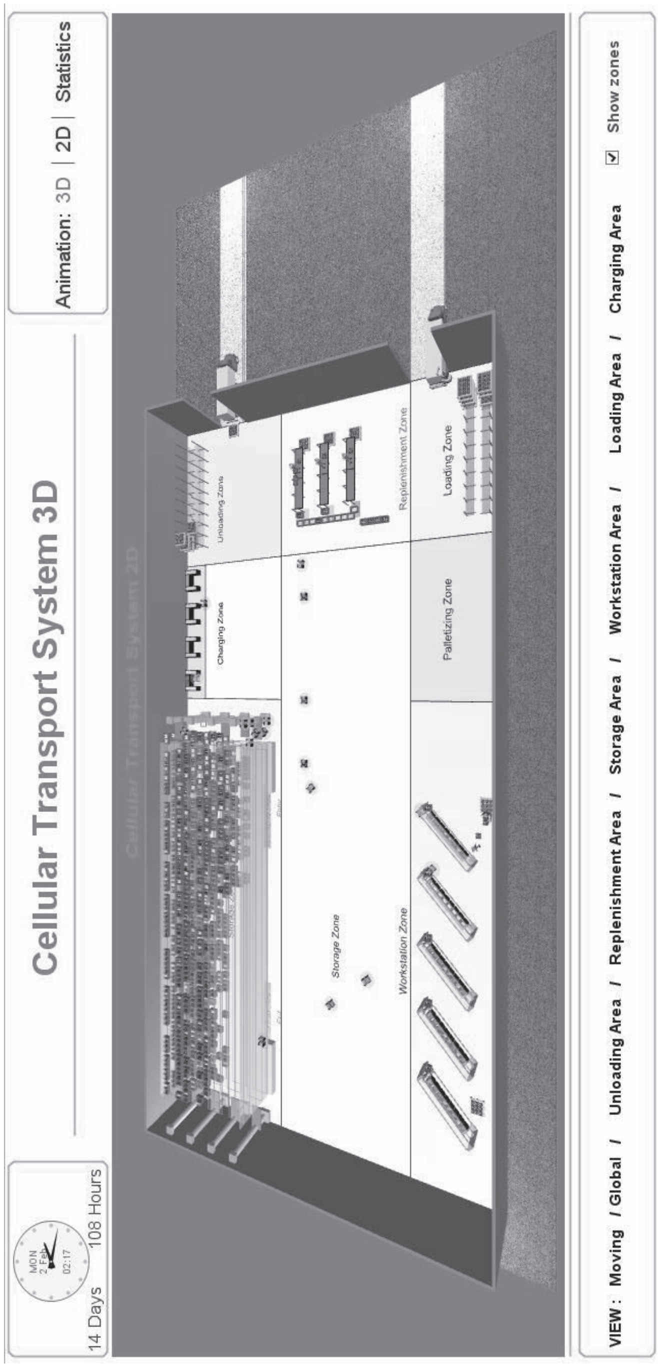


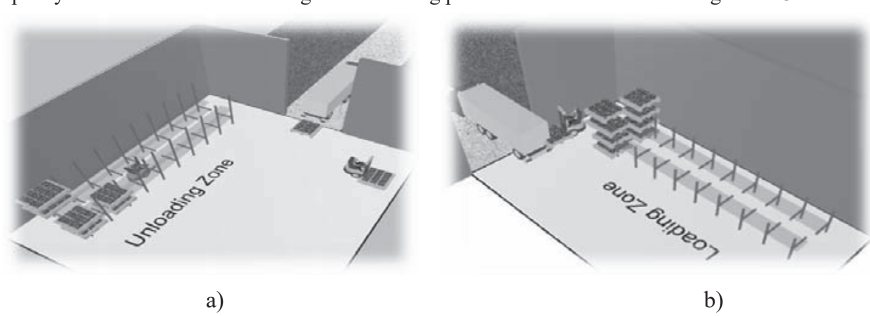
Figure 4-12: The screenshot of the entire Cellular Transport system.

4.4.1 The Order Management Process

The order management process aims to provide better arrangement between customer requirements and intralogistics systems. According to various arrival rates, such as normal or uniform distribution, all customer requests are entered into the system. In order to construct an order, three essential input values should also be known. These are product type, amount of required products, and delivery time. With respect to order picking workstation capacity, the obtained orders are accumulated in a pool. In a CTS simulation case study, each workstation is able to deal with eight customer orders simultaneously. Due to having five workstations, forty orders can be handled at the same time. It is obvious that demanded product types and amounts differ from one order to another. Hence, the quantities of each product type in forty orders are added up to find the total request in terms of red, blue or yellow product types. The next task is to determine how many bins it is necessary to bring from storage. Meanwhile, the current stock is checked to establish whether the available amount of products is under the re-order-point. If it is, the purchasing order is created automatically. The order management system is entrusted with allocating the duties of the retrieval process to shuttles by sending messages.

4.4.2 The Unloading & Loading Process

The unloading process begins with accepting the purchased items after unloading from trucks into the intralogistics system. The incoming materials should be checked, inspected and recorded into the system before transporting to the storage area. In the unloading area is a high bay storage, which is constructed to store pallets before sending to the de-palletizing operation. The bulk storage is composed of four levels and thirty pallet capacities for one corridor. In total, one hundred and twenty pallets could be stored simultaneously, and a single supply truck is able to bring, at most, twenty pallets for one arrival. Hence, the CTS simulation must give a purchase order equal or less than five trucks. The loading process is carried out after customer orders are completed and accumulated on the pallets. The forklifts carry these pallets from the workstation area to the loading area. The loading area contains a high bay storage rack which is identical to the storage in the unloading area. The purpose of establishing this storage is that pallets should wait until the number of pallets is equal to truck capacity. Screenshots of the loading and unloading process are shown below in Figure 4-13.



a) b)

Figure 4-13: a) Screenshot of Loading Zone, b) Screenshot of Unloading Zone

4.4.3 The De-Palletizing & Palletizing Process

Purchased materials from suppliers have been brought in the form of pallets. Although it is possible to keep products on a pallet in bulk storage, all pallets should be repacked in order to reassemble full pallets to small bins. Two reasons are available behind the de-palletizing process. One of them is that the storage system in CTS is designed based on mini load principles. The other one is that shuttles are capable of transporting just bins due to their dimensions.

While the whole customer orders are packed into boxes, the placing of boxes on pallets are carried out at the same time by workers. The palletizing process is available because of two reasons. The first is to facilitate carrying by forklifts, and the second is to facilitate both dispatching and shipping. A specific place is not allocated for the palletizing or de-palletizing operation in the CTS simulation, however, the de-palletizing process is performed inside the replenishment area, and the palletizing process is executed with the packing process simultaneously inside the workstation area.

4.4.4 The Storage Process

Due to the novelty of the CTS, sufficient research has not been carried out in literature. To implement the storage configuration, design parameters including the number of aisles, bays, tiers and operational parameters i.e. re-order-point policy and safety stock are deeply investigated. Firstly, a trial hall with a multi-shuttle system, established for experimental testing, is used as a base and extended by inserting additional storage racks. The storage structure is composed of four aisles and each aisle contains two storage racks in which five tiers and seventy five bays are included. In total, the storage is formed from three thousand bays. The general perspective of storage is illustrated below in Figure 4-14.

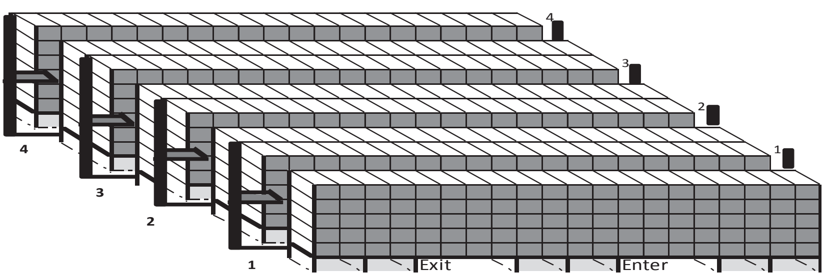


Figure 4-14: The configuration of the storage structure of the CTS.

According to the depth of the stored product, two options can be detected from literature and present intralogistics applications which are; 1) Single-Deep Storage, which stores products only one bin deep on each side of the aisles. Although it provides low density storage, single-deep storage is the most commonly used in any intralogistics system and 2) Double-Deep Storage, which allows the storage of one bin in front of another one. Despite the fact that it uses twice as much storage capacity as single-deep, flexibility has not been ensured because of limited access. In the CTS simulation, the single-deep storage model is used. The reason for this is that the shuttle is not capable of handling the rear loads; in other words, the front of bins should be unoccupied to be picked by shuttles. The screenshot of storage areas is provided in Figure 4-15.

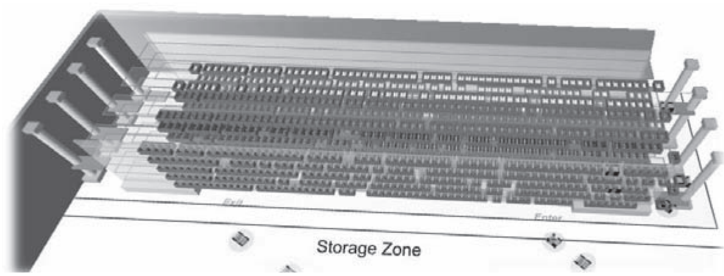


Figure 4-15: Screenshot of Storage Zone.

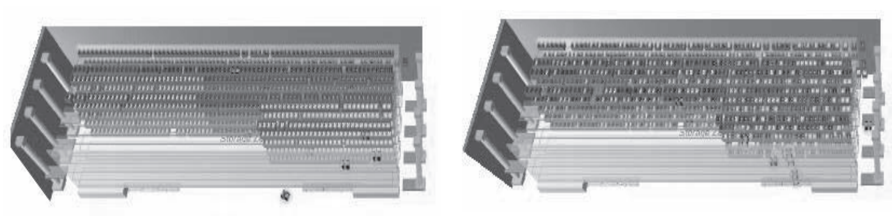
For the operational configuration, the assignment of products to storage can be discussed under three headings; dedicated storage, random storage and class-based storage, which are the more frequently used methods for any intralogistics system, and are explained in depth as follows.

Random Storage
All kinds of products can be assigned any unoccupied location without making any categorization. This method increases storage density more than dedicated storage.

Dedicated Storage
Each product type must be stored in its specific location in the storage area. The major drawback of dedicated storage is that reserving a unique location for all items can result in maximum inventory levels.

Class-Based Storage
This method is an integration of dedicated and random storage policies. Firstly, all products are categorized into classes in terms of their common features, as in the case of dedicated storage. However, the product can be stored arbitrarily within a class as in the case of randomized storage logic

In the CTS simulation, the random storage and class-based storage policy options are offered to give the user the freedom to make experimental tests. See Figure 4-16.



a) b)

Figure 4-16: Screenshot of Class-Based Storage and Random Storage Assignment.

Re-order point and safety stock parameters are also determined as an alternative operational parameter on the basis of the amount of products in storage. Before that, explanations of each term are given as follows.

Re-order point (ROP): A pre-specified level at which the new purchase order is generated. It refers to the minimum acceptable inventory level for each product type.

Safety stock: In order to avoid the case of stock out, a part of inventory is hedged as proactive or buffer inventory. When an unexpected increase occurs in demand, safety stock can be used to ensure the fulfilment of customer orders on time.

For the CTS simulation, safety stock policy is embedded into the system, and is an optional control strategy for users who can activate it as a preventive measure. ROP is utilized as necessary, but still, the quantity of it can be changeable.

4.4.5 The Purchasing Process

In an attempt to restock the storage, purchasing operations are carried out based on three different logics. 1) Forecast Strategy is established on the value obtained from the prediction of demand. The Change Planning Simulation explained in Chapter 3 is able to produce demand and supply forecasting graphs every month. Hence, this graph is taken as a base to determine the purchase order quantity. 2) The maximum level is a specific value for each product class determined at the beginning of the simulation. The order quantity that will be supplied from the supplier is the difference between the maximum level and the available inventory. 3) Fix value might be offered as an alternative method, apart from the forecast and maximum level method. In this model, the user can arrange the quantity of the order without any specific rule.

The question of when the purchase option is needed and how many products should be purchased for each product type is determined by using the continuous check system. In cases when the existing quantity is lower than ROP, a purchase order is triggered from the inventory management system automatically. The typical inventory cycle is illustrated in the following Figure 4-17. The quantity would be specified according to the abovementioned methods. The purchase order is given as a unit of trucks. In order to find how many trucks are required, the necessary product amounts are converted into the truck unit.

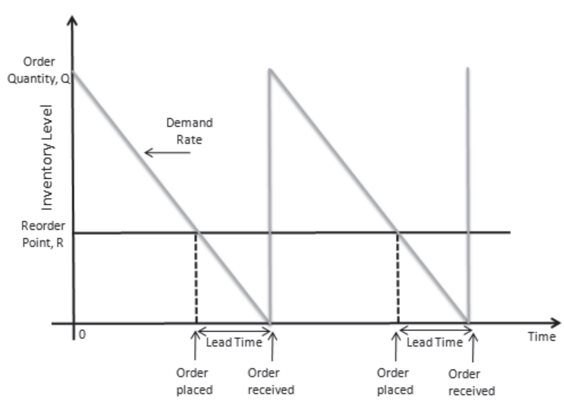


Figure 4-17: The inventory order cycle.

4.4.6 The Order Picking Process

In the CTS simulation, order picking is composed of two essential duties: 1) collecting and accumulating of products according to a pre-determined order list by the shuttles, 2) allocating and sorting products on the basis of customer requests by the workers. There are three order picking methods that are clarified below in depth to ascertain which one is most appropriate for the CTS simulation.

The Batch Picking method includes allocation of one product type for a group of orders to a picker who is responsible for taking all of them at the same time, within a single trip. Although this method can be advantageous for large density orders that contain the same items, the selection and sortation operation is needed to apportion products according to customer requirements, after picking products as a batch.

The Zone Picking method is beneficial for orders that contain limited numbers of items and need to complete soon. In zone picking method, the storage area is divided into several zones, and one or more than one picker is assigned one particular zone to pick all orders.

Wave Picking is a picking method in which orders are assigned into groups (waves). Order lists are generated to be picked within definite time duration.

In the CTS simulation, the products required by the customer are collected by shuttles, based on the batch order picking strategy. The following Figure 4-18 demonstrates the five workstations that are in charge of allocating picked products in regard to the demand of customers. After an order is accomplished, the customer boxes are placed on the pallets for shipment.

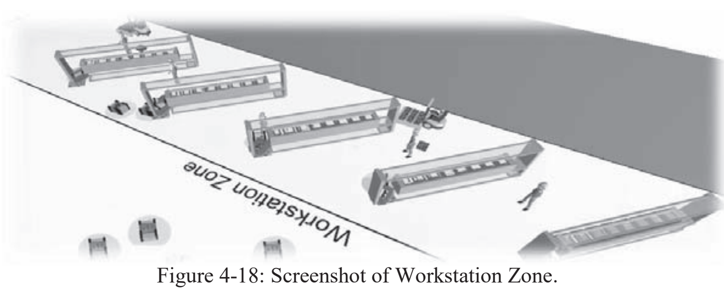


Figure 4-18: Screenshot of Workstation Zone.

4.4.7 The Replenishment Process

The replenishment process includes all functions that are related to both transferring pallets from a bulk storage area to bins, and refilling the empty bins that have emerged during the picking process. Three replenishment tables are constructed for each product type and a worker is assigned to each table. The process begins when empty bins are brought by shuttles and the pallets from the bulk storage area are also carried in by forklifts. . The worker firstly reassembles pallets to fill empty bins. After replenishment, full bins which belong to different product types are accumulated in front of tables. Lastly, full bins are moved into storage racks by shuttles. The replenishment process and its components are depicted in the following Figure 4-19.

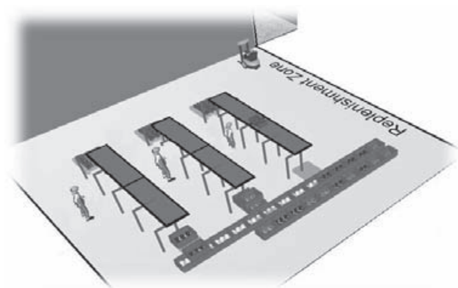


Figure 4-19: Screenshot of the Replenishment Zone.

