UTILITY ANALYSIS AND COMPUTER SIMULATION OF RFID TECHNOLOGIES IN THE SUPPLY CHAIN APPLICATIONS OF PRODUCTION SYSTEMS

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YURTSEVEN BOLATLI

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Approval of the Graduate School of Informatics

____

Prof. Dr. Nazife BAYKAL
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

____

Assist. Prof. Dr. Tuğba Taşkaya TEMİZEL
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science/Doctor of Philosophy.

____

Assist. Prof. Dr. P. Erhan EREN
Supervisor

Examining Committee Members

Assist. Prof. Dr. Altan KOÇYİĞİT (METU, II) ____________________

Assist. Prof. Dr. P. Erhan EREN (METU, II) ____________________

Prof. Dr. Nazife BAYKAL (METU, II) ____________________

Assoc. Prof. Dr. Nihan Kesim ÇİÇEKLİ (METU, CENG) ____________________

Assist. Prof. Dr. Alptekin TEMİZEL (METU, II) ____________________

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Name, Last name: Yurtseven Bolatlı

Signature : __________________

ABSTRACT

UTILITY ANALYSIS AND COMPUTER SIMULATION OF RFID TECHNOLOGIES IN THE SUPPLY CHAIN APPLICATIONS OF PRODUCTION SYSTEMS

BOLATLI, Yurtseven
M.S., Graduate School of Informatics
Supervisor: Assist. Prof. Dr. P. Erhan EREN

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In this thesis, the feasibility of deploying RFID technologies in the case of "low-volume high-value" products is considered by focusing on the production processes of a real company. First, the processes of the company are examined and associated problems are determined. Accordingly, a simulation of the current situation is constructed by using the discrete event simulation technique, in order to obtain an accurate model. In addition to modeling the current situation, this simulation model provides a flexible platform to analyze different scenarios and their effects on the company production. Next, various scenarios including RFID technology deployment are examined, and their results are compared with respect to profit analysis which takes into consideration the changes in the production, work in process (WIP) inventory, stockouts, transportation and initial investment. Finally, the analysis of the results and conclusions are given in order to provide guidance for companies with “low-volume high-value” product portfolios.

Key words: Radio Frequency Identification (RFID), Supply Chain Management, Discrete Event Simulation, High Value Products, Low Volume Production

ÖZ

ÜRETİM SİSTEMLERİNDEKİ TEDARİK ZİNCİRİ UYGULAMALARINDA RFID TEKNOLOJİLERİNİN FAYDA ANALİZİ VE BİLGİSAYAR BENZETİMİ

BOLATLI, Yurtseven
Yüksek Lisans, Enformatik Enstitüsü
Tez Yöneticisi: Yrd.Doç.Dr. P. Erhan EREN

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Bu tezde, düşük miktar yüksek değerde olan ürün durumunda RFID teknolojilerinin kullanımının uygulanabilirliği, gerçek bir firmanın üretim süreçlerine yoğunlaşılarak ele alınmıştır. İlk olarak, firmanın süreçleri incelenmiş ve ilgili problemler belirlenmiştir. Doğru bir model elde etmek için ayrık olay benzetimi tekniği kullanılarak mevcut durumun benzetimi düzenlenmiştir. Mevcut durumun modellenmesinin yanı sıra, bu benzetim modeli farklı senaryoları ve bunların firmanın üretimine etkilerini analiz etmek için esnek bir platform sağlamaktadır. Sonrasında, RFID teknolojilerinin kullanımını da içeren çeşitli senaryolar incelenmiş ve bu senaryoların sonuçları, üretimi, yarımamul envanterini, gecikmeleri ,nakliyeyi ve başlangıç yatırımını göz önünde bulunduran karlılık analizine gore kıyaslanmıştır. Son olarak, düşük miktar yüksek değerde ürün portföyüne sahip şirketlere yol göstermek amacıyla sonuçların ve çıkarımların analizi verilmiştir.

Anahtar Kelimeler: Radyo Frekansı Kimlik Tanımlama (RFID), Tedarik Zinciri Yönetimi, Ayrık Olay Benzetimi, Yüksek Değerli Ürünler, Düşük Miktarlı Üretim

To My Mom, Dad, Sister and Düriye

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LIST OF SYMBOLS AND ABBREVIATIONS

APS: Advanced Planning and Scheduling

ARENA: Name of the simulation program used

ATP: Acceptance Test Process

Auto ID: Automatic Identification

CBRT: Central Bank of Republic of Turkey

DES: Discrete Event Simulation

DNS: Domain Name System

EPC: Electronic Product Code

ERP: Enterprise Resource Planning

FIFP: First In First Out

IP: Internet Protocol

LPT: Longest Process Time

MES: Manufacturing Executive System

MRP: Material Resource Planning

NPP: Number of the Producible Product

ONS: Object Naming Service

PML: Physical Markup Language

PB: Printed Board (Printed Circuit Board)

PBWO: Printed Board Work Orders

PWO: Product Work Orders

R&D: Research and Development

RFID: Radio Frequency Identification

ROI: Return on Investment

SCM: Supply Chain Management

SPT: Shortest Process Time

S/R: Shipper/Receiver

WIP: Work In Process

WO: Work Order

CHAPTER 1

INTRODUCTION

1.1. Background

Increased technology and competition among companies force them to create product and process innovations and develop improvements in internal and external environments. Supply chain performance is one of the hot topics that are subject to heavy research and development in the last century. Starting from 1970s manufacturing and supply chain processes are tried to be sophisticated by application of technologic developments. The story began by Material Resource Planning (MRP) software that has been used to create production plans in a plant. Now, it has reached the advanced level of technological achievement which enables companies to track material and product flow of entire supply chain with Radio Frequency Identification (RFID) technology.

RFID technology is an old innovation originated in the times of Second World War and developed with the mission of distinguishing friend and enemy planes. However it took a long time to be used in the supply chain processes. RFID technology is based on four main elements; unique identification code which identifies the product, RFID tag attached to product carrying the identification information of the product, a reader for communication with tags attached to products and an IT infrastructure to record and process the data received from readers. In the implementation of RFID, every product is tagged with an RFID tag which stores a unique identification code belonging to the product and sends this unique ID number to readers via its smart microchip and antenna. Readers receive the ID number sent from RFID tags and send this information to computing system. This mechanism provides location information of each product tagged with RFID tags. Accessing the location information of each product in the supply chain, companies are able to follow the material flow and instant inventory levels through the supply chain.

RFID technology has speeded up in the last decade as a result of the collaboration between Massachusetts Institute of Technology and the industry. This cooperation has created the Auto-ID Center which is an establishment dedicated to development of cheaper RFID technology for supply chain implementation. This center created a totally new view point and managed to decrease the set up cost of technology. In 2005 Wal-Mart decided to use RFID tags for supply chain management. Company requested its top 100 suppliers to send their products with RFID tagging. This application fired the change in the industry.

The increasing need for change in the industry motivated the research in this area and researches contributed to some amount of work in the last years. RFID is an important technological supply chain application since it eliminates the major causes of low supply chain performance. Bullwhip effect and outdated information are the two main problems of poor performance in supply chains. Bullwhip effect stems from the misinterpreted demand fluctuations in the supply chain. Under the conditions of uncertainty and change, moderate demand fluctuations may cause higher stock saving decisions taken by producers than needed and this action creates large stock saving tendency in the supply chain. In addition, out of date information related to customer demand and inventory levels creates wrong production and stocking decisions in the supply chain. However, in an RFID applied supply chain, the supplier at the end of the chain would be able to follow the inventory levels and material flow of the producer at the very beginning of the chain, which enables the supplier to track real demand fluctuations for finished goods. This advance material tracking ability increases the visibility of the chain and decreases the uncertainty on a large scale (Lee, Cheng, & Leung, 2004). In addition, it contributes to the additional abilities like advance production planning, inventory holding and material purchasing decisions (McFarlane & Sheffi, 2003). What is more, RFID creates process freedom for inventory and material verification processes by scanning them automatically (Alexander, Gilliam, Gramling, Kindy, Moogimane, Schultz, &

Woods, 2002a). Moreover, with this technology producers might be prevented from lost sales and product shrinkage problems based on better forecast decisions and the increased accuracy of the inventory information (Lee, et al., 2004).

It can be easily said that in supply chain domain, due to the abilities provided by RFID technologies, using them in high-volume production brings in more control over the inventory and production system. Related to this, literature has valuable studies for RFID dominated by high-volume low-value products and industries. Moreover, because of the high volume size, the values of the products are generally low. Researchers came up with important conclusions as a result of the case studies and simulations made for distribution centers and retailers in high-volume low-value consumer production area and therefore these do not provide much guidance for low-volume high-value production

In this thesis, research is focused on the low-volume high-value product industries to investigate:

- Gain from usage of RFID technologies in low-volume high-value production systems
- How RFID technologies should be used in low-volume high-value production systems
- When RFID technologies are worthwhile to use in the low-volume high-value production systems

To make this investigation, a production company has been selected to show the feasibility of RFID systems. The initial situation of this company is analyzed and possible usage of RFID technologies by the company and gains from this application are examined with the help of simulation technique. The company selected in this study makes low-volume high-value production and its application area is electronics industry. In this thesis, the printed board production of the company is examined because some parts of the production of the printed boards are performed by the subcontractors so the transportation of the printed boards between the company and the subcontractors is the point at issue. Moreover, the production is controlled mostly by workers and this causes high delays in the production. Furthermore, because of reasons, the values of the printed boards are quite high and the disadvantages of RFID technologies regarding the costs are negligible in this situation. Due to the low volume of production and high value of the product, not only the inventory levels are tried to be adjusted, but also the control of the employees over the production is tried to be minimized and the impacts of these adjustments over the performance of the system are examined. Discrete event simulation is the method of study used in this thesis.