4.4.8 The Transportation Process inside the Warehouse

The transportation process is carried out by two sorts of vehicles, namely; 1) the shuttle that is able to carry only bins due to its design configuration and 2) the forklift that is used to transport pallets for loading and unloading operations. In CTS simulation design, a large area is allocated for the transportation area. The major reason behind this decision is to prevent the rate of collision between shuttles. In the existing trial hall, fifty shuttles have already been made available. Therefore, in the over-average demand situation, it is impossible to increase intralogistics efficiency, even by having a sufficient number of shuttles, because of the unacceptable waiting times between shuttles to avoid collision. The configuration of storage and the order picking operation of the CTS simulation is quite complicated, because it involves a wide range of operational and design parameters. The following Figure 4-20 is based on the study of (De Koster, et al., 2007) and the implemented options in the CTS simulation are marked by taking them into the red frame.

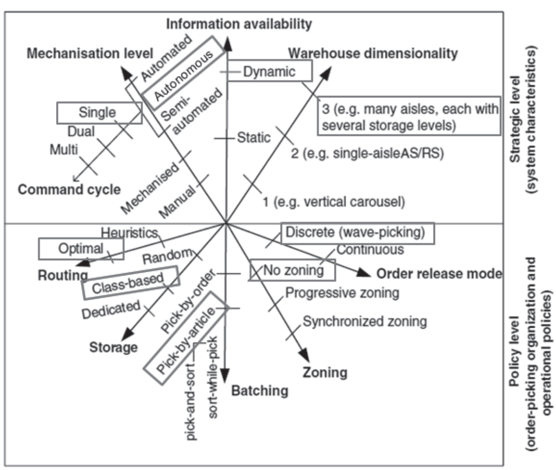


Figure 4-20: Design and Operational Parameters of the Order-picking and Storage System of the CTS based on (De Koster, et al., 2007)

Chapter 5

Assessment Methodology and Statistical Analysis

Within the context of this study, the most significant section is Chapter 5, among others. Generally, the statistical analyses and evaluation charts obtained from both simulation and analytical models are provided. In the first sub-section 5.1, Change Planning Simulation, which is an integral part of the Anticipatory Change Planning approach, is provided with a well-developed simulation tool. The results graphs demonstrated are concerned with flexibility corridors, and two proposed methods to evaluate the limits of the flexibility corridors are explained, with an example application in sub-section 5.2. To increase the competence of the proposed model, the cost parameters are included in this study, and further explanations about the costing of existing expenditures are presented in 5.3. Other main analyses about performance availability obtained from three methods, along with an example are provided in 5.4. Measure analyses and implementation of proposed frameworks are carried out in 5.5.In order to prove the accuracy of the proposed system, five scenarios are generated. All scenarios, with their results are given in sub-section 5.6.

5.1 Determination of System Load and Change Planning Simulation

A significant amount of literature has been published on the categorization of possible risks or changes in other saying change drivers. An example of this kind of literature is by Christopher and Pack (2004), who divide the source of changes into five classes: environment, supply, demand, control and process. On the other hand, Tang, et al., (2008) diversify the classes by adding political, social and behaviour source of risk. Some other studies have also attempted to classify the source of change, for example, (Chopra, et al., 2004), (Harper, 2012), (Park, 2011). Based on the abovementioned studies, the following Figure 5-1 is constructed in order to see all possible change drivers as a whole.

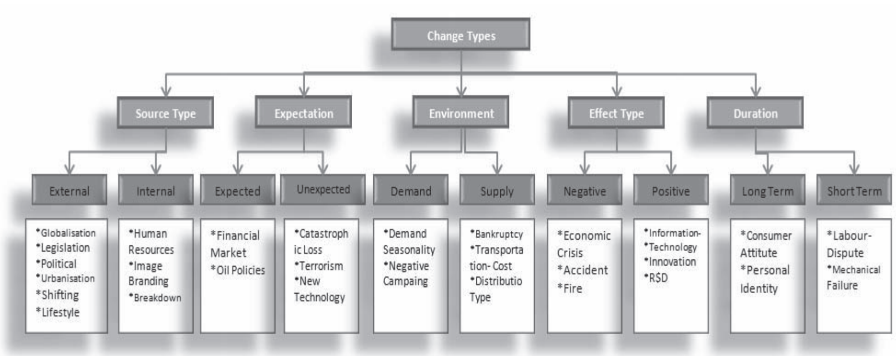


Figure 5.1: The possible sources of change classification.

Table 5-1: Change classification for the change planning simulation.

Social Changes	Financial Changes	Natural Changes	Technological Changes	Supplier Changes
Shifting Lifestyles	Oil Policies/ Energy	Legislation & Regulation	Manufacturing Technologies	Supplier Bankruptcy
Consumer Attitudes	Financial Market	Political	Technological Innovation	Production Cost
Globalisation	Capital Availability	Catastrophic Loss	Information Infrastructure	Competitor
Socio-Demographics	Economics Crisis	Terrorism / War	R&D	Transportation Delay

Different from classification in literature, changeability that is emerged from change drivers has been categorized into five areas in terms of the environment of risks: Social, Financial, Natural, Supplier and Technological. The proposed classification is used to establish the Change Planning Simulation (CPS) which is represented in the following Table 5-1 with examples for each class.

5.1.1 Specification of Change Drivers

Although the specifications of change drivers might be examined differently for other kinds of research, the essential features of every type of change driver are investigated within both the context of this study and Change Planning Simulation. This is explained in depth as follows:

Social Effect refers to an impact on the community that can change personal identity or customer wants and trends. These kinds of effects might take a long time when they happen. However, the occurrence probability is seldom or unlikely. The impact of social change can be realized on all kinds of product types, and both customer and supplier could be influenced by it. Additionally, it is assumed that the social effect can have possession of either negative consequences or positive consequences.

The Technological Effect possesses only positive effects on all product types. Contrary to social effects, technological effects can occur frequently. On the other hand, the severity of this effect can be accepted as being between moderate and major. The impact on product price and lead time depends on uniform distribution as well as on the other change drivers.

The Financial Effect is generally accepted as an economic crisis or any uncertainty in the business market. However, the financial effect can also be positive. Hence, the financial effect might be both harmful and beneficial for the enterprise. The frequency of occurrence of financial effects is reasonably probable, but still, the volume of change is not critical. Due to the fact that the financial effect is concerned with monetary expansion or depression, the price of the product is merely influenced.

The Natural Effect contains political and legislation/ regulation changes besides catastrophic hazards. Different from other change drivers, the impact of natural events can be recognized immediately by both customers and suppliers. It is accepted as a harmful effect on the price of product and delivery time within the frame of this study. The volume of change is determined by using a uniform distribution function.

The Promotion Effect comes into play when a decrease in the price occurs. It is obvious that the impact on demand is always positive, as customers always want to be able to buy products at an affordable price. In fact, the suppliers are not affected from any kind of promotion directly. Another different aspect of the promotion affect is that the time of realization of one promotion is known exactly. In other words, it is not regarded as an unexpected event.

The promotion effect is divided into two parts based on the extent of the region in which the promotion will become effective. The first one is 1) Global Promotion made for all regions. 2) Local Promotion is carried into effect for merely one region. What is supposed is that the duration of impact should be longer than local promotion. Apart from that, the effect and the occurrence probability are similar.

Supplier Effect differs from other types of effects with regard to the affected target group. The production cost, supplier bankruptcy and serious competition environments which are not directly related to customers might be given as an example of supplier effects. Other kinds of change drivers are able to affect the product price and quality and lead time, whereas supplier effects have a serious influence on the raw material cost, quality and lead time. As can be understood from the above examples, the supplier effect could be almost harmful when it occurs. In addition, the expectation of the occurrence is annual, as well as a serious severity.

The abovementioned change drivers take place either manually or randomly. For the random happening, the probability of the occurrence is embedded into each change function, and for the manual happening, the button controls are created, as can be seen in the following Figure 5.2.

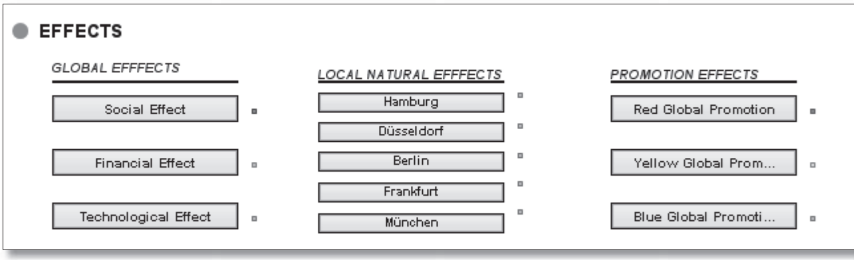


Figure 5.2: Change drivers inside Change Planning Simulation

5.1.2 The Agent- Based Approach for Change Planning Simulation

Agent- based modelling deals with some systems in which the number of active objects are included such as, human, consumer, machine, etc. Additionally, it could be more suitable to use the agent based model if the application is modular, decentralized, changeable and complex (Jennings, 1996). In a decentralized environment, these active objects, namely, agents should communicate with each other in order to complete a predefined task, without any central authority. The proposed model, within the borders of the present study, answers to the description of the above properties by having active objects such as customers and suppliers etc. and a challenging and changeable business market. Therefore, the Change Planning Simulation (CPS) is constructed according to agent based modelling philosophy. Simulation of the virtual market with change drivers and two agents as active objects: Customer and Supplier will be explained with their characteristics behaviours as follows.

5.1.2.1 Customer Behaviour

Firstly, five regions of Germany namely, Hamburg, Berlin, Düsseldorf, Frankfurt and Munich that are illustrated in the following Figure 5.3, are created, and 2000 customers are positioned randomly in a different region of the country.

Figure 5.3: Five Regions of Germany

At the beginning of the simulation favourite products are assigned to each customer at random. However, the customer's preference shows an alternation during the simulation period because of the influences of various changes happening in a different time. There are three parameters that determine whether the customer switches to another product type or remains loyal to a previous favourite product. These are product quality, lead time and product price, and can be seen in Figure 5.4, which is a screenshot of the control panel. In order to reflect the reality, habitual behaviour effect and product loyalty effect are included in the Change Planning Simulation, by giving a specific percentage when the equation is used to calculate the customer‘s preference. Also, it is possible that none of products can be purchased by any consumers that are called unwilling customers.

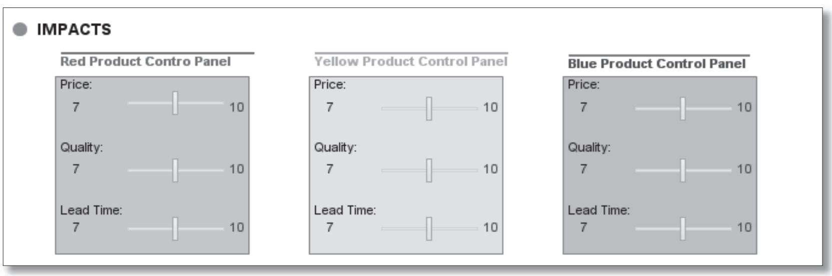


Figure 5.4: Control Panel for Price, Quality and Lead Time of Three Products.

The Customer Preference Function

In order to evaluate the function of the customer's preference after every change occurs, two proportions are taken into account which are: 1) memory parameters are allocated arbitrarily at the beginning of the simulation which refer to the weight of previous preferences; this value can be altered when the remaining influence parameters change, 2) the volume of influence and ratio of the accumulated value of price, quality and lead time effects. It is certain that each change driver has a particular and separate influence on price, quality and lead times. . Thereby, this specific influence is considered as a volume of influence. In addition, the relationship between customer preference and quality is in direct proportion whereas price and lead time are inversely proportional.

Moreover, the following functions are embedded into customer behaviour in order to more accurately reflect reality:

The Contact Function is a function in which the contact influence is calculated. When two or more consumers come together, the contact effect occurs. Every contact results in an influence, due to having an effect on one customer and on another consumer's decision.

The Move to another County Function involves displacement effects. Consumers are able to move from one region to another region based on a relocation rate, because of some natural disaster or catastrophic loss.

The Add or Remove Customer Function is written with Java programming code to show the real market conditions more precisely. After some changes, the amount of consumers in a specific region could increase or decrease by adding or removing customers based on the volume of impact.

5.1.2.2 Supplier Behaviour

Social, financial, natural, and technological changes affect both consumers and suppliers at the same time; however, supplier effect only impacts on the amount of supplied product. Three products namely blue, red and yellow are supplied from three different suppliers, each producing one type of product separately: Red-product supplier, blue-product supplier, and yellow-product supplier are illustrated in the following Figure 5.5. The amount of supplied products from each supplier are based on three variables; the material cost of the product, the lead time and the quality of raw materials or semi-finished product, which will be used for the finished product. Therefore, each change has a particular influence on such variables, and the supplier can determine the amount of products to produce by looking at the changes of these variables.

In order to calculate the amount of supplied products for each type, there are two variables available, which are; 1) the expected demand value that is forecasted weekly, and 2) the ratio of the accumulated value of material cost, quality and lead time.

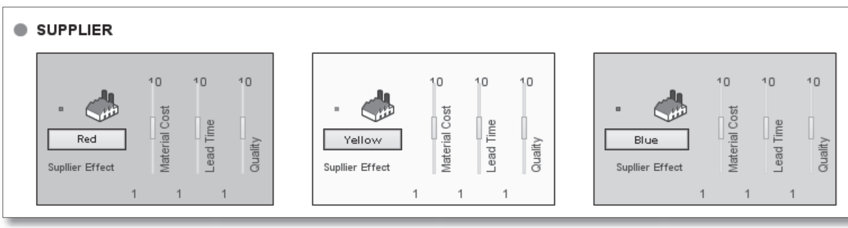


Figure 5.5: Control Panel for Material Cost, Quality and Lead Time of Supplied Products

5.1.3 The Logic behind the Impact of Changes

It is absolutely clear that each change driver has some distinctive features. In order to differentiate the possible impact of every change, some parameters, given in detail below, are comprehensively identified.

Product type: The number of product types which are influenced by change or risks

Beginning time of impact: The time of day shows how many days are required after a change happens to realize the impact of change.

Duration of impact: The duration in days shows over how long the change impact takes place.

Rate of the change occurrence: The number of change occurrences per a pre-determined time period or the frequency of change or risk.

Volume of impact: The volume of impact is caused by a particular action and it refers to a total influence on a customer or supplier.

Total impact on price, quality or lead time: The amount of influence on each parameter, namely, price, quality and lead time, which are used to determine the customer's decision in the preference evaluation.

Effect type: The effect of change could be always positive, like promotion, or always negative, like natural disaster, or both, like financial or social effects.

The values of all parameters for all kinds of change drivers that are used in CPS are given in the following Table 5-2 and Table 5-3.

Table 5-2: The Properties of Change Drivers for the Supply Process.

Change Types on Amount of Supply					
	Social	Financial	Natural	Technological	Supplier
Product Type	3	3	3	3	1
Begin Time	5	3	0	3	3
Duration	50 days	30 days	50 days	20 days	20 days
Rate	1/5 years	2/year	1/5years	2/year	1/year
Volume	0,5	1	1	0,5	1
Price	Uniform(0,1)	Uniform(0,1)	Uniform(0,1)	-	Uniform(0,1)
Quality	Uniform(0,1)	-	-	Uniform(0,1)	Uniform(0,1)
Lead Time	-	-	Uniform(0,1)	Uniform(0,1)	Uniform(0,1)
Effect Type	Both	Both	Negative	Positive	Negative

Table 5-3: Properties of Change Drivers for the Demand Process.

Change Types on Amount of Demand							
	Social	Financial	Natural	Technological	Local Promotion	Global Promotion	Contact
Product Type	3	3	3	3	1	1	1
Begin Time	5	3	0	3	5	5	0
Duration	50 days	30 days	50 days	20 days	15 days	10 days	5 days
Rate	1/5 years	2/year	1/5years	2/year	1/year	1/year	1/year
Volume	0,5	1	1	0,5	0,5	0,5	1
Price	Uniform(0,1)	Uniform(0,1)	Uniform(0,1)	-	Uniform(0,1)	Uniform(0,1)	-
Quality	Uniform(0,1)	-	-	Uniform(0,1)	-	-	-
Lead Time	-	-	Uniform(0,1)	Uniform(0,1)	-	-	-
Effect Type	Both	Both	Negative	Positive	Positive	Positive	Both

5.1.4 Implementation of Change Planning Simulation

Before a CPS simulation is run, a control panel, shown in Figure 5.6, is generated in order to give users a chance to set the initial value of the change drivers. At the same time, it is possible to say that one change driver can be eliminated from the system completely with the help of the checkbox control, located in the control panel. To avoid accidental mistakes during value entering into the system, the slider controls that allow users to select a quantitative value, inside a limited interval by sliding a mouse, are used.

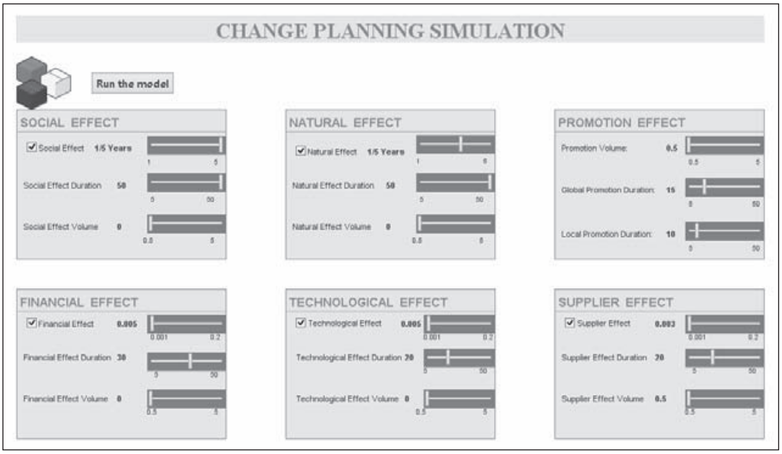


Figure 5.6: The Simulation Panel to Set Initial Values of All Change Drivers

After running the simulation, the following Figure 5.7 appears on the screen. Apart from customers who are scattered around regions, suppliers, change drivers, impact control parameters, and the statistics part are included into the system. The statistics analysis consists of two pie charts and time series charts that show the fluctuations of demanded and supplied products.

The following Figure 5.7 shows the screenshot of the change planning simulation which is created based on Agent- Based Modelling methodology

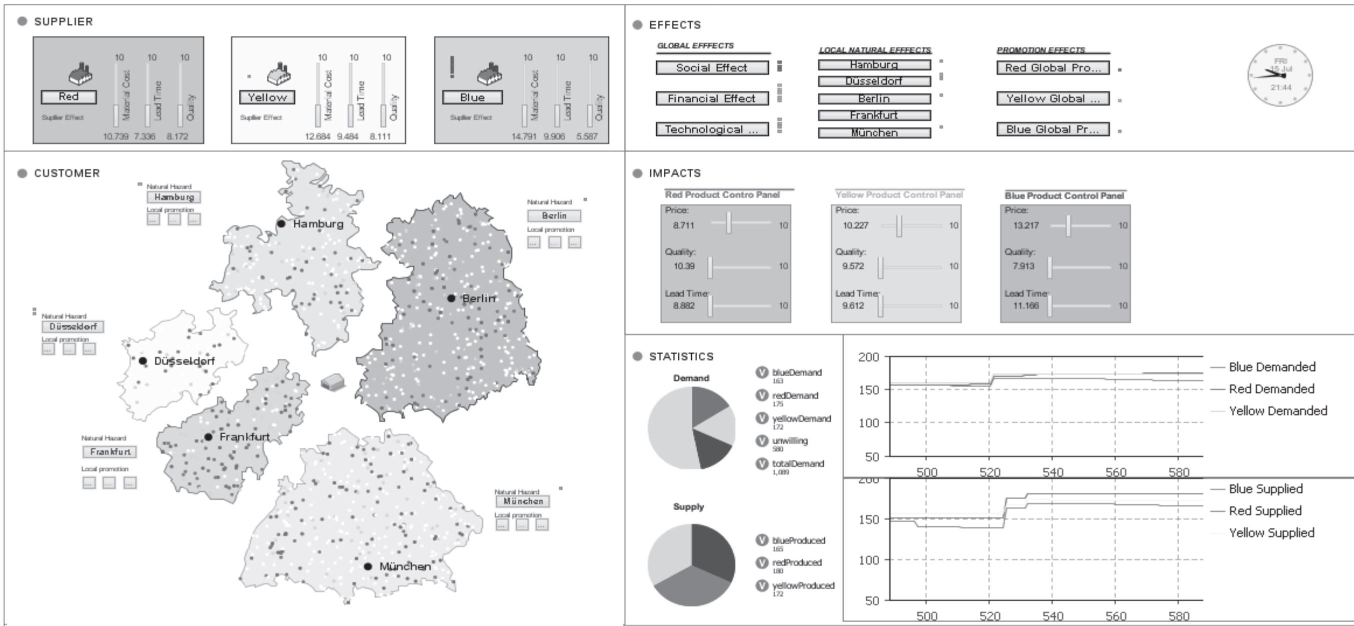


Figure 5.7: The Screenshot of the Change Planning Simulation.

The simulation period for the CPS is determined for one year, and it simulates the virtual market conditions by taking all change drivers into consideration. The major expectation from the CPS simulation is to obtain a chart that shows when the changes occurred, and how much the demanded or supplied products are affected from this event. Hence, users could follow all changes that had occurred, along with their positive or negative impacts, from the following Figures 5 -8 and 5-9.

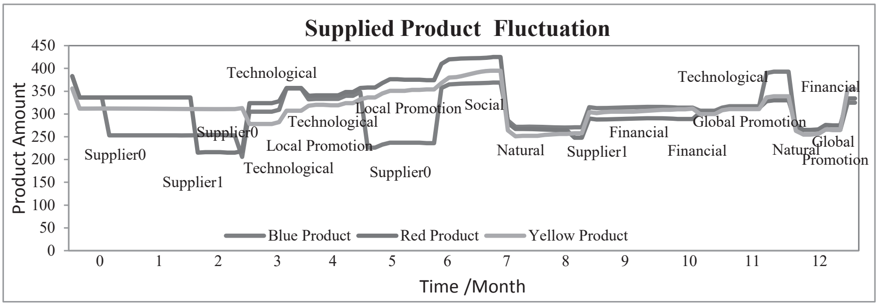


Figure 5.8: The Amount of Supplied Products

It is apparent from the above time plot chart that the amount of supplied products increases or decreases sharply, whereas the following chart shows that there has been a slight rise or fall in the number of demanded products from the customer. The reason behind these consequences is that the supplier effects are additional effects for the supplier, but the demanded products are not influenced by it directly.

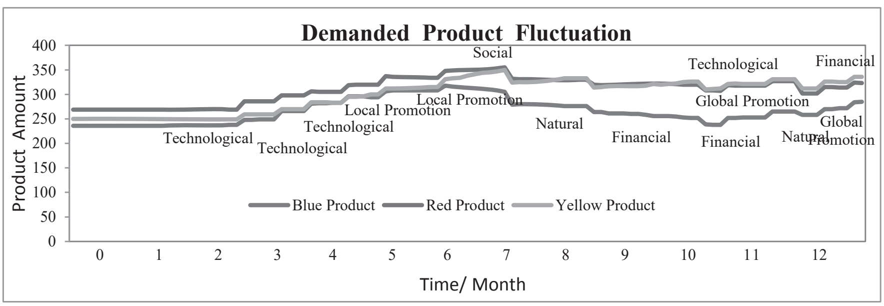


Figure 5.9: The Amount of Demanded Products

5.2 Determination of Flexibility Corridors

Up to now, there has been no study about the calculation of flexibility corridors in literature. This study seeks to determine flexibility corridors. To cope with this deficiency, two methods are investigated. One of them is the Statistical Control Chart (SCC) approach, the other one is the Experimental Research Method (ERM), and a further explanation about them is given as follows:

5.2.1 The Confidence Interval and Control Chart

There are similarities between the attitudes of the SCC and the flexibility corridors. Because of this, , the principal of the process control chart can be utilized, in order to make sure key performance indicators for the intralogistics systems stay within the normal range.

A control chart, which is also called a quality control chart, represents whether the process is in a state of control or out of order. If the variation of the process falls outside the upper or lower limit, the process is named as an ‘out of control processes. A control chart consists of the upper control limit, lower control limits and the average line that distinguishes the common behaviour of processes from unfamiliar causes of variation.

A confidence interval provides an approximate range of values which include an unknown population parameter (Easton, et al., 2004). The width between the lower limit and the upper limit of the confidence interval shows how the process fluctuations are uncertain. Confidence intervals are generally calculated to detect the width of confidence limits according to these percentages; 90%, 95%, and 99%. For the following studies, a 90% confidence interval is used. The Figure 5.10 below illustrates a 90% confidence interval on a normal distribution curve.

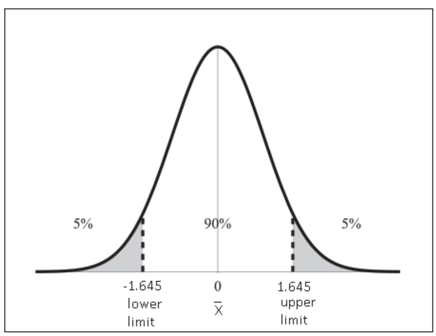


Figure 5.10**:** 90% confidence interval on a standard normal curve

In the following Figure 5.11, the shape of the flexibility corridors are merged with the shape of the 90% confidence interval, in order to provide a better understanding of the proposed method.

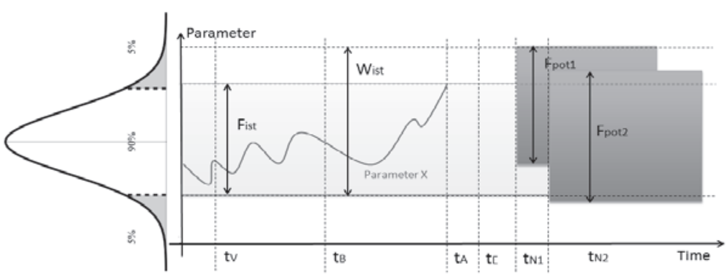


Figure 5.11: Combination of the flexibility corridors and the confidence interval.

In an attempt to calculate lower and upper limits, in other words, flexibility corridors in the case of the current study, the confidence interval equation should be put into practise. The confidence interval formula and notations are given below:

$$\bar{X} \pm Z_{\alpha/2} \frac{\sigma}{\sqrt{n}} \qquad 5\text{-}1$$

Where;

$\bar{X}$: The average

$Z_{\alpha/2}$: The Z value for the required confidence level α

σ: The standard deviation

n: Sample size

The $Z_{\alpha/2}$ value is obtained from the Z- table which is a calculation of area under normal curve. Within the context of the current study, the Z value is 1,645 for $\sigma = 0.1$ value. The other values for the above equations are as follows: The average value = 0.5, the standard deviation= 0.05 and for the 90% confidence interval $\sigma = 0.05$.

According to the above given input variables, the estimated lower limit=0,277 and the upper limit= 0.723, which is shown in the following graph.

Vehicle utilization is given as an example in Figure 5.12. Labour utilization, machine utilization, order completion performance, due date performance, lead time performance, and overall capacity graphs are being monitored within the flexibility corridors which are calculated using the SCC method.

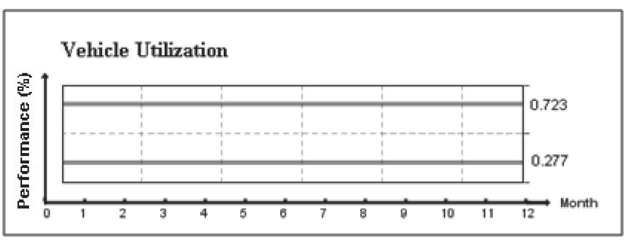


Figure 5.12: Flexibility Corridors for Vehicle utilization

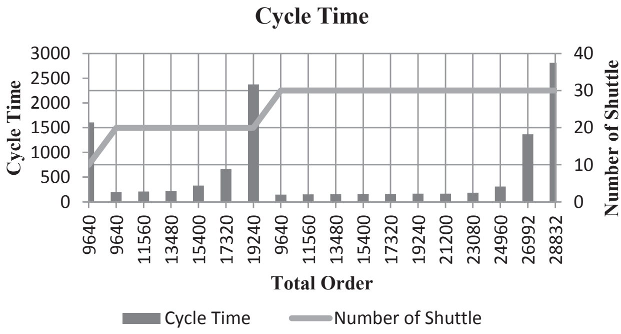
5.2.2 Experimental Research Methodology

Key defines Experimental Research Methodology (ERM) as an attempt by the researcher to maintain control factors over all factors that may affect the result of an experiment. Besides, the researcher may try to determine or predict what may occur during the experiment (Key, 1997). As can be understood from the above definition, two groups are available in the experimental methods which are; the control group and the experimental group. The researchers modify one or more parameters in the experimental group and monitor and measure any change in other parameters. In this study, the value of one or more than one parameter is varied in order to determine the minimum and maximum value of experimental groups.

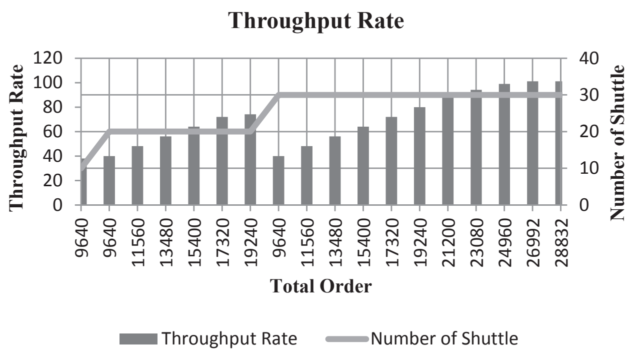
The number of shuttle, lead time and initial inventory is included in the control groups. The throughput rate, cycle time and customer waiting time are contained within experimental groups. To calculate the boundaries of the experimental group, and the control groups, the amount of shuttle is fixed in three values = 10, 20, 30, the lead time =6 hours, the maximum stock level =1800. Incidentally, on time delivery performance should be greater than 72.3% and the late delivery performance also lower than 27.7 %. By looking at time and late delivery performance, the experimental groups' maximum and minimum values might be detected from the following Table 5-4, which Table 5-4 is obtained from CTS simulation. Besides that, the following Figure 5.13 shows breaking points of performance variables which are throughput rate, cycle time and customer waiting when the customer orders are increased gradually.