1.2. Purpose of the Thesis

The main objective of this thesis is to determine the possible impacts and outcomes of RFID technology in a low-volume high-value production system by simulating RFID implementation in a company which is producing high value products in low volumes. The subject of the simulation model is a real company and the printed board production of this company is the focus of the simulation. In the study both financial and operational performance results are examined via different performance measures.

With this thesis study, it is expected to make a contribution in the way to further fill the gap in the literature for low-volume high-value products. In addition, this study is expected to add another valuable example to the literature as a study covering both internal and external processes of a manufacturer. As a result, it may serve as a starting point for further study for researchers who are interested in these types of production industries.

1.3. Limitations

In the study, as a representation of a production area, simulation is constrained with the printed board production part of the company. In the company various types of productions are made and the printed board production is one of the most important production activities in the company. In this study simulation models incorporating small number of products, resources and subcontractors are constructed, in order to prevent too much complexity that could be a burden both technologically and logically for the simulation model.

1.4. Focus of Study

This study focuses on the applicability of RFID technologies over the production area of a production company which produces low-volume high-value products, and the analysis of the results obtained. Examination of this type of company with the detailed discrete event simulation method is the distinguishing property of this study.

1.5. Method

The method of the study is given below in Figure 1.

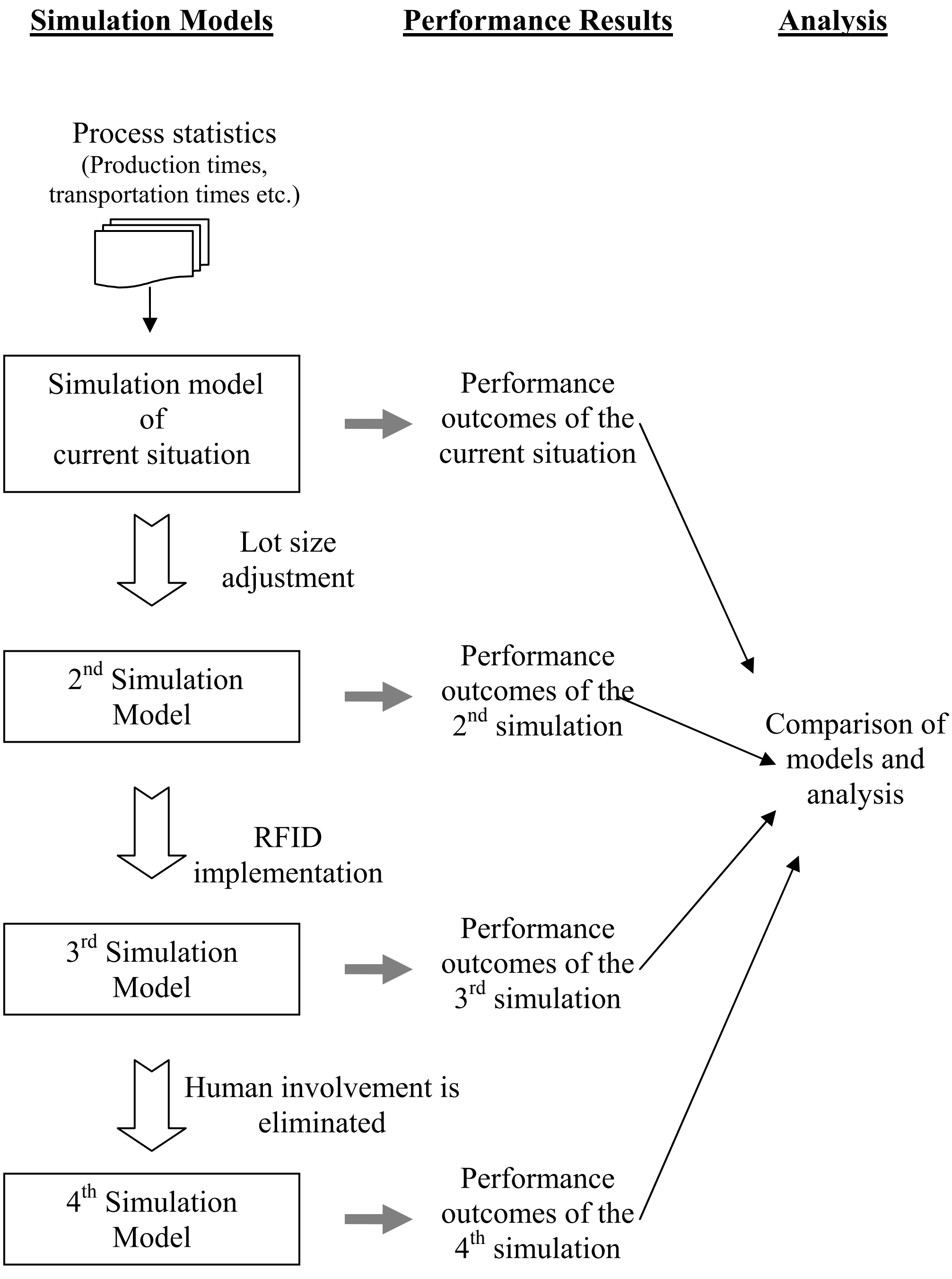

Figure 1. Method of the Study

The discrete event simulation technique is used to see the effect of RFID technology usage over the production of the printed boards. First of all the state of the production of the company is examined. Some items like production times, transportation times, and cause of the delays are investigated. After that, the current situation of the production is simulated. The second simulation model is constructed by adjusting the lot sizes in the first model and the outputs of this simulation model are compared with the outputs of the first one. Then RFID technology is applied to the second model and a new simulation is done for this case. The outputs of this model also are compared with the others. Finally, the human factors in the control of the production are tried to be eliminated by the usage of RFID technology. This case is simulated in the final simulation model and all the outputs of the four simulation models are compared and the results are analyzed.

1.6. Outline of the Thesis

A literature review is made and the related concepts are mentioned in Chapter 2. The case of a real company is examined for further investigation in Chapter 3. The company background, data from the company and problems seen in the company are studied in sections 3.1, 3.2, and 3.3 respectively. In Chapter 4, some information about the discrete event simulation technique is given in Section 4.1 and the simulation of the initial cases is mentioned in Section 4.2. The approaches are examined in the sections 4.3, **Hata! Başvuru kaynağı bulunamadı.**, 4.5, and 4.6. The analyses of these approaches are presented in Chapter 5. Finally, the conclusions are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1. Literature Review

In the literature, application of RFID Technology in the Supply Chain Management (SCM) is discussed by both RFID Technology researchers and Supply Chain Management researchers.

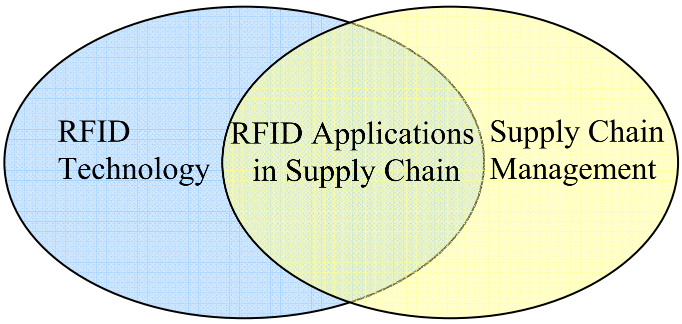

Figure 2. Relationship between RFID Technology and Supply Chain Management

RFID technology researchers cover the topic with a more technical view; studies mostly deal with the research and development of hardware, software design of RFID tagging for different stages of the supply chain. On the other hand, SCM researchers focus on the application methods and its impacts on the supply chain. Based on the purpose of this study, literature which examines the effects of RFID technology on inventory and supply chain will be taken into consideration as the starting point in this study.

RFID technology has a long history that goes back to the World War II however, development and implementation of technology in supply chain area are relatively new and limited. Studies based on this topic mostly have been done in the last seven years. Despite the unity of researchers to examine impacts of technology on supply chain, the performance criteria and the measures vary from study to study. Researchers are mostly interested in impacts of RFID technology on inventory inaccuracy, replenishment policies and bullwhip effect. Generally, the researchers could be classified in two groups. While the first group of researchers uses the simulation method to measure the effects of RFID technology on supply chain performance, the second group uses Return on Investment (ROI) analysis to examine cost-benefit results.