Table 5-4: The control limits for performance variables

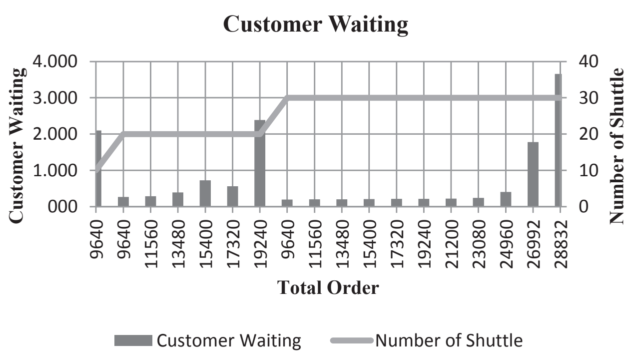
Shuttle Amount	Changes	Total Order	Throughput Rate	Cycle Time	Customer Waiting	On-Time Delivery	Late Delivery
10	0 % Increase	9640	38	**1608**	**2095,04**	**0,20**	**0,76**
20	0 % Increase	9640	40	199,42	267,29	1,00	0,00
20	20 % Increase	11560	48	207,28	282,37	1,00	0,00
20	40 % Increase	13480	56	222,33	390,27	1,00	0,00
20	60 % Increase	15400	64	330,19	721,56	0,99	0,00
20	80 % Increase	17320	72	661,36	559,57	0,97	0,02
20	100 % Increase	19240	74	**2375,85**	**2383,69**	**0,20**	**0,73**
30	0 % Increase	9640	40	149,52	194,38	1,00	0,00
30	20 % Increase	11560	48	153,70	199,86	1,00	0,00
30	40 % Increase	13480	56	156,03	202,89	1,00	0,00
30	60 % Increase	15400	64	160,21	208,31	1,00	0,00
30	80 % Increase	17320	72	161,93	210,56	1,00	0,00
30	100 % Increase	19240	80	165,94	215,82	1,00	0,00
30	120 % Increase	21200	88	168,60	219,24	0,99	0,00
30	140 % Increase	23080	94	185,42	241,14	0,90	0,07
30	160 % Increase	24960	99	308,41	401,19	0,83	0,13
30	180 % Increase	26992	101	**1368,03**	**1779,61**	**0,24**	**0,65**
30	200 % Increase	28832	101	**2812,43**	**3658,48**	**0,13**	**0,71**



a)



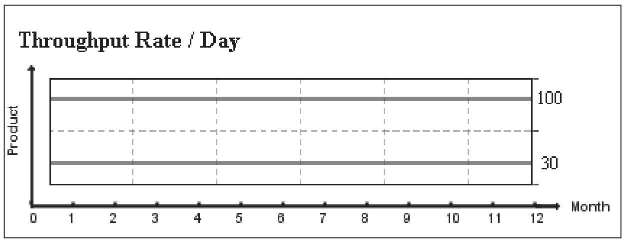
b)



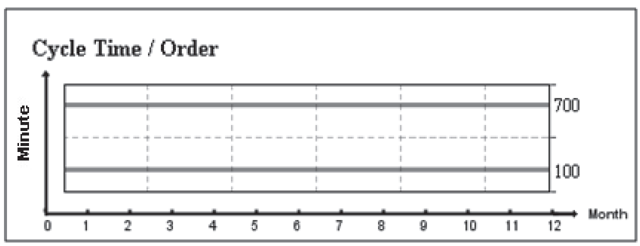
c)

Figure 5.13: a) The cycle time, b) the throughput rate and c) the customer waiting time.

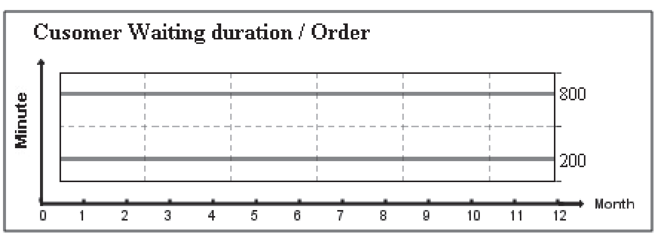
As a result of experimental research methodology, the minimum boundary of throughput rate=30 and the maximum boundary of throughput rate=100, which are determined according to Table 5-4. The lower and upper limit of flexibility corridors for cycle time and customer waiting time are observed in a similar way, and are represented in the following Figure 5.14 flexibility corridors.



a)



b)



c)

Figure 5.14: Flexibility corridors of a) throughput rate, b) cycle time, c) customer waiting time.

5.3 Assessment Model using Cost Analysis

Throughout the present study, the cost analysis is inserted into CTS simulation because of the desire to reflect more reality into the simulation. Therefore, it is much easier to make decisions by looking at cost parameters besides throughput rate or cycle time parameters. In order to perform construction cost analysis, two well-known costing approaches are embedded into CTS simulation. These are Traditional Costing Analysis and Activity Based Costing Analysis, which are explained in this part in detail.

5.3.1 The Traditional Costing Approach

The Traditional Costing Approach (TC) is a well-known method in which an overhead cost is assigned to products in terms of direct costs, such as direct labour hours, the use of machines etc. The traditional costing methodology accepts that each product has resulted in a cost. The cost drivers for the traditional costing method, as well as their explanations are listed below. The traditional cost is detected by accumulating the following expenditures:

Space Cost is calculated by multiplying the total area of the whole warehouse system with space cost. The price per square is assumed for the CTS simulation as being about $4 per year, and this value is taken into account as well as a space cost.

Labour Cost refers to the fixed cost of each worker such as, salary, insurance etc. The worker cost is determined as being between $30- 40% per hour. Within the concept of CTS simulation, three workers in a replenishment area and five workers in a workstation area are allocated. Also, one operator should be responsible for one forklift.

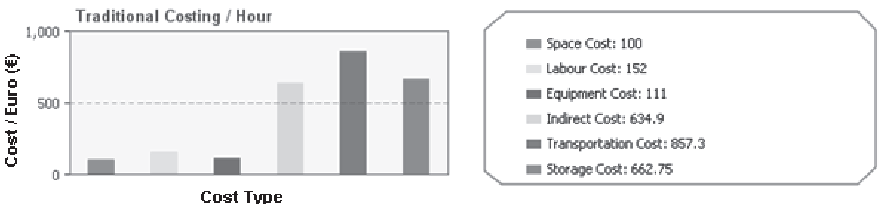
Equipment Cost is associated with machines, for instance maintenance of machines or fuels. Firstly, the equipment cost for each machine is determined hourly, and the multiplication of the number of machines and their specific machine costs have been inserted in the total equipment cost.

Transportation Cost contains two kinds of travelling cost; forklift travel costs, and shuttle travel costs. In order to calculate transportation costs, the total travelling distance in terms of meters, is worked out for both the forklift and shuttle during simulation. Then, these values are multiplied by the travelling cost parameter. In order to insert the merchandise cost of the machine into the cost analysis, forklifts and shuttle amounts are multiplied by the average unit cost of each vehicle.

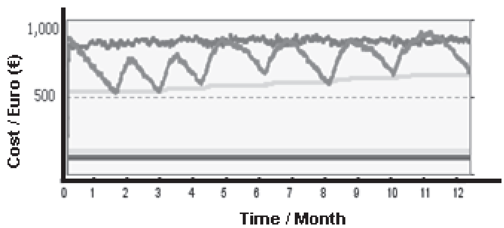
Storage Cost is related to the holding cost of a single bin or pallet in the storage area, per hour. In fact, the holding cost of bins differs from the holding cost of pallets which are respectively, $0.5 and $1.5 per month.

Indirect Cost could be investigated under two headings, 1) the order management cost, which includes some expenses incurred during the generation of a purchase order; such as fax, post or workforce costs to prepare an order list and 2) operational costs which are associated with company insurance, taxes and other expenses that are supposed at being between $2-$3 per square / annually.

A bar chart of the traditional costing approach and the fluctuations of cost drivers obtained from the CTS simulation are demonstrated in Figure 5.15.



a)



b)

Figure 5.15: a) Bar chart of traditional costing approaches b) The fluctuations of cost drivers.

5.3.2 Activity-Based Costing Approach

In the Activity- Based Costing approach (ABS), specific activities are determined as an essential cost driver. The reason behind cost cutting into activities is that logic assumes that activities cause costs instead of products. That is why; general expenses are separated into activities. Although Ronald (1995) claims that the traditional cost accounting system has become less reliable, both traditional cost and activity-based cost approaches are integrated into CTS simulation to trace the cost fluctuations accurately. Activity-based cost is calculated by taking summation of various kinds of charges explained comprehensively below.

An Order Management Cost is occurred each time a purchase order is generated and a customer order is received. In addition, a fixed cost is added for each late delivery order as a penalty cost.

An Unloading and Loading Cost is an accumulation of all expenditures that are incurred in the unloading or loading area. These are storage costs because of pallet bulk storage and space costs.

A Charging Cost is a cost in which charging machine cost and space cost are included.

Storage Cost is also called a holding cost, and is related with possessing inventory on hand. The space cost of the storage area is inserted into the overall cost as well.

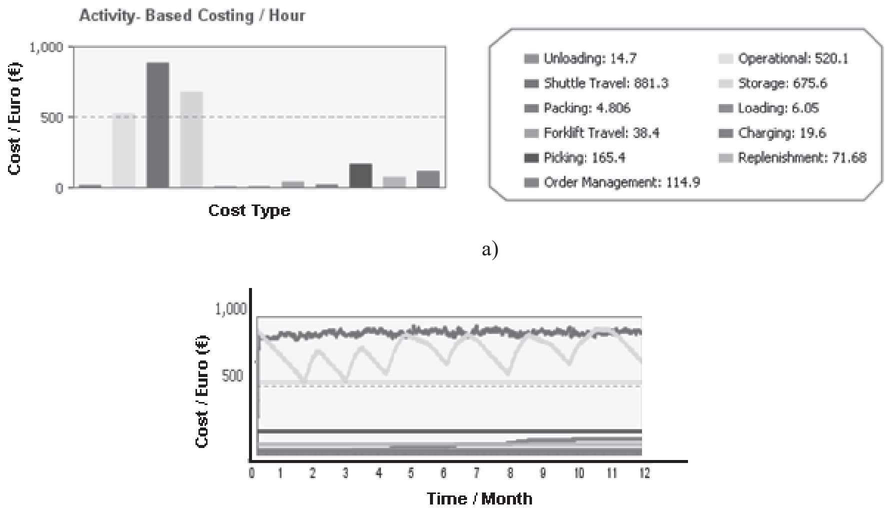
Picking Costs arise during performance of the order picking operation, in which the workforce cost for picker, equipment cost for order picking machines and space costs for the workstation area are encompassed.

The Packing Cost refers to a cost which is incurred during the palletizing process. It is evaluated by multiplying the number of pallets prepared for shipment by a specific packing charge.

The Replenishment Cost is computed in a similar way to the picking cost. The replenishment cost is a summation of labour cost, machine cost and space cost.

The Travel Cost results from the total travelling cost of the shuttle and forklifts, and the space cost of the transportation area.

Bar charts of activity-based costing approaches and the fluctuations of cost drivers obtained from the CTS simulation are demonstrated in Figure 5.16.



a)

b)

Figure 5.16: a) Bar chart of activity-based costing approaches b) the fluctuations of cost drivers.

5.4 Assessment Method using Performance Availability

Three assessment models to calculate performance availability are explained in Chapter 3, while in this chapter results tables are provided to compare whether they are able to show the entire CTS simulation efficiency or not. The result of waiting times and weighted average method assessments are obtained from CTS simulation. However, the calculation of the fuzzy logic method is realised by using an excel spreadsheet.

5.4.1 According to Waiting Time

As explained in Chapter 3, one of the simplest methods of computing performance availability is the proportion of total waiting times of some specific resources to the total simulation time. However, in the present case study, the performance availability of the whole CTS is required. To accomplish this requirement, the mean of all the shuttles performance availability is taken as the performance availability of the entire system. This is because shuttles play a role as a bottleneck inside the CTS, and it means that shuttles are working at their full capacity and cannot carry out any further tasks. In the following Figure 5.17, gained from CTS simulation, the first figure depicts the average performance availability of shuttles, while the other shows when the system waits and works in detail.

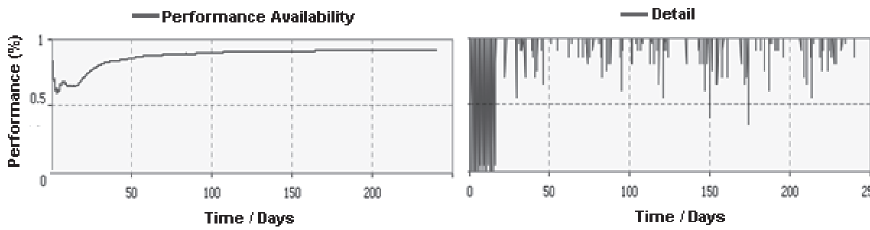


Figure 5.17: Average performance availability of shuttles calculated based on waiting time.

5.4.2 According to the Weighted Average Method

For the weighted average method, three parameters are chosen to determine the performance availability of the entire system. These are; throughput rate, on time delivery, and cost parameters. The importance of these control parameters and relations can differ from one company to another one. Thus, the weighting coefficient of each parameter and the relationship between parameters are determined in the CTS simulation on the basis of individual preference. The result graph of the weighted average method can be seen in Figure 5.18.

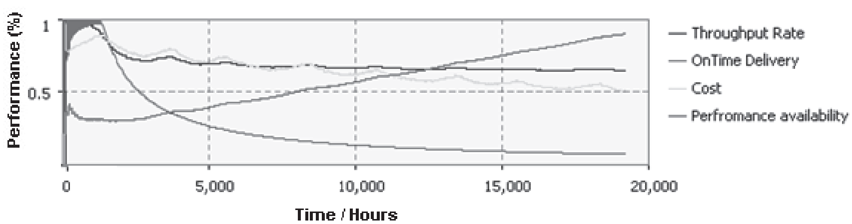


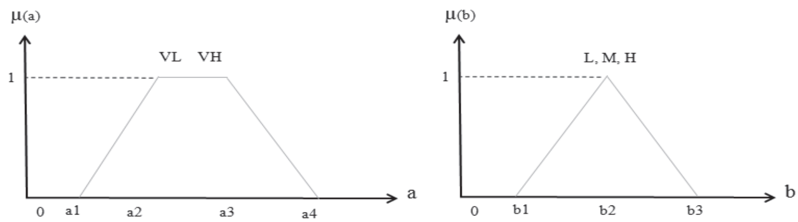
Figure 5.18: Performance availability calculated based on the weighted average method.

It seems clear that performance availability tends to increase like other results gained from the waiting time model. Although the performance availability is increasing all year round, it could be accepted that this graph, acquired from the weighted average method demonstrates the same behaviour.

5.4.3 According to the Fuzzy Logic Method

A major concern is obtaining the performance availability of entire intralogistics systems by taking into account only some parameters, due to the fact that performance availability cannot be evaluated easily with the help of a deterministic function of cost, throughput rate and delivery time. In previous studies, such as (Follert, et al., 2012), (Maier, 2011), (Maier, 2010), some mathematical expressions are offered to detect performance availability in terms of waiting time or loading amounts. However, the accurate performance availability values of whole systems cannot be assured using simple equations. Besides that, the correlation between control parameters and performance availability is too challenging to express with a mathematical function. Because of this, formulating the performance availability manner can be achieved by using the fuzzy-logic rule (Mahmoudia, et al., 2012).

In this fuzzy system, as part of the present study, there are three inputs, which are cost, due date performance and throughput rate, and the output parameter is performance availability. In this study, the linguistic variables, which are very low (VL), low (L), medium (M), high (H), and very high (VH) are used and, according to (Becher, 2009), the combination of low, medium and high is represented with triangular fuzzy numbers, whereas the trapezoidal fuzzy numbers should be utilized in the case of adding very low and very high variables.



a) b)

Figure 5.19: a) Trapezoidal b) Triangular Fuzzy Numbers based on (Mahmoudia, et al., 2012).

The input and output variables, with their values are given as follows in Figure 5.20. As can be realized from the below shapes, five linguistic variables, namely; very low, low, medium, high and very high are generated for cost parameters. In a similar way, five of the linguistics variables are created for due date performance. However, the throughput rate parameter includes only three linguistic variables, which are low, medium and high.

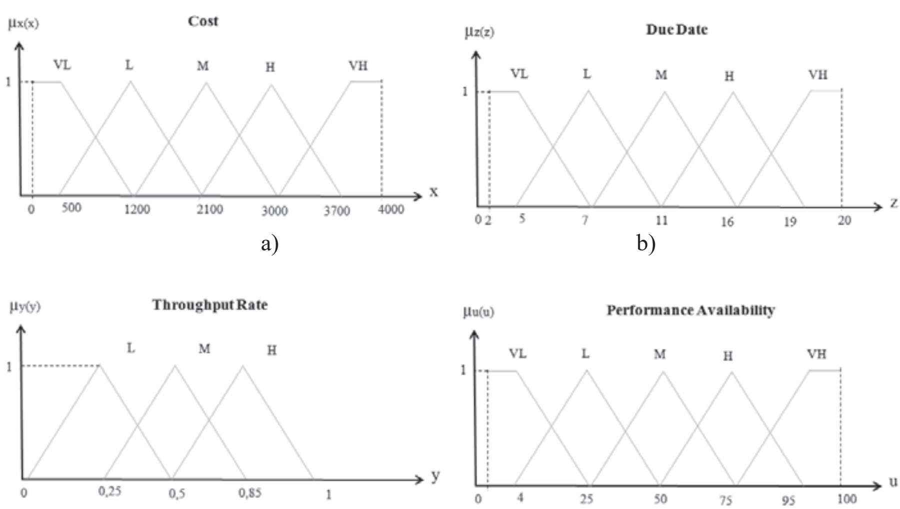


Figure 5.20: The proposed example for the fuzzy set of output and input variables.

The Fuzzy Logic Method (FLM) is composed of 'if-then' rules that are constructed of linguistic variables. Firstly, the linguistic variables are obtained from the user and then, if-then rules are structured based on the linguistic variables by getting the opinion of experts. In this study, the paper of (Mahmoudia, et al., 2012) plays the role of experts and creates if-then rules, and lastly they are entered into fuzzy logic. For this research, seventy five rules, which is a multiplication of five linguistic terms of cost and due date, and three linguistics terms of throughput rate, are created for this study. All fuzzy rules are given in Table 0-1 in the Appendix. One example of these rules could be given as follows:

IF Cost = Very Low, and

Due Date Performance = Very Low, and

Throughput Rate = Medium

THEN Performance Availability = Medium

In contrast to the evaluation of weighted average model and the waiting model to obtain performance availability, fuzzy logic evaluation is made by using Visual Basic programming language embedded in excel macro. In total, 1920 different costs, due date performance and throughput rate combinations are entered into the excel calculation system, as a dataset to find the entire system performance. The dataset is obtained from CTS simulation, and the same dataset is used for all performance availability results handled from different three methods. The result of performance availability calculated through the fuzzy logic algorithm is provided in Figure 5.21.

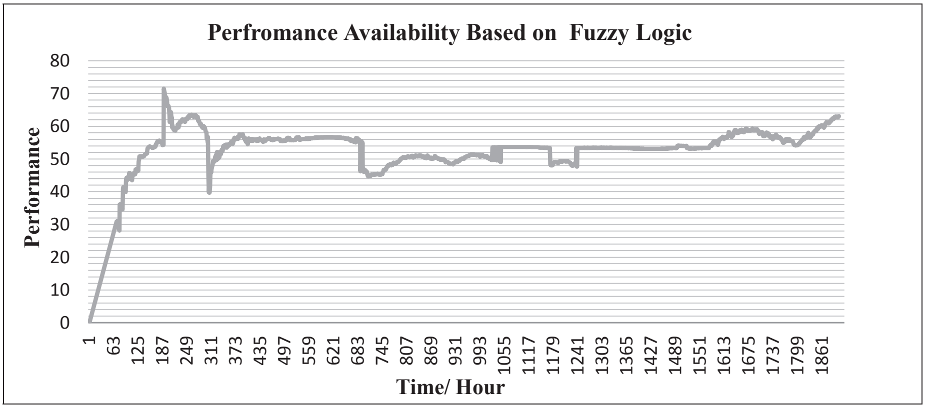


Figure 5.21: Performance availability calculated based on the Fuzzy Logic Method

It can be easily realized from three results, belonging to each performance availability method, that both differences and parallels between them exist. However, one of the most obvious consequences of three performance availability figures is that the behaviour of fluctuations is similar. . In the above shape, performance availability increases sharply for the first part of the dataset, like the other outcomes of other methods, then, it shows similar waving for the remaining part of the year. In the first two methods, the performance availability line is increasing steadily and without any sharp rise or fall. The reason behind this result is to take an average of all values. On the other hand, all combination of costs, throughput rates and due date values is used independently, while the calculation of performance availability uses fuzzy logic. Thus, the apparent steep oscillations could be noticed in the result graph of the fuzzy logic method.

5.5 Implementation of Measures using Six Steps Planning

As has been pointed out in Chapter 3, the term 'measure' is composed of not only dealing with how to reduce the unwanted impact of risk or uncertainties, like the mitigation strategy step in risk management, but also of various precautionary approaches in return for any anticipated changes in intralogistics systems. The under mentioned measures are integrated into CTS simulation, to take precautions if the control parameters are outside the flexible corridors after changes are applied. It should also be emphasized that the following measures are generated on the basis of the six steps planning strategy that is stems from process chain methodology. This is because six step planning offers a systematic approach to evaluate all control parameters which have a significant influence on warehouse efficiency.

5.5.1 System Load Generation

Creating different customer orders depends on the amount of products, the product type and the delivery time. This is turn means that each customer order might be changeable, not only in terms of the amount, but also in terms of the product type and the varied delivery date. Hereinafter, the changes relating to scale system load are listed.

Order Rate
The arrival rate of the customer order might be altered by determining the minimum and maximum value of an inter arrival time whose distribution is uniform.

Order Type
To compose various sorts of order combinations by changing the amount of products within one order depends on four specific options. These are; 1) based on the Forecast option obtained from information on the quantity of products from the Change Planning Simulation, 2) based on the Normal Distribution option which creates a different product quantity based on normal distribution with mean μ and standard deviation σ, 3) based on the Uniform Distribution option which generates dates that suit uniform distribution with minimum and maximum value, and 4) based on the Fix Value option which is inserted into the simulation to give a change to users, allowing them to create a product line on the basis of their own desires.

Due Date
Delivery dates for each customer order can be generated in various ways. To provide freedom for users to arrange the due date period, two edit boxes are created for modifying the due date variable that have fixed uniform distribution with minimum and maximum values.

The measures related to regulate the system load are presented below in Figure 5.22.

Figure 5.22: Measures are concerned with of the system load determination.

5.5.2 Organizational Structure Planning

This step allows the user to set up an organizational arrangement. The most important resource within the scope of CTS logic is the shuttle; consequently allocating responsibility for the shuttle includes consecutively arranging the balance of the efficiency of the whole warehouse system. Two main duties of the shuttle are taken into consideration when planning shuttle behaviour. One of them is putting storage bins into the rack; the other one is retrieval of the bins from the rack to convey workstations. Thus, three options are generated to adjust prioritization of the shuttle when two kinds of tasks need to be accomplished at the same time. 1) Storage is Important, 2) Retrieval is Important and 3) Both of them have the same importance.

5.5.3 Resource Planning

Resource planning includes five subclasses which are personnel, space, inventory, means of production, auxiliary means of production and organizational resources.

Personnel
To increase or decrease the capacity of personnel or vehicles, it is possible either to change the number of workers, shuttles, or forklifts or to modify the speed of available resources. These variables are designed as a modifiable to provide an opportunity to change the values at the model run time.

Space
To use the existing layout efficiently, firstly, each warehouse operation is located in a specific area. Then a potential capacity is determined by dividing each area by the amount of shuttles. The essential five zones are namely the transportation zone, the replenishment zone, the workstation zone, the storage zone and the home zone.

Inventory
In order to avoid an out of stock or surplus stock situation, the inventory option provides the opportunity to arrange initial stock (maximum stock levels) that is composed of three different product types. It should also be noted that a re-order point can be specified before or during the simulation run. All measures for adjusting resource capacity and efficiency are given in the following Figure 5.23.

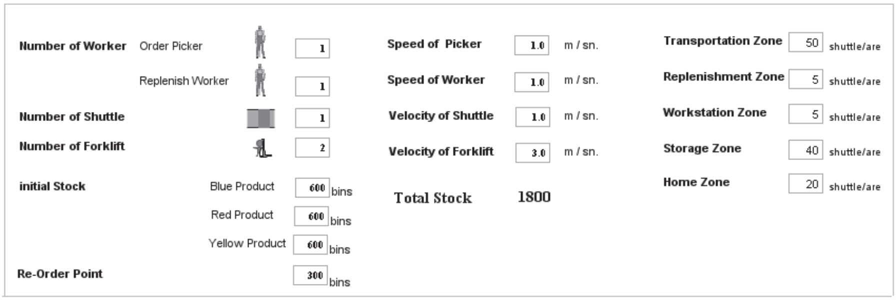


Figure 5.23: Measures concerned with resource planning.

5.5.4 Layout Planning

In this planning level, the user is able to deal with setting up the topology of resources in addition to the planning layout. Two alternative measures are offered under the layout planning concept. These are setting the routing policy and avoiding collisions, as explained below.

Routing Policy

The shuttles normally choose the shortest path to reach a predetermined destination point. In other words, the default behaviour of shuttles is to arrive using the straightest route between two points without any path. In addition to this, a pre-specified way option is integrated by drawing particular paths that the shuttles must follow. By means of this option, it might be possible to prevent collisions in front of enter or exit points.

Collision Avoidance

Firstly, the collision avoidance measure is optionally inserted into the simulation. . The same can be said that the user is able to run the simulation regardless of collision by omitting the mark on the Check-box control variable. In the case of putting a check mark on the box, it is also possible to assign a range among all the shuttles to detect an accident. If two or more than two shuttles are approaching each other, and they are located within the determined collision range, the collision avoidance state chart becomes active.

5.5.5 Control Rules Planning

In order to provide consistency and accuracy between warehouse processes, the following operational or technical measures, such as duration of working, the principles of purchasing, and the rules of keeping products in storage are generated.

Working Type

One way to coordinate existing capacity with customer demand is to extend or shorten the working time. Four alternative working durations for CTS simulation are produced, which are; 1) Regular Time-8 hours, 2) Over Time-13 hours, 3) Short Time-5 hours, and 4) Night Shift-16 hours.

Supply Strategy

The strategy of purchasing is diversified in an attempt to extend user ability to adjust present warehouse conditions, based on changes using three suggested measures which are; 1) based on Forecast choice providing the amount of product that should be supplied outside of the Change

Planning Simulation, 2) based on Maximum Level choice, which refers to the difference between an amount of existing stock and the initial stock (maximum stock level). It aims to make storage as full as the first situation of simulation, 3) based on Fix Value choice, which is designed for reflect the user's decision, independently from any rules.

Charge Strategy

To give an answer to the question of which charging machine should be chosen, three different strategies are developed. These are; 1) the *Random* option, which states that any of the charging machines are chosen arbitrarily, 2) the *In Order* option, which means that all charging machines are enumerated and used in regularly, and 3) the *Empty One* option, which means that the shuttle can decide on the machine only by considering whether it is idle or not. Another possible measure related to charge strategy is setting the duration of the shuttle battery in terms of minutes. For the present CTS simulation, the shuttles should go to the charging zone to load their battery every 250 minutes.

Safe Stock Policy

In the case of facing an unexpected increase in customer demand, the user chooses a safety stock policy to use a previously hedged amount of inventory. If the radio button is checked, the safety stock is added on to a re-order point.

Inventory Policy

With the offered CTS simulation, the user would be able to decide on which design of placing products into a storage rack should be applied. Two options are suggested within the context of the CTS simulation; 1) the ABC strategy refers to inventory positioning based on product type. The commonly used products are located at the forefront of storage while some types of products whose rate of stock turns is insufficient are place to the rear of storage, 2) Random Strategy means that each product is put into storage arbitrarily. Other measures concerned with planning of control rules are demonstrated in the following Figure 5.24.

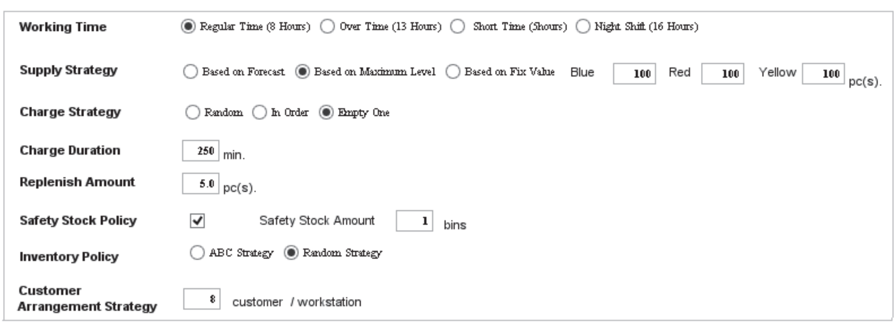


Figure 5.24: Measures are concerned with planning of control rules

The measures are also discussed under three sections on the basis of planning terms. In other words, the available measures are separated into three headings, and the essential point on which they are distinguished is related to their primarily influence domain namely; to increase system load, to decrease cost and to increase performance, and can be seen in Table 5-5 below. Also, companies could have been possessed with an absolute idea of what measures might have an influence on capacity, cost or even throughput rate.

Table 5-5: Measures based on influence area

To Increase System Load	To Decrease Cost	To Increase Performance
Definition of System Load	**Definition of System Load**	**Definition of System Load**
Order Rate	Order Rate	Order Rate
Product Type in an Order	Product Type in an Order	Product Type in an Order
Due Date	Due Date	Due Date
Planning of the Organizational Structure	**Planning of the Organizational Structure**	**Planning of the Organizational Structure**
Shuttle Responsibility		
Resource Planning	**Resource Planning**	**Resource Planning**
Number of Order Pickers	Number of Order Pickers	Number of Order Pickers
Number of Replenish Workers	Number of Replenishment Workers	Number of Replenishment Workers
Number of Shuttles	Number of Shuttles	Number of Shuttles
Number of Forklifts	Number of Forklifts	Number of Forklifts
Speed of Shuttle	Maximum Stock Level	Speed of Shuttle
Speed of Worker	Re- Order Point	Speed of Worker
Speed of Forklift		Speed of Forklift
Speed of Lifts		Speed of Lifts
Maximum Stock Level		Maximum Stock Level
Re- Order Point		Re- Order Point
		Zone Capacity
Layout Planning	**Layout Planning**	**Layout Planning**
Routing Policy		Routing Policy
		Collision Avoidance
		Collision Range
Planning of Control Rules	**Planning of Control Rules**	**Planning of Control Rules**
Working Type	Working Type	Working Type
Supply Strategy	Supply Strategy	Supply Strategy
Customer Arrangement Strategy		Charge Strategy
		Charge Duration
		Replenish Amount
		Safe Stock Policy
		Inventory Policy

5.6 Validation and Verification of Anticipatory Change Planning

The purpose of the present study is to develop a framework for all kind of intralogistics systems, to apply anticipated changes and to find the appropriate solutions in case of unwanted situations after putting changes into practice. The proposed framework is an extension form of the study that belonged to (Güller, et al., 2014), and which is explained comprehensively in Chapter 3. In additional to their study, the following framework has been developed based on the principle of the flow chart diagram and certain conditional statements. The main goal of this framework is to be an applicable procedure for all sorts of companies who should be able to follow the framework easily. Each significant process of the integrated anticipatory change planning framework and the six step planning procedure will be explained gradually, and in depth below.

System Load Creation

This step is the initial step in which three different product types are generated. A particular simulation model called Change Planning Simulation (CPS) is created in order to obtain a virtual marketplace situation by reflecting real business conditions. In an attempt to handle this kind of simulation, both expected and unexpected events are taken into consideration. After running CPS, two time series graphs related to the demanded and supplied products fluctuations are acquired.

Scenario Generation

Due to the presence of a countless number of events, incidents and natural happenings which might occur in the future, it is unachievable to make plans for all above mentioned events. Therefore, a scenario- based approach to anticipatory planning is preferred to convert potential events into an experiment set. Wulf et al., (2011) define the aim of scenario planning as a development of various possible views of the future and thinking through the consequences of handled views for enterprises. In addition, they suggested that the scenario planning approach gives an opportunity to managers to challenge their assumptions to achieve being prepared the future developments. That is why scenario planning is merged into the proposed system.

Within the scope of the present study, two kinds of uncertainties are basically examined. 1) Inside the warehouse, uncertainty has a significant impact on the numbers of products, products types or the due date of the customer order. . 2) Outside the warehouse uncertainty also has an impact; however, it is produced from external sources.

Assessment of the Existing State

After the scenario creation, the original form of the experiment set is firstly run in order to realize whether any unwanted consequences happen or not. One of the most important parts of CTS simulation is statistical analysis that is composed of many flexibility corridors and statistical graph or charts. It is also called the assessment section, and depicts the overall results in a simple way and also ensures that users recognize which control parameters are not within the acceptable borders. Besides specific analysis, such as cost or storage assessment, the performance availability analysis also gives an idea about the overall capacity of the entire intralogistics system.

Determination of Alternative Measure

This step is put into practise if the conditional statement, which is checking all potential classes in an attempt to understand how to behave after change is applied, returns a negative reply. In the case of detecting an undesired increase or decrease, the alternative measures that are defined previously are chosen. At this point, three aims are considered, while finding an appropriate measure, these are; increase the system load, decrease the total cost and increase the system performance. During the selection of precautions, the Six Step Planning (SSP) method that emerges from process chain methodology provides a systematic approach to follow and a broad perspective to evaluate all parameters without any oversight.