Researchers use simulation models to examine the dynamic behavior of supply chain with RFID technology and try to optimize its performance. Joshi (2000) analyzed the impact of RFID on supply chain in the means of increased information visibility. He chose beer production and its supply chain as the subject of the study. He analyzed the dynamic behavior of supply chain under different scenarios of information visibility and forecasting decisions via simulation method. In this study, he concluded that the real time inventory visibility provides 40% to 70% decrease in inventory costs. As a result of the study, he emphasized the intangible benefits like reduction in the lost sales due to the absence of backlogs, higher customer satisfaction provided by higher visibility of products in supply chain. Kang and Gershwin (2004) argued the inventory inaccuracy due to the undetected stock loss cause difficulties in the products replenishment and severe out-of-stock situations. In their study, they pointed out that the stock loss can cause higher lost sales than it did. Lee et al. (2004) examined the indirect benefits of applying RFID in supply chain and used a simulation model to quantify these indirect benefits. They analyzed the performance improvement in three factors; inventory accuracy, shelf replenishment policy and inventory visibility. In the simulation model a three echelon supply chain is designed and "S,s" policy is applied as the replenishment policy. Fleisch and Tellkamp (2005) analyzed the relationship between inventory inaccuracy and performance in a retailer supply chain. They tried to solve the question that is how the supply chain performance changes when the inventory inaccuracy is eliminated. Considering incorrect deliveries, misplacement, theft and unsellable goods as the source of inaccuracy, the study shows that the inaccuracy caused by the theft has the biggest impact on the supply chain performance compared to the other factors like misplacement or unsalable goods. Ustundag and Tanyas (2009) examined the cost effects of product value, lead time and the demand uncertainty under RFID application. The study shows that the product value and demand uncertainty have a significant influence on the expected benefits of the system. Higher product value results in an increased supply chain cost savings while higher demand uncertainty decreases the savings. Moreover, in a manufacturer-distributer-retailer supply chain, retailer has the highest cost savings among the three and the cost savings of the manufacturer and the distributor increases almost equally with product value increase.

Implementing RFID technology in supply chain brings many direct and indirect benefits however it requires some amount of investment. The amount of investment changes according to level of RFID tagging; it is possible to tag and follow each product (item level tagging) as well as case of products or a pallet of products. In addition, the level of technical performance and advancement also affects the cost of RFID implementation. Considering different levels of tagging, technology used and the type of business area, different studies have been carried out by researchers. Angeles (2005) gives an overview of RFID use in supply chain and emphasizes some critical points for new adopters. In her study, she argued about making a ROI analysis before implementing RFID and she emphasized the importance of the framing ROI analysis within the organization's business context. Sarac, Absi, & Dauzère-Pérès (2008) carried out an ROI analysis in addition to the analyzing impacts of RFID on the supply chain. According to the study, a ROI of RFID application strongly depends on the business settings; chosen the technology, the tagging level and the product. Lee et al. (2004) criticized the ROI analysis since most part of the ROI analysis consider only the direct benefits of RFID like the increase in the sales or the decrease in the losses however the ROI analysis ignores the indirect benefits like increased customer satisfaction and decrease in customer response time.

In addition to the simulation models and the analytical models carried, a number of researchers carried out case studies in companies. One of these studies is carried out from IBM Business Consulting (Alexander et al., 2002a), (Alexander, Birkhofer, Gramling, Kleinberger, Leng, Moogimane, & Woods, 2002c), (Alexander, Gilliam, Gramling, Grubelic, Kleinberger, Leng, Moogimane, and Sheedy, 2002, b, d). In a series of white papers, researchers examined the impacts and the potential opportunities of applying RFID in retailers, distribution centers and studied the effects on product shrinkage and product obsolescence. Case studies were done by the contribution of Auto-ID Center and many companies like; Unilever, Wal-Mart, Tesco, Procter & Gamble, Gillette, Philips Semiconductors, Intel, Sensormatic Electronics etc. Similar to the previous study Chappell, Durdan, Gilbert, Ginsburg, Smith, & Tobolski (2003) contributed a study including case studies in many companies and examined the retailer supply chain. In the study they tried to answer the question of how RFID can serve to retailers to overcome their supply chain problems. This study covers some part of the retailer supply chain, starting from the point where the products leave the vendor and finishing where the products arrive to be stored. As a result of the study Chappel et al. revealed that the direct labor cost savings will range from 5 to 40 percent depending on the level of automation in the supply chain processes and the frequency of the material handling in the supply chain.

The use of RFID technology on the supply chain is an emerging application and the researchers are mainly interested in the application of RFID in mass production and retailer supply chains. These kinds of products are relatively cheap. Most of the studies involving RFID technologies focus of high-volume low-value production, this thesis instead examines the situation for low-volume high-value production.

2.2. Related Concepts

2.2.1. Auto ID & RFID

Auto ID is a bench of technology that is used to identify objects. RFID is one of these technologies. Auto-ID covers the technologies of barcodes, voice recognition, touch memory, smart cards, radio frequency identification etc.

The history of RFID dates back to the II. World War when the British Air Force used the radio frequency technology to separate the friend aircraft from enemies (Asif & Mandviwalla, 2005). However, until the last decade it was a technologically immature and financially expensive solution. This situation is changing with technological advancement and increasing demand for RFID use (Pohoresky, 2003).

In 1999 the Uniform Code Council, EAN International, Procter & Gamble and Gillette signed an agreement to establish the Auto-ID Center at the Massachusetts Institute of Technology. The aim of this center was to develop a low cost RFID technology in order to track all the products through the supply chain. This initiative created a change in the idea of RFID tags. Until the studies of the Auto ID Center, researchers were trying to develop RFID tags which were accepted as mobile database carrying information about the object they are attached. Auto ID Center came up with the idea of RFID tags that carry only a unique identification number. This new idea enables the producers to manufacture RFID tags at cheaper prices since the microchip required in the design of the new tag was very simple and that is why it is relatively cheap according to the older design. However, new design of the microchip wasn’t the only change in RFID model. The center created a whole networking technology letting RFID tags interacting with the internet as well. According to the Auto-ID Center new design, RFID tags would carry a unique identification number that is linked to the internet and could be followed by all the actors in the supply chain. Auto ID Center gained the support of more than 100 large companies and the U.S. Department of Defense and many key RFID vendors. They opened new research labs in Australia, the United Kingdom, Switzerland, Japan and China. The center developed two air interface protocols (Class 1 and Class 0). Later, the center developed a numbering scheme called the Electronic Product Code (EPC), and a network architecture for searching data associated on an RFID tag on the Internet. Auto ID Center completed its research in October 2003 and moved its responsibilities to new establishment called Auto-ID Labs ("A Guide to Understanding RFID," n.d.).

A general RFID system is composed of 4 main parts (McFarlane & Sheffi, 2003);
-An unique identification code.
-A tag which is attached to the object with a chip.
-RFID readers that are capable to read multiple RFID tag signals.
-An IT system that processes and saves the information collected from readers in its database

Unique Identification code: In RFID system unique identification number enables to distinguish one object from the others. In the design of Auto ID Center this unique identification number is named as Electronic Product Code (EPC) which is a 96 bit code of numbers embedded into microchip of RFID tag (McFarlane, 2002). EPC works similar to Internet Protocol (IP) address, given to each object.

Figure 3. EPC (Sarma, Brock, & Ashton, 2001)
Each X in the Figure 3 means 8 bits. This identification number enables people to search product information of each object with EPC.

Tag: A microchip with a radio antenna attached to an object. Tags can store different amount of information based on their technological advancement. Auto-ID Center smart tags can store 96 bits EPC code (Sarma, et al., 2001), however, it is possible to store more information such as product information, date of production, destination etc. on a more complex tag ("How much do RFID," n.d.).

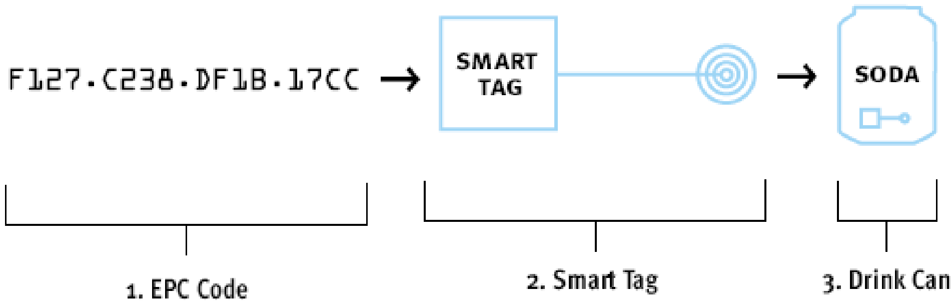

Figure 4. Smart Tag on a Soda Can (McFarlane, 2002)

Reader: In the simplest meaning a reader is a device which consists of one or more antennas to emit radio waves and receive signals coming from tags. Then reader converts the signals received from the tag to digital formats and transfers them to IT system which processes and stores the received data (McFarlane, 2002).

IT System: In RFID system, the IT System receives the data transmitted from readers and stores the data in its database. The IT system enables people to search real time information about products.

In the last decade as a result of the Auto ID Center studies, RFID technology got advanced to enable the companies to track their products via the internet. The new technology uses two main concepts; Object Naming Service (ONS) and Physical Markup Language (PML). ONS shows the computers where to find the product info in the internet using EPC of the object. It could be imagined as similar to Domain Name System (DNS) in the internet. The computer system uses PML as the common language to communicate within the network (McFarlane, 2002).

In an RFID system, tags could be either passive or active according to the source of the power in the communication. If a tag has its own power source like a battery, it creates the signals between the tag and the reader, and these kinds of tags are called active tags (Saygin, Sarangapani, & Grasman, 2007). Active tags are mostly used for high value products that are needed to be tracked for long distances. Since they have their own batteries, they are more expensive and bigger in size (Pohoresky, 2003).

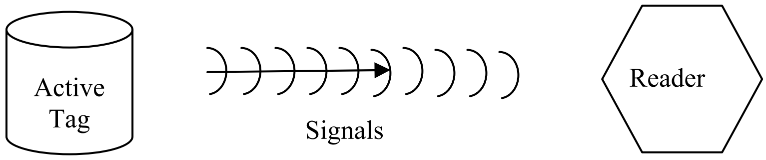

Figure 5. Active Tag

On the other hand, it is possible to create communication between the tag and the reader even if the tag doesn’t have its own power source. In the case of passive tag, the tag draws power from the reader’s signals and sends the signals back to the reader with identification data (Saygin, et al., 2007).