Assessment of Measure

In order to be certain that the applied measure is profitable, and the undesired results of the projected scenario are prevented, the measures should be tested. Because of this, the simulation is re-run with the measures. The procedures explained in the assessment of the existing system step are repeated iteratively, in order to evaluate the suitability of the recommended measures. If the applied measures cannot satisfy expectations in terms of cost, performance or system load after testing the impact of measures on different kinds of potential classes, another measure should be examined. Otherwise, there is no obstacle to implement the chosen measures.

All the above explained steps are demonstrated explicitly in the following flow diagram in Figure 5.25.

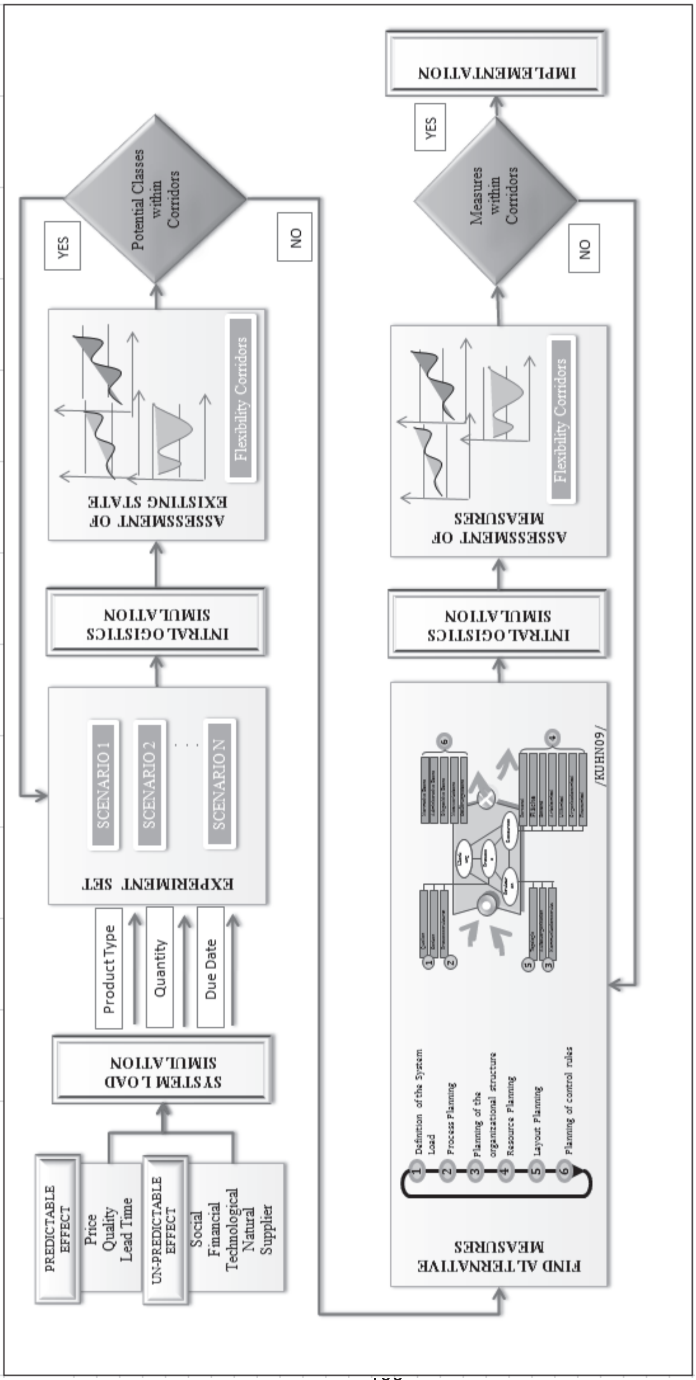


Figure 5.25: An integrated anticipatory change planning framework with six step planning method for cellular transport system simulation.

In an attempt to prove the efficiency of the anticipatory change planning integrated into the CTS simulation, validation and verification of the recommended framework is provided by using the scenario planning technique. Within the compass of this research, five representative change scenarios are thought out. While planning these sorts of change scenarios, the main concern is to take, not only more widespread, but also well-rounded problems or alterations into consideration. The first three scenarios are concerned more with the fluctuation in product demand, and these are accepted as the external changes. The generated scenarios enhanced changes which have originated both inside and outside of the intralogistics system. In this context, the last two change scenarios are organized in deference to internal alteration. All generated change scenarios are given below in more detail.

5.6.1 Change Scenario 1: The Seasonality Effect on All Product Types

In the first scenario, the demand goes up 100% for all products. In order to reflect this change in the simulation, each customer begins to give orders two times during a single day, whereby the interval time of two orders is determined as being 480 minutes under normal conditions. After a pre-specified change is applied within the context of scenario 1, the essential performance parameters, with their flexibility corridors are given below in Figure 5.26.

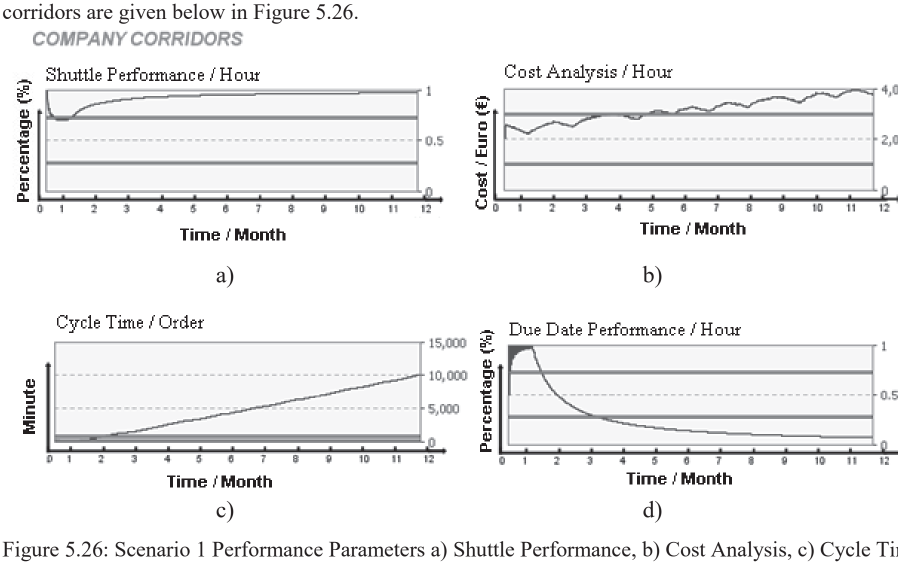


Figure 5.26: Scenario 1 Performance Parameters a) Shuttle Performance, b) Cost Analysis, c) Cycle Time, d) Due-date Performance.

As can be detected from the graphs above, the capacity of the intralogistics system is increasing step by step, in order to deliver customer orders on time. However, the last graph shows that there has been a sharp decline in the performance of the due date. On the other hand, the cycle time of an order, which starts after the order is entered into the system, is increasing steeply. There is also a marked rise in the total cost because of the penalty cost of late delivery. In any case, it seems clear that the existing cellular transport system was not able to overcome the seasonality effect as a result of the sudden increase in demand. In order to regulate the insufficient condition of the system, three kinds of measures are selected by using the systematic approach of six steps planning, originated from process chain methodology.

Increasing Velocity

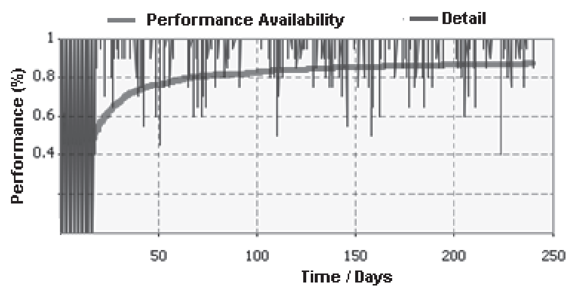
The first measure is increasing the velocity of the shuttle that is located under the fourth step of process chain methodology called resource planning. The velocity of a single shuttle is increased twofold.

Increasing Working Hours

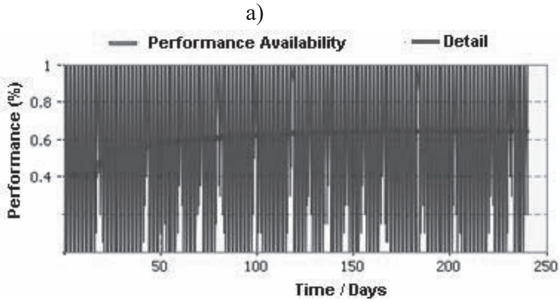
The second measure is increasing the working hours; which is related to the planning of control rules step. The default working hours of existing systems is eight hours per day, whereas for this case, the working hours are increased by 100%, and the company begins to work sixteen hours each day.

Increase the Number of Shuttles

The last measure is about increasing the number of shuttles, again from the resource planning sub classes. The initial number of shuttles in the cellular system is twenty, and then ten shuttles are inserted into the system to enhance the inadequate warehouse capacity. The analysis of abovementioned measures are given below in Figure 5.27.



a)



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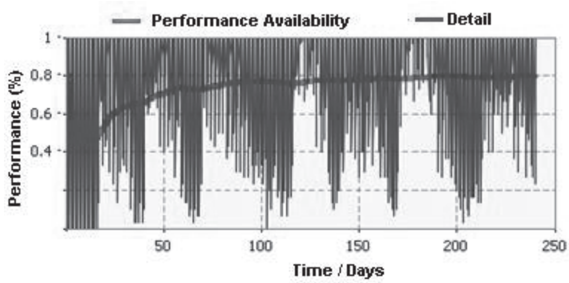
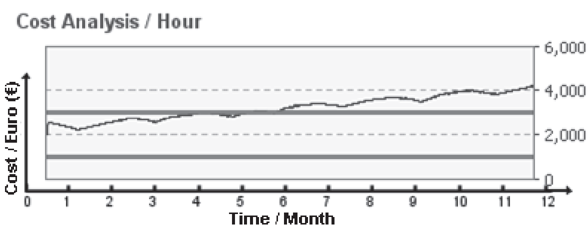


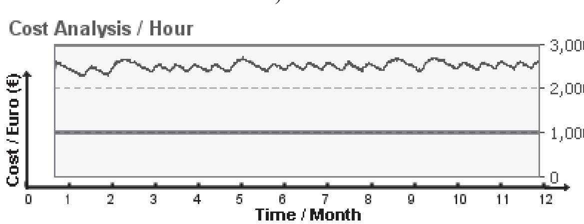
c)

Figure 5.27: Scenario 1 Performance Availability for a) Increased velocity b) Increased working hours c) Increased number of shuttles.

As stated before, the performance availability inside the context of CTS simulation is calculated by taking an average of all available shuttle performances. When the detailed shuttle performance graph is investigated, it is noticed that the shuttles are waiting periodically because of completing a demanded order or in the case of an item being out of stock. However, over the simulation run time, the duration of waiting times is going down slightly. This is why the performance availability increases steadily over time.Besides performance analysis, the cost behaviours of each measure are demonstrated in the following Figure 5.28.



a)



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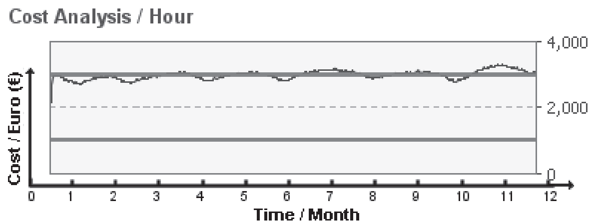


c)

Figure 5.28: Scenario 1 Cost Analysis for a) Increased velocity b) Increased working hours c) Increased the number of shuttles.

Based on the performance availability, the cost analysis graphs above and Table 5-6 given below, that summarizes the simulation results under basic performance parameter headings, the third measure is chosen to implement.

Table 5-6: Scenario 1 a comparison of the selected three measures.

Measures	Total Order	Throughput Rate	Cycle Time	Order Uncompleted	Order Completed	Customer Waiting	On Time Delivery	Late Delivery	Cost
Increase # of Shuttles	19240	80	217	0,00	1,00	277,44	0,89	0,11	2986
Velocity increase	19240	76	1147	0,05	0,95	1207,75	0,10	0,87	3201
Night Shift	**19240**	**80**	**241**	**0,00**	**1,00**	**300,55**	**0,96**	**0,04**	**2499**

5.6.2 Change Scenario 2: Twice as Many Orders Due to Local / Global Promotion

For the second scenario, the Change Planning Simulation is utilized in order to obtain a sharp increase on only one product. To accomplish this goal, local and global promotions are made only for the blue products and the related graphs are represented as follows in Figure 5.29. In short, demand goes up approximately 50-60 % for a blue product and an unbalance between order lines is observed.

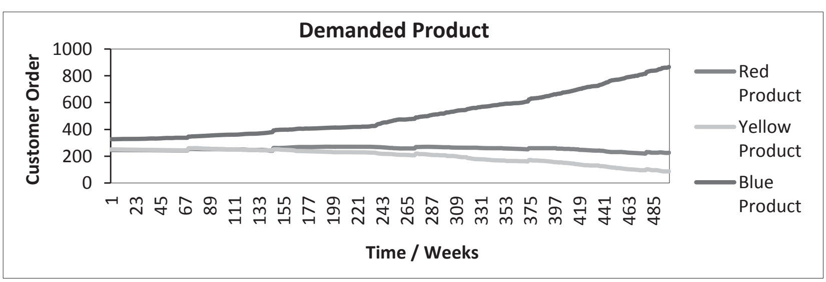


Figure 5.29: Scenario 2 Increased demand of about 50 % for a key product and the unbalanced situation between order lines.

After the abovementioned change is applied under the concept of scenario 2, the storage analysis and products fluctuations are given below in Figure 5.30.

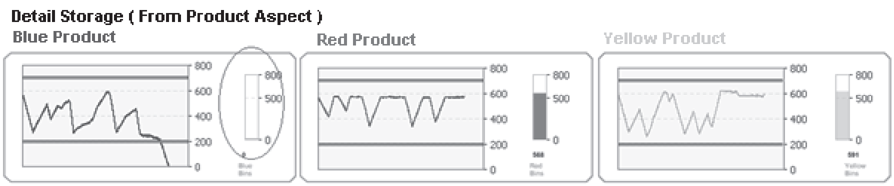


Figure 5.30: Scenario 2 Storage behaviour for blue, red and yellow products before measure implementation.

As demonstrated in the above three diagrams which present a detailed storage analysis, the blue product has run out. In order to strengthen understanding, the bar charts are attached next to the time plot and they show the total product amount in the storage for each product types. To put it simply, unbalanced demand between order lines can lead to huge fluctuations for some order lines; the blue product being one example. In order to overcome this challenge, three measures are chosen which are explained comprehensively as follows:

Increase the Maximum Stock Level

At the beginning of the CTS simulation, a specific amount is assigned for each product type. This amount, also called the maximum stock level, is determined as 600 bins for every type of product. However, the maximum stock level goes up by 33%, and the new amount of product varies from 600 bins to 800 bins. The graphs concerning storage behaviour after increasing the maximum stock levels are represented below in Figure 5.31.

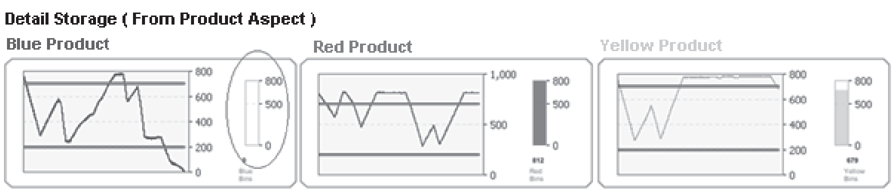


Figure 5.31: Scenario 2 Storage behaviour for blue, red and yellow products after increasing the maximum stock levels.

What is remarkable is that 'run out of blue product problems' has emerged again. Thus, it can be concluded that increasing maximum stock levels is not viable for solving the encountered problems.

The Adding Safety Stock Policy

Another measure is selected from the most important part of six steps planning, in which control rules and warehouse strategies are modified by removal or insertion. Safety stock policy is an example under the headings of the planning control rules step. Normally, re-order point rules are carried out in order to avoid stock deficiency. However, re- order point rules remain incapable in the case of scenario 2. At this point, 100 bins are kept in reserve as safety stock.

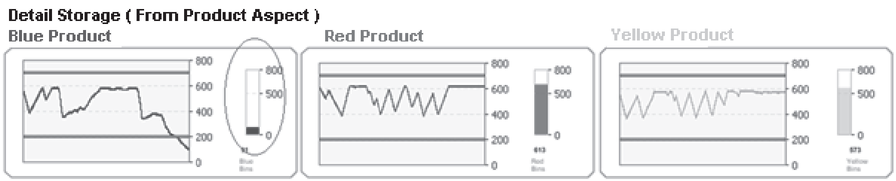


Figure 5.32: Scenario 2 Storage behaviour for blue, red and yellow products after adding safety stock

It can be seen from the above stock graphs Figure 5.32, that even though the simulation is completed without a non-available situation, an enormous wave can be observed on the blue product. Hence, inserting the safety stock measure cannot be accepted as an exact solution for this case study.

The Alter Supply Strategy

Within the concept of CTS simulation, the purchasing process is performed under three strategies. The first is based on forecast strategy that obtains the purchasing amount from the Change Planning Simulation. The second strategy is carried out according to maximum levels, and aims initially for full storage. , The third strategy is based on the fix value strategy, in which users are able to arrange the purchase amount for each product group. The default value of CTS simulation is the maximum level method. However, other supply techniques will be applied to understand which strategy is the most suitable when an unbalanced case is realized between demanded products.

The Forecast Option

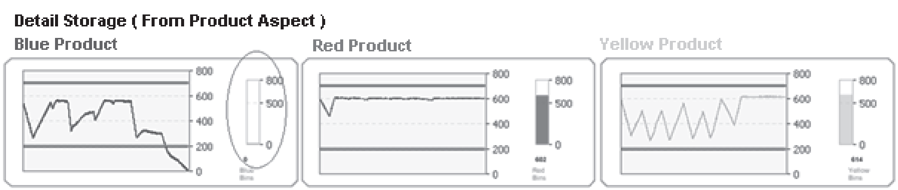


Figure 5.33: Scenario 2 Storage behaviour for blue, red and yellow products after applying forecast option

The graphs above in Figure 5.33 illustrate that the forecast options are not capable of handling out of stock problems. On the other hand, waving on the blue product has also appeared.

The Fixed Order Quantity Option

The Fixed Order Quantity (FOQ) method is used when demand for the product is invariable and the required quantity are not quite known. As can be understood from the demanded product Figure 5.29, blue products should be supplied two times more than red and yellow products. According to this logic, the amounts of products that will be purchased for each product type are given below in Figure 5.34.

Fix order quantity for the blue product = 400
Fix order quantity for the red product = 200
Fix order quantity for the yellow product = 100

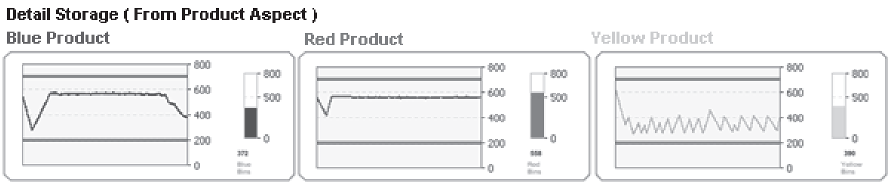
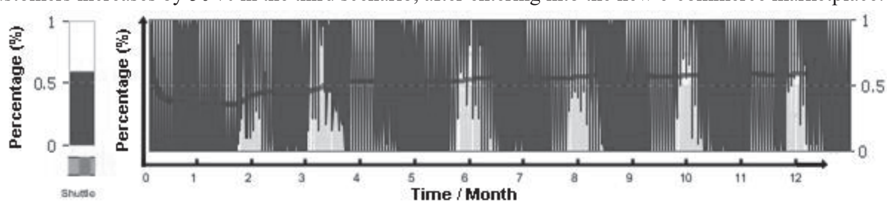


Figure 5.34: Scenario 2 Storage behaviour for blue, red and yellow products after applying the fixed value option.

Ultimately, the huge fluctuations and the non- available situation for the supplied blue product can be prevented by using the fixed order quantity supply strategy.

5.6.3 Change Scenario 3: 50% Increase in Customer Numbers Due to e-Commerce Marketing

From the following resource analysis in Figure 5.35, which is obtained from CTS simulation, it can be seen that the shuttle and order picker have enough available capacity to enlarge the existing target market with online transaction-based marketing; also called electronic commerce. Therefore, the number of total customers increases by 50 % in the third scenario, after entering into the new e-commerce marketplace.



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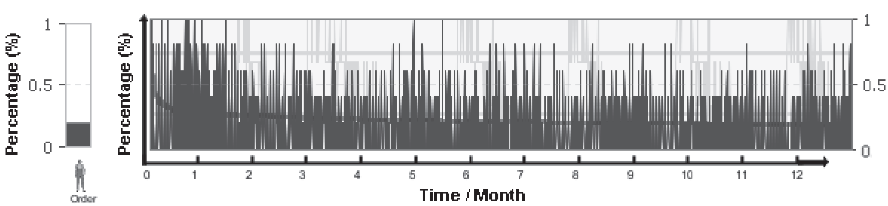
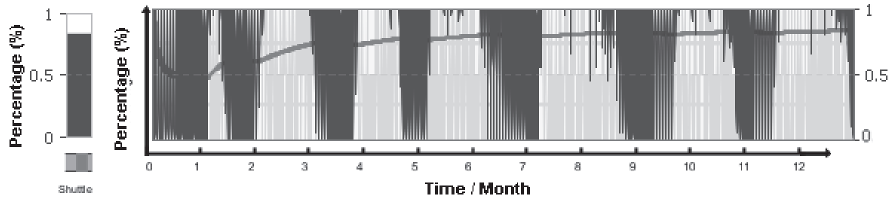


b)

Figure 5.35: Scenario 3 Initial State a) Shuttle capacity b) Order picker capacity in the workstation.

Scenario 3 is established, firstly to understand whether the existing system is capable of overcoming the 50 % increase in the number of customers, and secondly to determine the maximum level of customer numbers that the present CTS can cope with whilst still delivering the orders on time. The following shapes, shown in Figure 5.36, demonstrate the shuttle and order picker performance after a 50 % increase in customer numbers.



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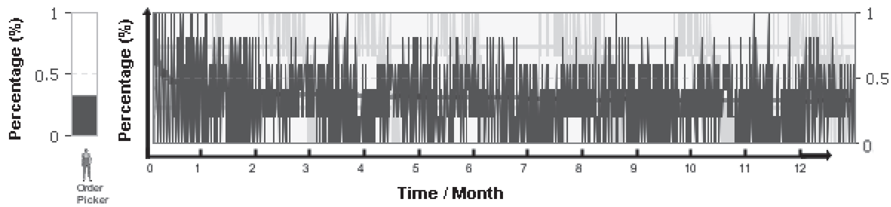
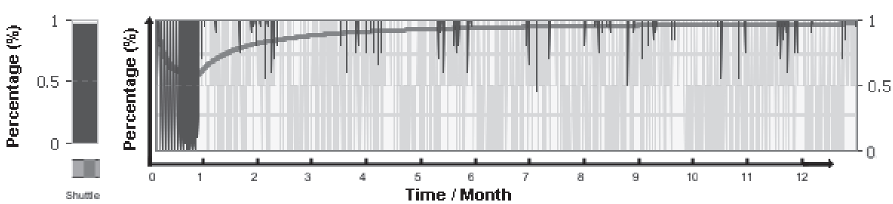


b)

Figure 5.36: Scenario 3 Customer increase of 50% a) Shuttle capacity b) Order picker capacity in the workstation.

The percentage of shuttle performance is increased from 59% to 83%, and order picker performance is increased from 19% to 32%, both at the same time as changes to the number of customers have been carried out.

The other experiment is related to quantifying the upper limit of customer numbers whose order can be fulfilled on time, within the CTS simulation. Thus, eight more customers are inserted for each workstation, in other words, the capacity of each workstation is doubled.



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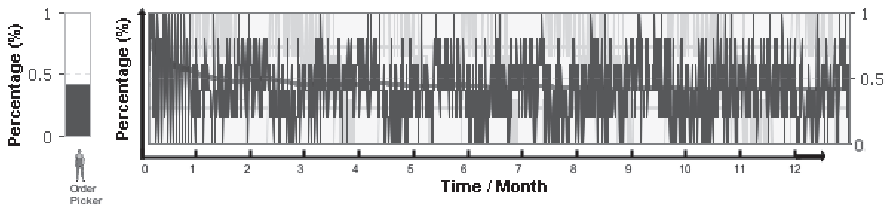


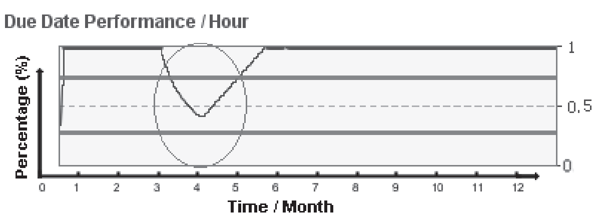
b)

Figure 5.37: Scenario 3 Customer increase of 100 % a) Shuttle capacity b) Order picker capacity in workstations.

The above shapes shown in Figure 5.37 show that the case study is about doubling workstation capacity, by assigning two times more customers, and can be handled by the existing shuttle and order picker capacity. The last performance level for the shuttle is approximately 96% and for order picker is 41%. It seems clear enough that, although the order pickers have sufficient time to pick for more than double the number of customers, the shuttles are almost too busy for picking the requested item.

5.6.4 Change Scenario 4: Disruption in the Warehouse for a Month

In Scenario 4, the company has been shut down because of an unexpected event, either inside or outside the supply chain, such as natural catastrophic loss, strike or sabotage, for one month. The aim of this scenario is to give the company an idea by providing general system load analysis or specific analysis i.e. cost or storage analysis etc. under the closed-down circumstances. With the help of this series of analyses, companies might be able to arrange a precautions plan to apply when they encounter an undesired challenge. The logic behind scenario 4 is to stop the running of the warehouse for one month. However, in the meantime, customers are continuing to place orders. . The first of the following, in Figure 5.38 represents a sharp fall in due date performance. The important inference obtained from this graph is that at least two months are required to complete and delivery of accumulated and delayed orders. In addition, the last graph also shows the total customer waiting times. During the disruption, customer waiting times for orders have reached their peak values, and after one month of disruption, the customer waiting times cannot be held within the flexibility corridors throughout year.



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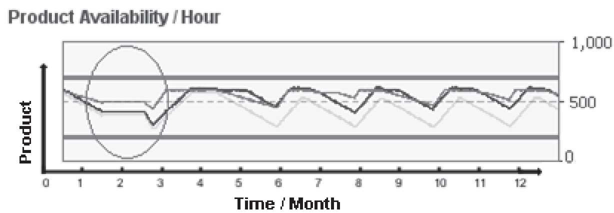

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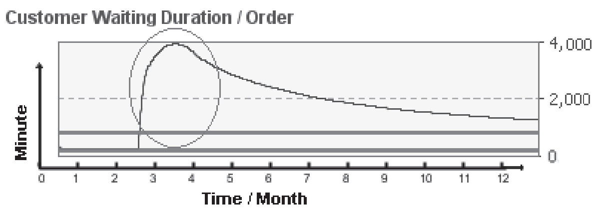


c)

Figure 5.38: Scenario 4 Disruption in warehouse a) Due date performance b) Product Availability c) Customer Waiting Duration

It is also apparent from the following Figure 5.39, that after a one month shutdown, the warehouse has been operating at full capacity for two months in order to fulfil undelivered orders. Then, the existing capacity is used in a balanced manner over the next months.

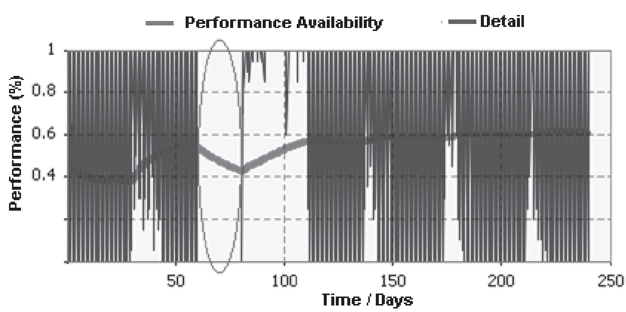
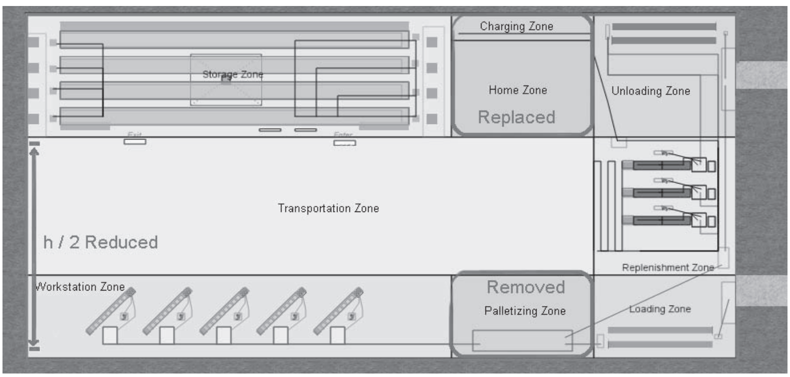


Figure 5.39: Scenario 4 Performance Availability in the close down case of CTS.

5.6.5 Change Scenario 5: Total layout decreases 20%

The initial layout is composed of nine zones, which are distinguished based on performed activities. The height of the warehouse is 50m, the length of the warehouse is 100m, and the surface area of the whole warehouse is $5000m^2$. Incidentally, the collision range and the time duration needed to avoid collisions are accepted as respectively 3 meters and 60 seconds. In a conventional system, huge, bulk conveyor systems are installed between the storage and workstation area to provide product flow, whereas the transportation area is left empty for shuttle movement. At first, the size of the transportation area can be thought of as being too large resulting in high space costs. On the other hand, a narrow transportation area might result in high collision rates. What is significant is that there is a challenge between the dimension of the transportation zone and collision avoidance. In order to show this challenge, scenario 5 is generated. The initial layout and narrowed layout are given in Figure 5.40 as a simulation screenshot.



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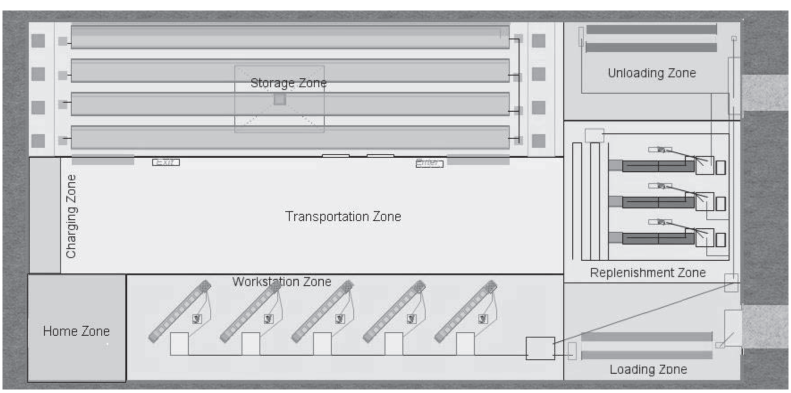


b)

Figure 5.40: Scenario 5 CTS Simulation screenshot of a) existing layout b) narrowed layout.

After a CTS simulation is run, the cost analyses of both layouts are represented below in Figure 5.41. The reason behind the difference between the two cost fluctuations can be explained by the fact that the total space has decreased by 20%.