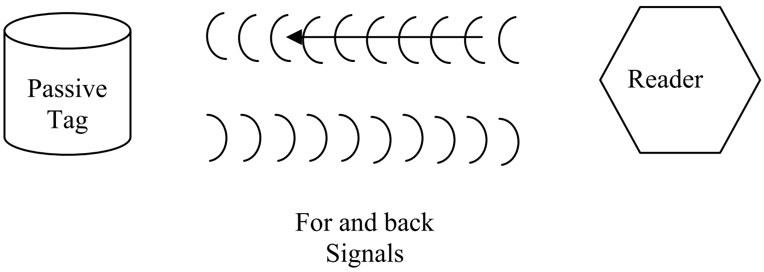

Figure 6. Passive Tag

Passive tags are lighter, cheaper and they provide longer product lives than active tags. That is why passive tags are preferred more for supply chain implementations (Pohoresky, 2003).

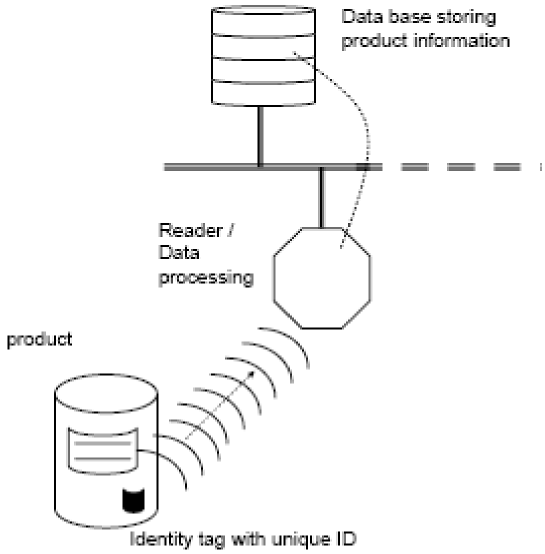

Figure 7. Simple Schematic of an RFID (McFarlane & Sheffi, 2003)

In a basic passive tagged RFID System, the system operates in the following steps (Pohoresky, 2003);

- The tag enters to the range of the readers emitting radio waves
- The passive tag draws power from RF signals
- The tag sends the data to the reader
- The reader receives the data
- The reader transforms the radio waves to digital format and sends to the computer system
- The Computer system processes the data, saves in the database

In an internet connected RFID system, it is possible to track products through the entire supply chain. For example, company A is sending a case of soft drinks to company B. If the cases are tagged by RFID, the tags on the cases are scanned while the products leave the warehouse and the information of the shipment is automatically sent to company B. When the shipment arrives at company B, case is scanned automatically and the information of the delivery of the shipment is sent to company A ("A Guide to Understanding RFID," n.d.).

2.2.2. RFID System vs. Bar Code System

RFID Systems and bar code systems are similar in nature since both of them emerge from the same reason of increasing visibility in the supply chain and both of them are constructed on labels and scanners and provide product information through the supply chain. Bar code scanning is a highly accepted and widely used system in supply chain systems. Till the development occurred in RFID technology in the last decade, bar-coding satisfied the needs of manufacturers, distributors and retailers. However, due to the raising technology and demand for increased visibility, RFID starts to shake the place of the bar code system.

Bar code system checks the products at special transaction points such as shipping, receiving and check-out. In addition, products are scanned by workers one by one, requiring a special line of sight. While RFID requires higher initial investment compared to the bar code system, it provides some advantages superior to bar-coding. These advantages can be listed as follows (McFarlane & Sheffi, 2003), (Gaukler & Seifert, 2007);

- RFID system doesn't require any human involvement, it scans automatically;
- It provides continuous, real time data
- In the long run it is cheaper since it doesn't require any labor to scan
- It is possible to read multiple products
- It is possible to read and write data
- It doesn't require line of sight;
- It is faster to scan many products;
- There is no need to open any package to scan products inside it
- It provides rough location information when the products are moving
- Unlike the barcoding, it is not effected easily from weather conditions

Nevertheless, McFarlane and Sheffi (2003) emphasize that the barcoding system is relatively cheap and theatrically highly accurate. That is why one should think about the advantages and disadvantages of Auto ID before replacing the barcoding system.

2.2.3. Supply Chain Management

"*The term supply chain refers to the series of players and activities that take part in the movement and transformation of raw material "in the earth" into finished goods at the consumers' hands*" (McFarlane & Sheffi, 2003, p. 4). The term chain is used to simplify the complex network of suppliers, manufacturers, distributors, wholesalers, logistic providers and sellers (McFarlane & Sheffi, 2003).

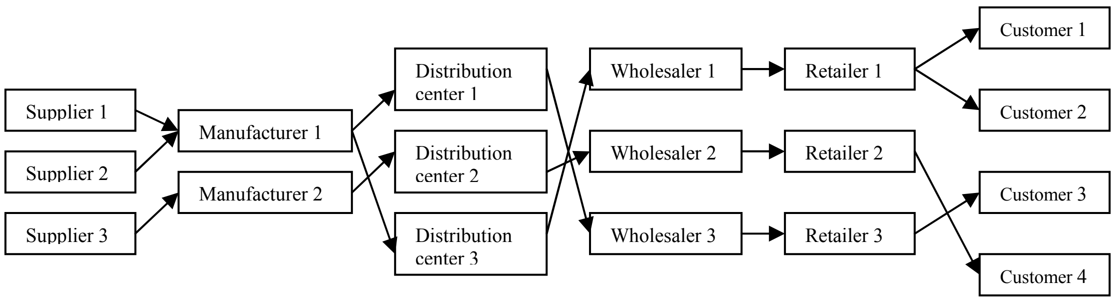

Figure 8. A Simple Supply Chain Mentioned by Joshi in 2000

Supply chain carries two main flows; flow of material and information. The chain processes start with supplier's service to provide raw material to manufacturers who carry the production activities and bring about the finished goods. Then manufacturers transport the finished products to the distributors. These distributor centers send them to wholesalers who deliver the finished products to retailers. The travel of products is finalized in the hands of the customers. In a supply chain mainly five processes occur; buy, make, move, store and sell (Joshi, 2000).

In order to gain a better control on the flow of the chain and optimize the processes, resources and capacity, companies try to develop new technologies and methods to manage the supply chain. First technological progress occurred by the development of materials requirement planning (MRP) in 1970s. MRP was developed as a software application which was to satisfy the demand of the companies to know "which material, in what quantities and when" is required by the company. MRP provided a control on the inventories, work orders, purchase orders and sales orders. This technology is followed by the raise of the MRP II which was built upon MRP adding the accounting and financial controls of the company. By the end of 1980s the companies needed better visibility and control over the company and Enterprise Resource Planning (ERP) application was developed to satisfy that need. ERP provided advance control over almost all the departments of the company. In addition to the production planning, inventory management, purchase, sales ordering properties, ERP enabled the companies to control the marketing, warehouse management, human resources management etc. Nevertheless, with the increasing competition and technological developments, companies needed more control and their needs went beyond the company and they demanded to control all the supply chain. Hence, Advanced Planning and Scheduling (APS) was developed. This software aims to optimize the whole supply chain with constraints of resource availability, capacity costs, labor and material cost and transportation resources. APS tools increase the rate of return by increasing the visibility and information flow through the supply chain. As a result, it gets easier and more accurate forecasts, production plans and schedules since companies feel more confident about the order date commitments and demand fluctuation with real time data (Joshi, 2000).

The success of all the software applications depends upon the availability of accurate information, in timely manner. Today the lag taking place between the events and the registration of it to the system is an important problem blocking the visibility of the system. In addition, wrong data entry is another important problem since it causes poor record accuracy and indirectly it results in inappropriate manufacturing plans and schedules (Joshi, 2000). This is where Auto-ID and RFID contribute crucial value to the supply chain management processes by providing timely and accurate data that tell where shipments are, what the current inventory level is, and where it is located (McFarlane & Sheffi, 2003).

2.2.4. RFID Application within the Supply Chain

The characteristics of supply chains differ in each business area. Moreover, one company could have supply chain more than one, based on the product variety of the company. Nevertheless, there is something in common for all the supply chains; all of them have a shipper (S)/receiver (R) pair, a seller and a buyer pair (McFarlane & Sheffi, 2003).

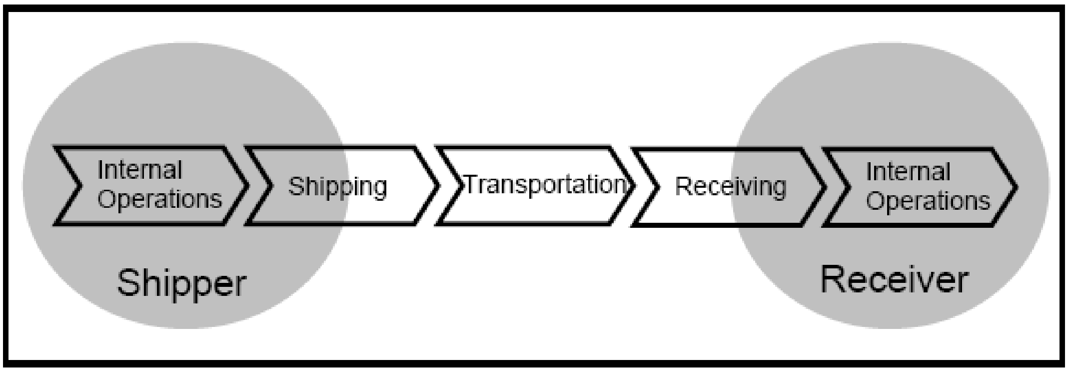

Figure 9. Physical Flow Processes of an S/R Pair (McFarlane & Sheffi, 2003).

The S/R pair could be either a supplier and a manufacturer or a distributor and a retailer.

Shipping:

In a shipment of products, loaders place cases and pallets to the trailers. In that process products that are being shipped should be checked in order to be prevented from shipping mistakes. That is why every case and pallet should be checked and verified which sometimes causes more labor cost than transferring products to trailers (K. Alexander, et al., 2002a).

In that process the use of RFID provides the physical control of every case or pallet. Moreover, RFID could provide item level information instead of bulk of products in the cases. In addition, the shipping process will be completed faster and more efficiently since RFID enables one to scan the products while loading eliminating the physical scan which requires line of sight. This system enables one to create shipping documents that are increasingly error-free (Angeles, 2005).

Transportation:

In the transportation process courier firms generally do not know what they are carrying. They usually realize the content of the load when a problem occurs like damaged goods. Auto-ID technology which use a satellite connection or GPS allows the companies to know what they are carrying in real time, where the shipment is, etc. Increase the efficiency of tracking shipment for couriers like UPS, DHL, Federal Express or this simply the work of LTL carriers to track (McFarlane & Sheffi, 2003).

Receiving:

When a shipment arrives to customer and trailer unload the shipment onto yard, all shipment should be verified for the accuracy of shipment and the purchase orders matching. In addition, after acceptance of the shipment every pallet is labeled to be able to track them in the warehouse. In the case of mismatch they are checked some more times to confirm the discrepancy. Moreover in the case of incorrect receipt of products creates bigger problems in the warehouse, this cause both poor inventory accuracy and monetary loss since product is paid but could not be received (K. Alexander, et al., 2002a).

Application of RFID technology creates a process freedom and increase the speed of the receiving process and increase checking accuracy by eliminating human involvement. Readers positioned in the unloading area, enable automatic check of the products tagged with RFID which eliminates the physical check of the cases (Angeles, 2005).

Internal Operations:

In a manufacturing plant according to the final good, production process could be very different from each other; however, the common thing is the movements of the materials composing the finished good through the production line. In every process, they are exposed to some kind of identity checking.

For example, in a consumer electronics plant in UK materials composing the finished good are being carried in boxes which are put in trolleys with racks. When the trolley is positioned next to production line, workers first read the barcode of trolley then rack and finally items' barcode and there are 50 racks in each trolley. This process occurs for each product whenever the trailer is loaded and whenever it is positioned next to the production line, it means a lot of reading in the production. This process could be simplified via the implementation of RFID in the production area (McFarlane & Sheffi, 2003).

The purpose of a warehouse is to put away the goods and pick up whenever it is needed. In warehouse processes RFID enables automatic and real-time visibility of the inventory. Not only it is possible to know where the specific good is, but also it is possible to flow the changing amounts in time (McFarlane & Sheffi, 2003).

2.2.5. Supply Chain Problems and Advantages of RFID

Material flow is the dominant concept in the supply chain management; however the information flow and the communication capabilities through the supply chain are other vitally important issues in the supply chain.

In supply chains the bullwhip effect and the out of the date information are two important problems that may have important effects on the performance of the supply chain. Bullwhip effect is the phenomena which is called the situation of increasing inventory levels when the supply chain is checked backwards. Bullwhip effect occurs when demand fluctuations are transferred backwards with increasing numbers in the supply chain. Thus, suppliers store larger amounts of inventory than needed. In addition, generally information flow in the supply chain is not efficient, which causes delays. Therefore, the information transferred is out of date, useless, even misdirecting for decision making (McGeoch, 2005).

Application of RFID in supply chain creates some kind of solution for these problems by creating automated detection of inventory with real-time data all over the supply chain.

Main benefits of implementation of RFID could be summarized as;

Labor Expense:

RFID enables operator-free data entrance and monitoring via the automated scanning of the materials and inventory. Based on the automation of the process, labor expenses decrease and supply chain efficiency increases (K. Alexander, et al., 2002a).

Accuracy:

Automated, real time inventory scan increases the accuracy of the logical inventory. Eliminating human involvement in data entrance increases the quality of the data since the data are not exposed to human faults and delay. Accessing the real-time inventory levels through the supply chain reduces the product shrinkage, lost sales and stockout based on the increased accuracy in inventory and demand levels (Lee, et al., 2004).

Visibility:

An RFID implementation throughout the entire supply chain increases the visibility for all players in the supply chain. Higher visibility in the supply chain reduces the effect of bullwhip phenomena. Sharing inventory information between players increases the fill rate of the supply chain and reduces the inventory levels (Lee, et al., 2004).

Throughput:

RFID increases the productivity and the efficiency (McFarlane & Sheffi, 2003). Products get ready faster and companies meet the customer demands faster with on-time delivery (K. Alexander, et al., 2002a).

2.2.6. RFID Use in Manufacturing Environment

Wide use of RFID in manufacturing processes provides additional capabilities and benefits for process control and management. Günther et al (2008) highlight the main benefits of RFID use in manufacturing based on their case studies in different companies. RFID provides the manufacturers with more reliable scanning, better tracking, better tracing, better data management, and reduced back-end communication (Günther, Kletti, & Kubach, 2008). For enhanced RFID application in a plant, reader gates are to be required in the main points of the product transportation paths. In addition, it is possible to install mobile readers and position tags on the plant floor.

Scanning: RFID is a good solution for the products that are hard for barcodes to be attached. RFID provides a convenient solution for those products. In addition, RFID decreases the scanning problems due to the product orientation the shop floor since RFID does not need any line of sight (McFarlane & Sheffi, 2003), (Gaukler & Seifert, 2007). Moreover, bulk reading provided by RFID increases the scanning speed and unlikely to barcodes RFID tags are not effected easily by the unfavorable conditions of manufacturing like dirt, heat, presents of metal etc (Gaukler & Seifert, 2007).

Tracking: Better tracking of production and products improves the shipment and inventory management in a company (Lee, et al., 2004). The system can follow the real time-accurate production statues and ensures the consistency among the processes and the production schedule. In a manually controlled production system, when a process is completed, the next production process might be forgotten to be booked. However, in an RFID deployed manufacturing environment, all the system runs automatically and the next production process is booked via the computing system when the previous process is completed (Günther et al, 2008). Hence, RFID provides a better control over the production and a decrease in the production errors related to the better data collection and the increased visibility of production processes (Günther et al., 2008).

Tracing: RFID implementation creates an important benefit in the case of product tracing. In a plant, production failure and detection of defective products are important occasions since they may even lead to product recalls from the customer. Without the automatic product tracing, in the case of a production failure, it might even require manual checking of shipped products in the customer’s plant. This causes additional labor cost, bad image and additional penalties. Yet, it is possible to follow which product is manufactured out of which components with RFID tagging. Hence, RFID implementation provides advanced traceability which decreases the additional costs of poor tracing of defective products. (Günther et al, 2008)

Data Management: Product and process data are generally recorded via paper documents and because these documents are not attached to the products, it is hard to match the correct couple of the document and the product. (Günther et al, 2008) RFID creates automated data recording which results in an increased data accuracy (Angeles, 2005).

Back-end communication: RFID tags with high data saving capability decrease the communication between the tags and the back-end IT infrastructure, which increases the reliability of RFID system. Low back-end communication is a favorable property for companies which have poor IT infrastructure and they prefer to invest for more independent RFID systems in case of an IT system collapse. (Günther et al, 2008)

In the application of an RFID in a manufacturing environment, filtering and transferring of the valuable data coming from the readers is an important process to feed the decision making system in the plant. The data coming from the readers pass through the following levels;

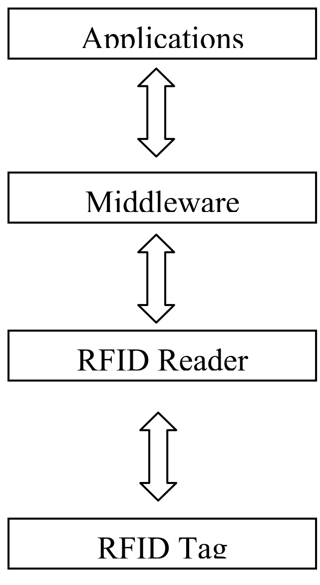

Figure 10. Information Flow in RFID Implemented Plant

Data coming from the tags are collected by the readers and they are transferred to the middleware software. The data flow till the applications is organized by the EPC (Electronic Product Code) Standards. However, the integration of the middleware and IT applications is a vitally important point for the performance of RFID implementation. The ERP and Manufacturing Executive System (MES) are the main IT applications used by companies to manage the company resources and information. ERP is a comprehensive IT application that provides a control over the company covering the financial management, operational management, human resources etc. MES is a relatively narrow IT application that mainly controls the production and the related functions in the company. In a plant, it is possible to use the ERP or MES either alone or together.