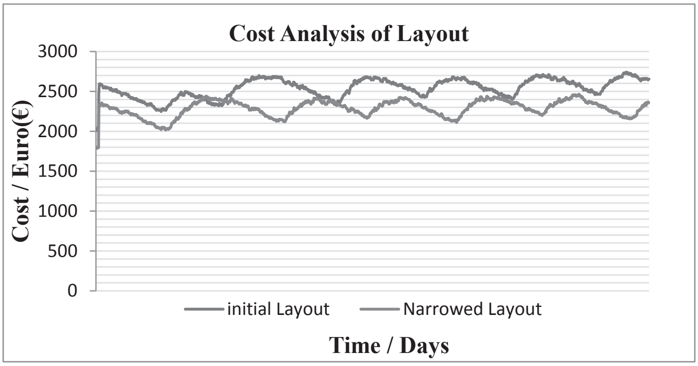
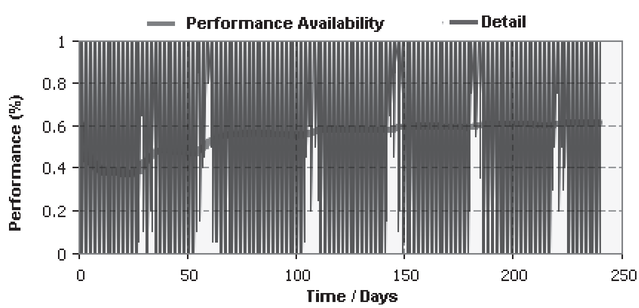
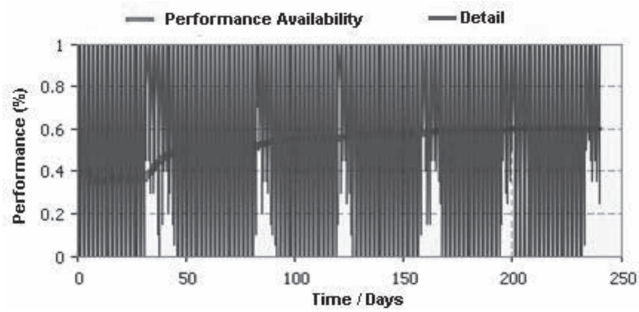


Figure 5.41: Scenario 5 Cost analysis of initial layout and narrowed layout.

It could be concluded from the following Figure 5.42, that there is no significant difference between the initial layout and the narrowed layout when deciding which of the two designs is better, from the point of view of performance availability.



a)



b)

Figure 5.42: Scenario 5 Performance Availability of a) existing layout b) narrowed layout.

Under standard conditions, it is expected that the due date performance should be high when the distance between activity is high. However, performance availability and late delivery rates are almost the same as the initial layout due to the waiting duration which has emerged during collision avoidance, as shown below in Table 5-7

Table 5-7: Scenario 5 the comparison of initial layout and narrowed layout

Parameters	Initial Layout	Narrowed Layout
Total Amount of Collision Detection	**2777**	3529
Total Amount of Collision Avoidance	**797**	1696
Late delivery (Percentage)	11	**8**
Performance Availability (Percentage)	59	**57**

Chapter 6

Summary and Conclusion

In the first part of this chapter, the main findings after completing the present research study and conclusions will be offered. In the second part, possible recommendations under the Future Research heading will be given.

6.1 Summary of Main Contributions

Concluding this thesis, the main findings are drawn as follows:

1. Due to the novelty of study components and the incompatibility between English and German researches in terms of scientific expression, extensive theoretical information and terms, definitions are provided after completing a comprehensive literature review.
2. A huge requirement for the use of simulation has resulted in a growth in the number of simulation languages and packages on the market, especially for Agent-Based Simulation. Due to this reason, which simulation tool is the most suitable, by taking all requirements of the study into account was unknown. AnyLogic simulation software has been selected for comparison with others completing analytical analyses.
3. With the help of the first developed simulation model called Change Planning Simulation (CPS), the user would be able to arrange the parameters of change impact such as, effect duration, rate and volume etc. Besides that, the CPS simulation is capable of ensuring the reflection of diversity of real word cases by offering many control parameters for each of the change drivers. Hence, users can also set the parameters of change effect according to the current situation of their countries.
4. Cellular Transport System (CTS) simulation composed of autonomous multi shuttles was simulated on the basis of Agent-Based simulation. Regardless of the lack of knowledge and research about the CTS, the all warehouse activities and inventory rules were inserted into the CTS simulation. In order to enlarge the specification of the CTS simulation, agent based simulation, discrete event simulation and statistical analyses, parts are generated by writing Java programming language.
5. The thinking of flexibility corridors was established into the study to ensure whether or not the changes are located within the acceptable upper and lower limits. Prior to this, there was no study that

determined the upper and lower limits of flexibility corridors. However, two methods were developed to specify the maximum and minimum values of boundaries.

6. Nevertheless, using current intralogistics systems, it is becoming more challenging to measure situations because of performing various operations simultaneously. Hence, the previous studies are not sufficient enough to quantify the performance availability of a whole enterprise as well as to overcome this challenge. Due to this reason, within the structure of this dissertation, two methods were utilized to compute performance availability. One of them is the weighted average method, the other one is the fuzzy logic method.
7. The main goal of this framework, which was to be an applicable systematic experimentation procedure that all sorts of companies would be able to follow easily, was realized. Each significant change which has influence on the CTS can be tested and the conditions of the warehouse, with or without the measure effects, can be assessed under favour of the Anticipatory Change Planning framework with the six step planning procedure.

6.2 Future Research

The results of this study suggest a number of new research fields given as follows.

The efficiency of the Cellular Transport System (CTS) is only compared in terms of cycle time. However, this comparison could be enlarged by inserting other performance indicators such as, storage type, dwell point strategy etc. into the analytical model. On the other hand, within the scope of this thesis, the simulation model designed is only the CTS. In order to evaluate the performance of the ASRS AVSRS and the CTS in an identical environment, a simulation model which involves these three intralogistics systems could be prepared.

As mentioned before, there was no scientific study to define the limits of flexibility corridors until this research. Therefore, new techniques can be improved, at least to examine the accuracy of the current study results. This recommendation is also true of the performance availability calculation.

Another suggestion as a future study can be an extension of the CTS simulation scope. In this study, the CTS was simulated according to distribution center thinking. Hereby, manufacturing activities and the production warehouse could be inserted into the simulation in order to obtain an extensive model.

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Appendix A

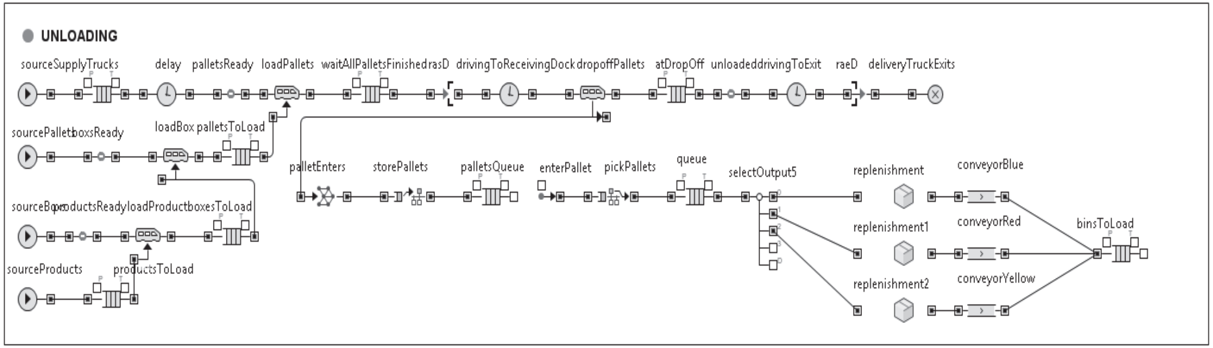

Figure 0.1: Model Logic of Unloading and Replenishment

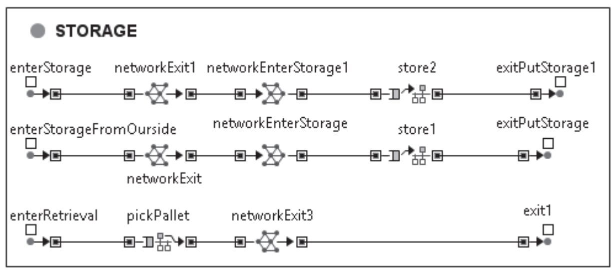

Figure 0.2: Model Logic of Storage

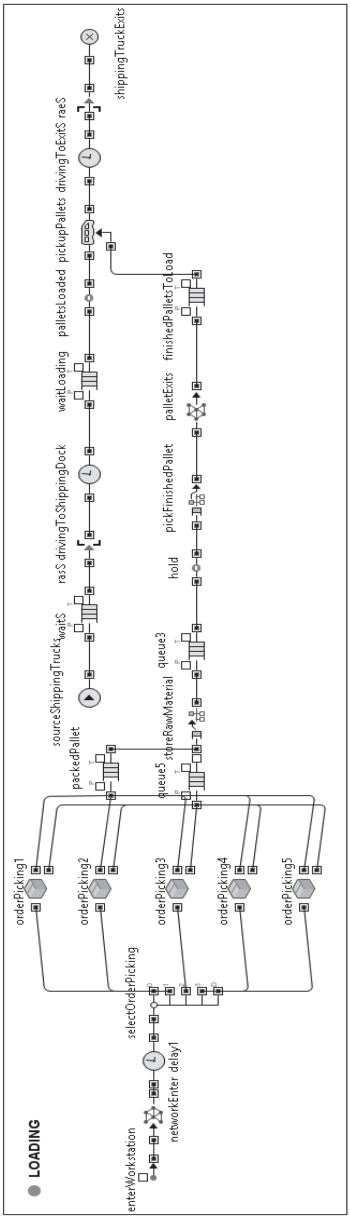

Figure 0.3: Model Logic of Loading and Order Picking

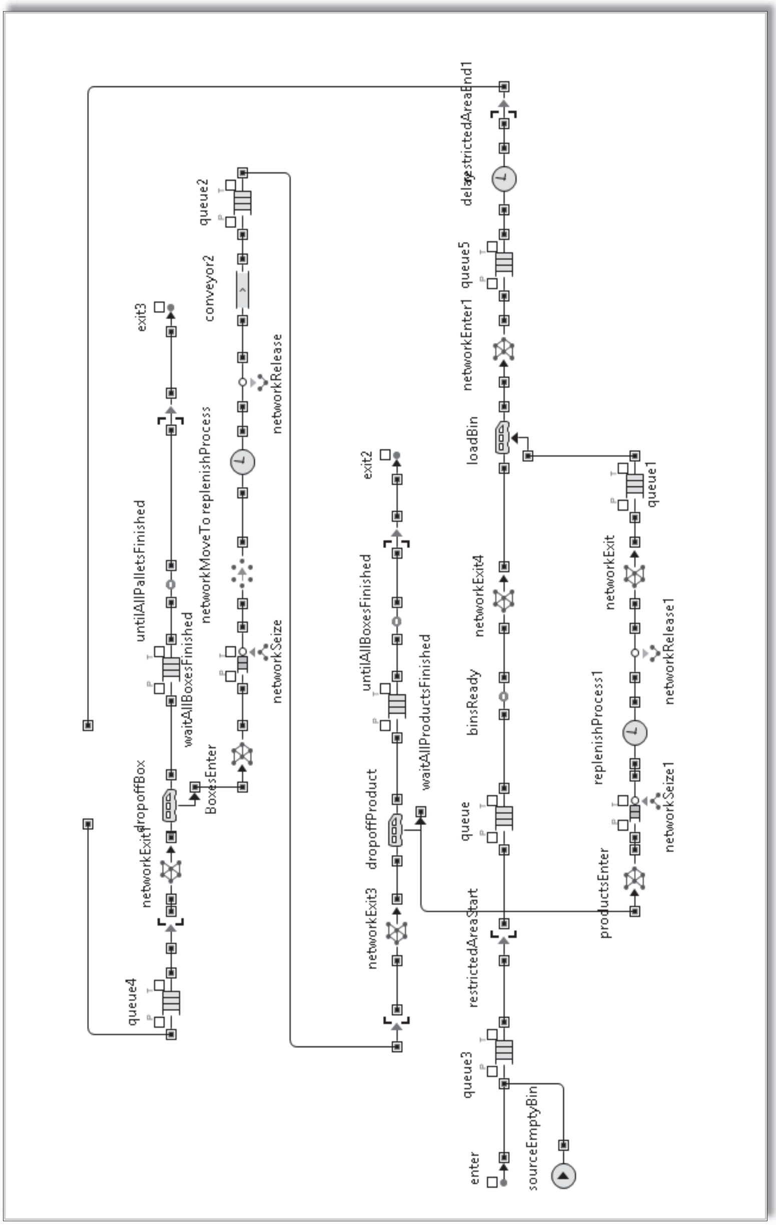

Figure 0.4 Model Logic of Workstation

Table 0-1: Fuzzy Logic Rules for Performance Availability Calculation

	Cost (euro)	Throughput (performance)	Due Date (day)	Performance Availability
1	VL	L	VL	M
2	VL	L	L	M
3	VL	L	M	L
4	VL	L	H	L
5	VL	L	VH	VL
6	VL	M	VL	VH
7	VL	M	L	H
8	VL	M	M	M
9	VL	M	H	L
10	VL	M	VH	L
11	VL	H	VL	VH
12	VL	H	L	H
13	VL	H	M	H
14	VL	H	H	H
15	VL	H	VH	M
16	L	L	VL	M
17	L	L	L	M
18	L	L	M	L
19	L	L	H	L
20	L	L	VH	L
21	L	M	VL	H
22	L	M	L	H
23	L	M	M	M
24	L	M	H	M
25	L	M	VH	L
26	L	H	VL	VH
27	L	H	L	H
28	L	H	M	H
29	L	H	H	H
30	L	H	VH	M
31	M	L	VL	M
32	M	L	L	L
33	M	L	M	L
34	M	L	H	VL
35	M	L	VH	VL
36	M	M	VL	M
37	M	M	L	M
38	M	M	M	M
39	M	M	H	L
40	M	M	VH	L
41	M	H	VL	VH
42	M	H	L	VH
43	M	H	M	H
44	M	H	H	M
45	M	H	VH	L
46	H	L	VL	L
47	H	L	L	L
48	H	L	M	VL
49	H	L	H	VL
50	H	L	VH	VL
51	H	M	VL	M
52	H	M	L	M
53	H	M	M	L
54	H	M	H	VL
55	H	M	VH	VL
56	H	H	VL	H
57	H	H	L	M
58	H	H	M	M
59	H	H	H	L
60	H	H	VH	VL
61	VH	L	VL	L
62	VH	L	L	L
63	VH	L	M	VL
64	VH	L	H	VL
65	VH	L	VH	VL
66	VH	M	VL	L
67	VH	M	L	L
68	VH	M	M	L
69	VH	M	H	VL
70	VH	M	VH	VL
71	VH	H	VL	M
72	VH	H	L	L
73	VH	H	M	L
74	VH	H	H	VL
75	VH	H	VH	VL

Table 0-2 Simulation Parameters

Number	Parameters	Value
1	Initial Stock Size	1800
2	Supply Truck Capacity	21
3	Supply Truck Arrival Rate	Immediate
4	Pallet Capacity	9
5	Bin Capacity	20
6	Unloading Forklift Speed	4 m/sc
7	Unloading Time per Truck	5 sc
8	Worker Speed for Replenishment	2 m/sc
9	Replenishment Time per Bin	5
10	Unloading Time per Pallet	5 sc
11	Capacity of Pallet storage area for Unloading	28
12	# of forklifts for Unloading	1
13	speed of Agent	2m/sc
14	collision Range	3 meters
15	# of workstation	5
16	# of charging area	4
17	Charging duration	15 sc
18	Speed of lifts	1,5 m/sc
19	First location of lifts	0
20	Order arrival rate	8 hr
21	Product distribution within the order	Normal
22	Product type	3
23	Max Order waiting duration	200 sc
24	# of enter/exit point	1
25	Delay time on the Enter/Exit point per Agent	15 sc
26	Worker Speed for Order Picking	3m /sc
27	Delay time on the workstation per Agent	10 sc
28	# of customer per workstation	8
29	# of forklifts for loading	1
30	Pallet Capacity for Delivery	9
31	Capacity of Pallet storage area for Loading	28
32	Shipping Truck Capacity	21
33	Shipping Truck Arrival Rate	Immediate
34	Reorder Point	300
35	Total Area	5000
36	Area of home location	400

37	Area of storage	640
38	Area of unloading	360
39	Area of Loading	480
40	Area of replenishment	400
41	Area of Workstation	720
42	Area of transportation	1600
43	Area of charging	400
44	Truck Speed	3 m/sc
45	Forklift Speed	4 m/sc
46	Delay time on the storage pick and put	5 sc
47	# of aisle	4
48	# of bays	60
49	# of tiers	5
50	# of storage position	2400
51	# of product capacity	48000
52	# of Consumer	2000