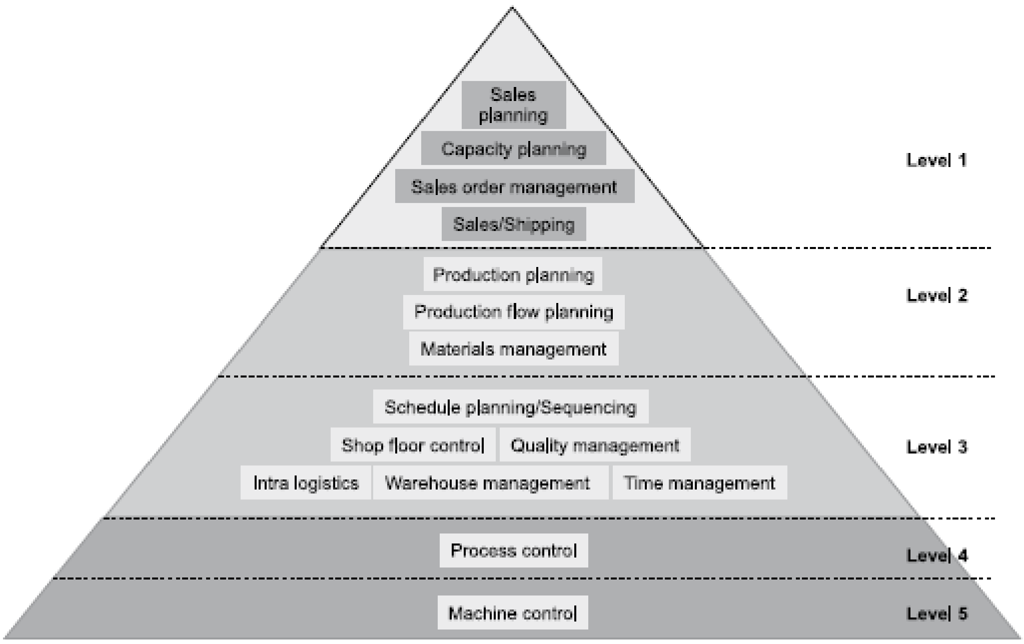

Figure 11. Functional Levels and Processes in a Company (Günther et al, 2008)

The tasks of level1 to 3, shown in the Figure 11, business planning, production planning and materials requirement are mainly the tasks of ERP application, whereas the control functions of the manufacturing processes and machines embedded to levels 4 and 5 are typical tasks of an MES application. Owing to the close relationship of MES with operational side of the company, RFID system and the

MES work in close contact. In addition, if the integration of RFID to MES is achieved successfully, then RFID system feeds the MES with useful real time information. Consequently, the real time data from the shop floor increase the capabilities of the MES in various areas including intra-enterprise logistic, shop floor control, quality management etc. (Günther et al, 2008)

CHAPTER 3

FINDINGS

In the previous chapter, background information about the related topics have been given and in the following chapters, an investigation about the applicability of RFID technologies for a high technology company which makes low-volume high-value production is carried out. In this chapter, the production process of the company is explored and the possible problems which can be solved with RFID technologies examined.

3.1. COMPANY BACKGROUND

3.1.1. General Information

The product variety of this high technology company is very high and the production volume of the company is low. The company runs its business under contracts. Therefore it has strict deadlines for deliveries.

3.1.2. Subcontractors

To help meet these deadlines, the company works with many subcontractors. Most of the subcontractors are located in the same city as the company, and very few of them outside the country.

3.1.3. Production in the Company

Most of the products of the company have a similar structure. They all contain chassis, printed boards, wires, connectors and some other specialized equipment. While few of the chassis are produced within the company, the remaining are produced by a subcontractor and shipped back to the company. The production of the printed boards is similar to the production of the chassis, because some of them are produced by the subcontractors and some of them are produced by the company. However, compared with the chassis, the amount of the printed board production made in the company is higher than the amount of chassis produced in the company. The actual ratio of the printed boards which are internally produced to all produced printed boards is about twenty five percent for the company. Most of the materials required for manufacturing are purchased from outside suppliers, except for very specialized pieces.

Finally, all these components are assembled together into final products in the company factory. In the assembly process joining and testing jobs are performed and this is done within the company with its own resources.

In this study, the processes of the printed board production and the assembly of the products are selected for examination. The reason is that, other materials like the special equipments, chassis, connectors and wires are produced in the suppliers and directly purchased by the company. On the other hand, some of the printed boards are produced in the company and the remaining are carried out by the subcontractors, which requires coordination by the company. The value of the printed boards in a product constitutes the largest fraction of the total cost of a product, so the printed board production is the most important process for the company. Also, since the final product assembly is a critical step in assuring the product quality, the assembly process is performed within the company.

Therefore, the printed board production and the assembly processes of the company are selected as a potential candidate for the application of RFID technologies. The production of the printed boards is composed of eight stages and the details of these stages are explained below in

The details of the assembly processes are explained in the section 4.2.6.

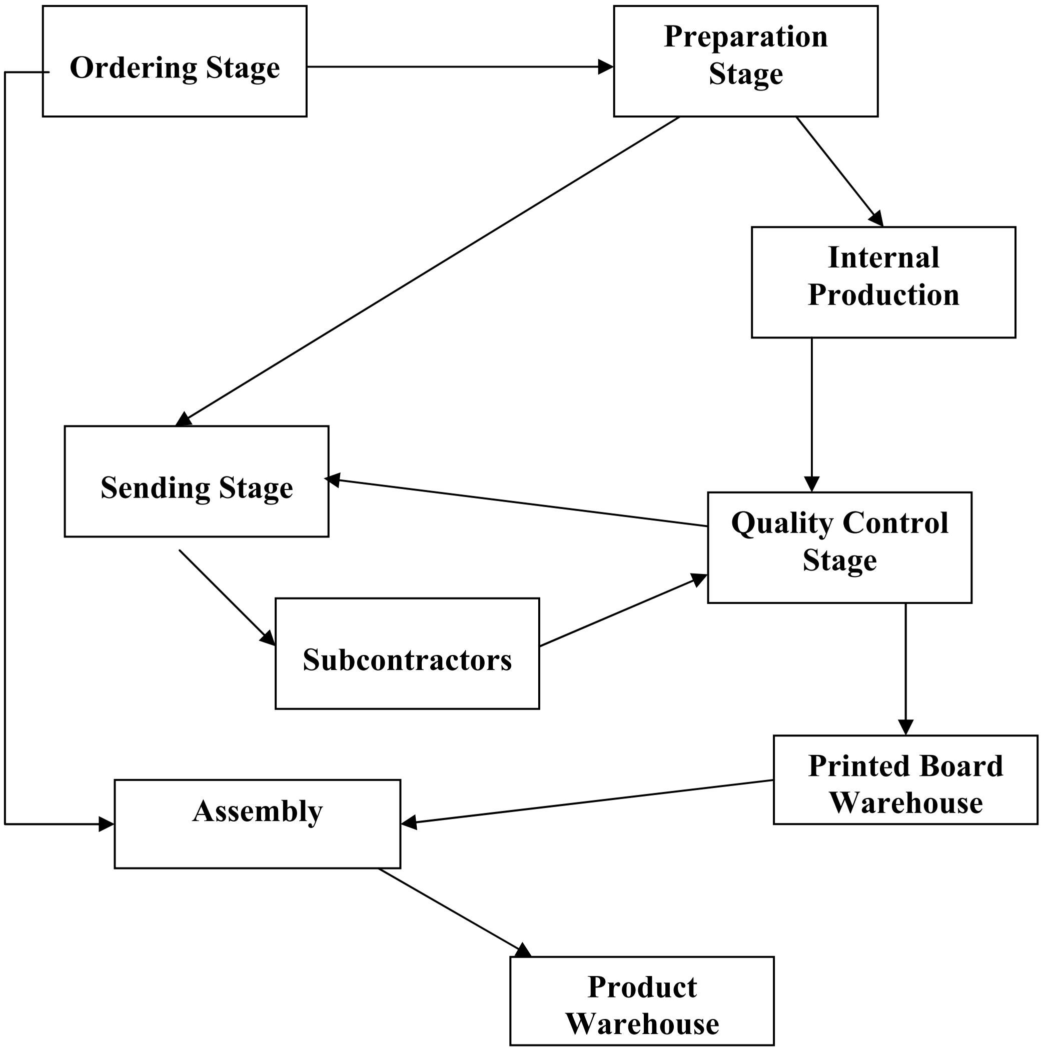

Figure 12. Production Stages of the Company

Ordering Stage

In the ordering stage, work orders are formed according to the master production plan and the need of the new projects via the ERP system. According to these work orders, an order for the preparation of the materials of the printed boards which is called printed board work order (PBWO) is sent to the material warehouse.

Preparation Stage

When a printed board work order for the preparation of the printed boards' materials is sent to the material warehouse, the worker checks the availability of all the materials. If all the materials are available, the worker packs the materials and puts this package into a stock area. In the ERP system the order for the preparation of the materials is checked as prepared. If all the materials are not available, the worker does nothing. The worker occasionally checks the availability of the materials. The production planner of this printed board may also check the availability of the materials and may warn the worker about the availability of the materials.

Sending Stage

After the preparation of a printed board's materials, it is sent to the subcontractor if the production of this board is to be performed by a subcontractor. Some printed boards are produced by the company. The worker in the sending unit checks the packages going to the subcontractors and takes them from the stock areas, then loads them to the vehicle and finally brings to the subcontractors. The size of the loads which are sent differentiates between 5 and 250. The sending lot size depends on the size of the initial work order.

Subcontractor Stage

The products packaged in the company are delivered to the subcontractors located in the same city within 1-1.5 hours. However for the case of the subcontractors outside the city, it takes around 1 day. The highest delivery time for the subcontractors outside the country takes around 1 week. The packages received by the subcontractors are put into production queue. The production system in the subcontractors is managed according to first in first out (FIFO) rule as long as another way is not stated by the company. The printed boards produced by the subcontractors are stored in the subcontractor's warehouse after the production. Once the amount of the printed boards in the stock area reaches a quantity between 5 and 50, the company is notified about this situation, and with the company's approval, they are shipped to the company.

Temporary Acceptance Stage

The produced printed boards received from the subcontractors come to the temporary acceptance stock area. Then, the information of the printed boards' entrance is entered into the ERP system by the workers. The time between the arrival of the printed boards to the stock area and entering the required information into the system varies from 10 minutes to a couple of days. As the activity of entering into the system finishes, the printed boards are taken to the queue in the quality stock area for the quality inspection. In the company, the temporary acceptance stage is counted as a part of quality stage because the printed boards go to the quality stage from the temporary acceptance stage without making any ERP system transaction.

Quality Stage

The printed boards waiting in the quality stock area are taken and enter the quality control unit according to FIFO rule. However, sometimes this sequence can be modified by the production planner and some printed boards may be taken to the front of the queue. In quality section, after the inspection activities, the printed boards are taken to the stock area.

Warehouse

The printed boards waiting in the stock area after the quality stage are then taken to the warehouse. The time spent between the stock area after the quality and the warehouse directly depends on the workers. Sometimes the materials may be forgotten in the stock area after the quality control process and it may take longer time to send them to the warehouse. The printed boards wait in the warehouse until the assembly process.

3.1.4. Current Situation of the Production

The production in the factory can be examined in two categories. First one is the production of the printed board and the second one is the assembly of the printed boards and the other parts of the products. However, since the volume of the mechanical production in the company factory is very low, it is not examined in this study.

Production of the printed boards

A printed board can be produced in the company or by a subcontractor. Wherever it is produced, the production stages are almost the same and they can be summarized as follows:

- *Cream soldering phase:* (Made in a machine) In this phase, the solder which is in the cream phase is rubbed to the board
- *Arrangement of the sub-materials:* (Made in a machine) in this phase, the discrete is arranged to the board.
- *Re-Flow Owen operation*: (Made in a machine) the solder which is in the cream phase is solidified.
- *Optic Inspection:* (Made in a machine) in this phase, the produced printed boards are inspected. If there is an error, the rework process is performed.
- *Putting the other hole inside the materials:* In this phase the mechanical and the chemical processes are applied to the printed board, then the printed board goes to the quality control.
- *In-circuit Test:* In this phase, every discrete is tested and if there is an error the rework operations are performed.
- *Functional Test:* (Made in a machine) in this phase, whether some functions of the printed boards work or not is checked. If there is an error, the rework operations are performed.
- *Quality control → Packaging → Warehouse*

The important point in the printed board production is that the printed board production is a serial production. The longest production step in this process is the in-circuit test. Because of these reasons, the length of this operation can be taken as the length of the unit production time of the printed boards.

3.2. Data from Production of the company

In this part, some data about the production of company are collected and examined to see the possible problems in the company.

In the study, five products of the company are examined and in the rest of the study, all the analyses and the improvements are made over the simulation models constructed for these products, the data below are the data of these five products. Why five products are selected for the examination is explained in the section 4.2. In this part, the production times of the products are examined and it is tried to grab the possible problems in this area. The printed board production of the company is divided into pieces according to the processes which are performed and after that the total and unit production time of these pieces are investigated.

The production times of the processes are collected with the help of the ERP system. In the ERP system of the company, times of the material movements are kept. This kind of information can be illustrative to understand the current situation of the production of the company. To grab this data, printed boards of the selected products are examined. The analysis below illustrates the maximum, minimum and the average value of the time between;

- Flowtime (Lifetime)
- Ordering and leaving of the sub materials from the company (Orderingtime)
- Entering to the quality control section and leaving the quality control section (Qualitytime)
- Entering to the subcontractor and leaving the subcontractor (Subcontractortime)
- Leaving the quality control section and entering the warehouse
- Ordering and completion of the printed board production (Order-to-warehouse)
- Entering the assembly processes and entering the product warehouse (Assemblytime)

3.2.1. Flowtime (Lifetime)

Table 1. Statistics of Lifetime in the Company

	Lifetime (days)
Max	293
Min	74
Average	195,4
StDev	54,3

According to the Table 1, the maximum lifetime is 293 days, the minimum lifetime is 74 days, and average interval is 183,9 days. Below part of the production which constitutes the lifetime are examined.

3.2.2. Time between Ordering and Leaving of the Sub materials from the Company (Orderingtime)

Table 2. Statistics of Orderingtime in the Company

	Orderingtime (days)
Max	45
Min	1
Average	13,6
StDev	11,3

According to the Table 2, the maximum interval between ordering and leaving of the sub-materials is 45 days, the minimum interval is 1 day, and the average interval is 13,6 days.

Furthermore, in theory after ordering, the sub materials can be collected about 2 hours on average. The main reason of the long Orderingtime is the collection in front of the preparation stage because the orders come to the preparation stage as lots and for the behind the lots, the preparation time is longer because they wait for the preparation of the others. However, there is also some extra delay which does not result from the collection of the orders in front of the preparation stage. First of all sometimes some of the sub-materials can be absent and the order can wait for the completion of the sub-materials and this can last 2-3 weeks. Moreover the orders can be forgotten by the workers and because of the lack of follow up, the ordering time gets longer. Furthermore after the preparation of the materials, the prepared packages cannot be taken by the sending worker immediately and this causes extra delays in the ordering time.

3.2.3. Entering to Quality Control Section and Leaving Quality Control Section (Qualitytime)

Table 3. Statistics of Qualitytime in the Company

	Qualitytime (days)
Max	47
Min	0,3
Average	15,5
StDev	9,7

According to the Table 3, the maximum time spent in the quality control section is 47 days, the minimum time is 0 day, and the average time is 15,5 days.

Furthermore in theory the quality control process can be performed in 1.5 hours on average. The reason of the higher qualitytime is the extra delays in this stage. The quality stage is composed of two places, the first one is the temporary acceptance place and the second one is the actual quality control place. The printed boards which are produced in the subcontractors come to the temporary acceptance place and the workers enter their information into the ERP system. Before the entrance of the information, the worker in the quality control section cannot know the existence of the printed boards in the temporary acceptance place. The time interval between the entrance of the printed boards to the factory and the registration sometimes happens to be very long. Moreover, the registered printed boards do not go to the quality control stage immediately, because no warning signal is sent to the quality control worker about the entrance of the printed boards. The quality control workers check the temporary acceptance place occasionally and sometimes the time delay between the consecutive checking operations of the temporary acceptance place can be very high. The extra delays explained above mainly result from the lack of communication and because of them, the total quality control time is a lot higher than the unit quality control time.

3.2.4. Entering to subcontractor and leaving subcontractor (Subcontractortime)

Table 4. Statistics of Subcontractortime in the Company

	Subcontractortime (days)
Max	121
Min	15
Average	52,4
StDev	27,4

According to the Table 4 maximum time spent in subcontractor is 121 days, minimum time is 15 days, and average time is 52,4 days.

Furthermore in theory production process in a subcontractor can be performed in a couple of days on average. The difference between theoretical and actual Subcontractortime caused by two reasons. First, the collection of the materials in front of the subcontractor. The usage rates of the subcontractors are very high and because of this reason the total subcontractortime gets longer. Second is the extra delay in this stage. These extra delays are explained in the section 4.2.3. Because of these two reasons, the actual total subcontractortime is higher than the theoretical total subcontractortime.

3.2.5. Leaving the quality control section and entering the warehouse

Table 5. Statistics of Time between Leaving Quality Control Section and Entering Warehouse in the Company

	Time (days)
Max	6
Min	0,1
Average	2,5
StDev	1,9

According to the Table 5, the maximum time for carrying the materials to the warehouse from the quality control section is 6 days, the minimum time is 0 day, and the average time is 2.5 days.

Furthermore, in theory the time for carrying the materials to the warehouse from the quality control section is 0.5 hour on average. After the quality control operation in the quality control section, the printed boards do not go to the warehouse immediately. There is an extra delay before the printed boards' entering to the warehouse. This extra delay is about two days and causes to increase the time to 2.5 days.

3.2.6. Ordering and Completion of the Printed Board Production (Order-to-Warehouse)

Table 6. Statistics of Order-to-Warehouse Time in the Company

	Order-to-Warehouse (days)
Max	155
Min	57
Average	75,3
StDev	35,7

This ordering time statistic measures the time between the giving order and entering of the produced printed boards to the warehouse. According to the Table 6, the maximum production lifetime for a printed board is 155 days, the minimum time is 57 days, and the average time is 75,3 days.

3.2.7. Entering the assembly processes and entering product warehouse (Assemblytime)

Table 7. Statistics of Assemblytime in the Company

	Assemblytime (days)
Max	163
Min	27
Average	121.3
StDev	42,3

According to the Table 7 the maximum Assemblytime for a printed board is 163 days, the minimum time is 27 days, and the average time is 121,3 days.

The high variation in this process is caused from the fact that all the printed boards of the products do not happen to be available in the warehouse..

3.3. Problems Seen in the Production

3.3.1. Long Production Flowtime (Lifetime)

For a company which has complex production processes such as having subcontractors, high range of production, high number of production processes, it is expected to have long production time. In the company inspected in this thesis, the production flowtime (lifetime) is also long. This result can be deducted easily when comparing the unit production time with the overall production time. The unit production time is the time required for the production of a semi-product in an isolated environment. For instance a machine processes a material in 2 hours; this is the unit production time. On the other hand, a batch of material is processed by this machine and all of the materials come at the same time, the overall production time of the first processed material equals to the unit production time, however the overall production time of the last material is much longer than the unit production time. The reason is that, the last material waits for the production of the other materials. Below, the Table 8 shows the unit production time and overall production time of some production stages.

Table 8. The Unit Production Time and Overall Production Time of Some Production Processes

Stage	Unit production time (approximately)	Total production time
Ordering stage	2 hours	12,8 days
Quality stage	1.5 hours	14,9 days
Internal Printed board production	2 hours	15,3 days

Generally, to reduce the overall production time, the batch size which comes to the production area is reduced by increasing the resources and making parallel processing. In the company, the long overall production time is the subcontractor overall production time and assembly time. The subcontractor overall production time can be lower by increasing the number of the subcontractors. On the other hand, by the help of the interviews made with the production planning engineer and the production engineer, it is understood that the long assembly times result from the absence of the materials. In the company, the products generally consist of some number of printed boards and some other parts like sensors, chassis and connectors and most of the time, some of them are absent in the assembly stage. Moreover, sometimes the machines in the production area can be out of order, so the assembly processes cannot be performed. Generally test machines are broken in the company. Because of these reasons, the overall assembly time is much longer than the unit assembly time.

3.3.2. Absence of the communication

One of the most problematic parts in the company is the communication. Communication is performed via telephones, e-mail, ERP system, and face-to-face meetings. A material is recorded in ERP system and can be tracked some how when it is in the company. Below where the ERP system checks are made in the company is listed.

- Product ordering
- Sending of packages
- Beginning of the printed board production
- End of the printed board production
- Entering of the Packages to temporary acceptance area
- End of the quality control
- Entering of the checked printed boards to warehouse
- Leaving of the printed boards from the warehouse
- Entering the printed boards to the assembly stage
- Finishing of the assembly processes
- Entrance of the finished products to the warehouse

When a material comes to an ERP system checking point, the information of the material is entered by a worker manually. Sometimes the worker can be busy and he may not enter the information of the material to ERP system, so the material waits idle in this checking point. Furthermore, sometimes the materials can be lost and its information cannot be entered into the ERP system.

Every product has a production planning engineer in the company and a production planning engineer deals with a few products. If a material is late or its information is not entered into the ERP system, the production planning engineer calls the related people to speed up the process. However, these people are so busy, this calling job can be delayed or forgotten. When the materials go to the subcontractors, the state of the materials cannot be known until this materials come to the company. Sometimes, the production planning engineer calls the subcontractor but generally this does not happen because of the work load of these engineers.

Face-to-face meetings are one of the communication tools used in the company. However, these meeting are made when the big and urgent problems come out.

As a conclusion, since the entering of the information of the materials to ERP system and tracking of the late materials depend on the people and tracking the materials and intervention to the materials in the subcontractor are very hard and limited, the communication in the company for the tracking of the materials are so problematic. The problems in the communication cause extra delays in the production and longer production times. To lower the production times, these delays are taken out of the production process and this can be made by minimizing the human intervention in the production process.

3.3.3. High Stockouts

One of the problems which the company is faced with is the high stockout rate. Stockout is not delivering the product on time to the customer. The company makes a contract with the customer and the delivery dates are determined in this contract. Because of the high production lifetime, sometimes the products cannot be delivered on time. These stockouts have two main costs; the first one is the punishment cost, the second one is related to the loss of prestige.

The punishment cost is the money which is paid to the customer when a delivery is not made on time and this amount is calculated by multiplying the selling price of the product with a rate for a day. The more the delay in the delivery, the higher amount of money is paid to the customer. The punishment rate is determined with the agreement of both sides and it is written in the contract.

The second cost is the prestige cost. If the company makes all the deliveries on time, the prestige of the company increases. If a company has a high prestige, the public has a good opinion about carrying on the business skill of the company. As a result, the company is invited and gets more bids. On the contrary, if a company has bad delivery time, its prestige is low and the number of the bid it's invited and wins is low and its sales get lower. Because of this reason the delivery dates are the most important issue for the company and the company can lower the margin of profit in exchange for the higher prestige.

3.3.4. Lost materials

Lost materials are another problematic issue for the company. The company has complex production processes and a small production area. Moreover it has small stocking areas and the diversity of the production range is high. Because of these reasons, the production areas are very crowded, and sometimes material lost occurs. According to the reviews made with the production planning engineer and the production engineer, at least twenty losses event occur in a month and most of them are found but a few of them are not found. The lost materials and the time spent for finding these lost materials are one of the costs of this production process. When compared to the other problems, this issue seems not to be a big problem because the impact of this problem to the production is minor since the total cost of the lost materials and labor cost are not so high with respect to the produced products. However, in the long run, this problem should be solved. The reason behind this is the continuous growth of the company. With the new designed products and increasing number of the contracts, the amount of the production made by the company gradually grows however the investments are not made with the same speed. In the Table 9 below, the ratio of the amount of the investment to the sales made by the company are seen.

Table 9. The Amount of the Investment and Sales Made by the Company

	2006	**2007**	**2008**
Investment/sales	0,084	0,064	0,056

It is easily seen that there is a disharmony between the investment and the sales and because of that, the production area of the company gets more complex. Finally this increasing complexity causes more lost materials and long times to find them.

3.3.5. High Work In Process Inventory

Another problematic issue is the work in process (WIP) inventory in the factory. The ratios of the WIP inventory to the sales for the years 2006, 2007 and 2008 are given below in Table 10.

Table 10. The Ratios of the WIP Inventory to the Sales for the Years 2006, 2007 and 2008

	2006	2007	2008
WIP Inventory /Sales	1,03	1,03	1,28

For all years the WIP inventory values are higher than the sales. High WIP inventory causes high cost in the factory because of the opportunity cost. Opportunity cost is one of the main concepts in microeconomic theory referring to cost of choice. It is the value of the other best option forgone by deciding to use a resource for some goal other than that one. It could be explained simply by a production decision. In the case of utilizing a material for producing the product A, the opportunity cost of this act would be the maximum value forgone by not deciding to use it for manufacturing product B or C etc (Dolan, & Lindsey, 2004).

Effect of Lifetime to Work in Process Inventory

For the year 2008 WIP inventory is A of the sale and if the opportunity cost is taken as CBRT primary interest rate, F, the total cost of carrying this amount of the inventory for one year is equal to A*F*sale. The high WIP inventory results from long production times, low communication and poor production panning.

The effect of long production times (causes high lifetime) on the high WIP inventory can be explained by the following fictitious example. In Figure 13, one production area is shown and the sub-materials are inputted to this production area with a constant rate. This coming rate and the unit production rate will be 10 pieces per day.

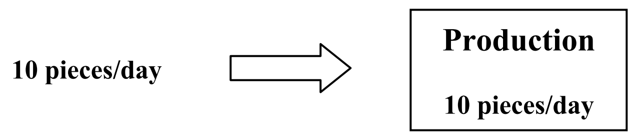

Figure 13. Representation of the Sample Case about Inventory

The amount of the sub-materials in front of the production area can be shown below in the Figure 14.

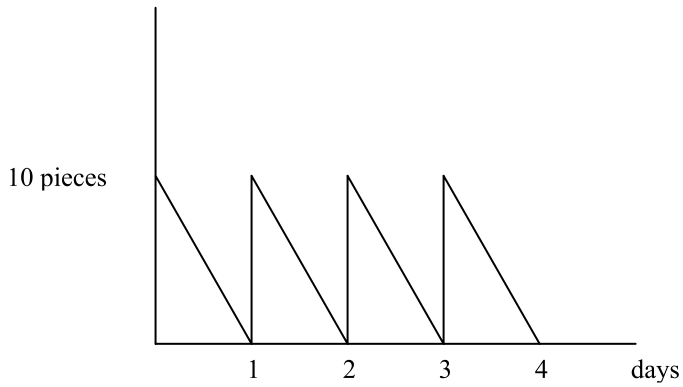

Figure 14. The amount of the Sub-materials in front of the Production Area

In the graph the state of the inventory in the production is shown and the total inventory at the end of the 4 days is calculated by summing the area of four triangular areas. The total inventory of the four days is 20 (10*1*0.5*4) piecesXdays and the average inventory is equal to 5 (20 piecesXdays / 4 days) pieces. If the production rate decreases to the 5 pieces per day (long production time), the state of the inventory can be seen in Figure 15.

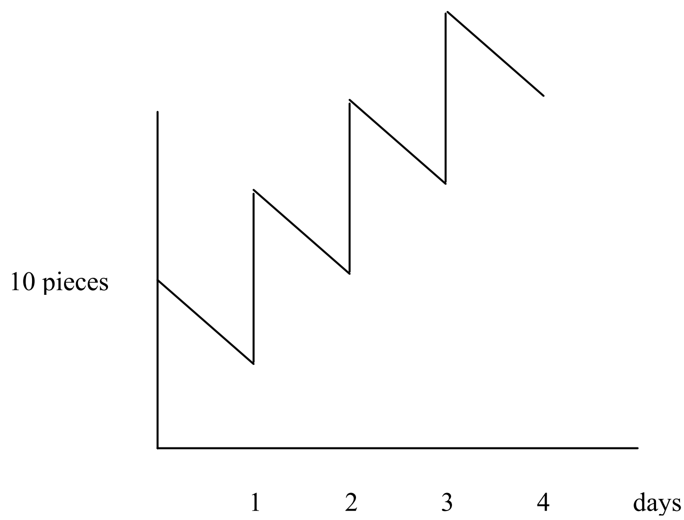

Figure 15. The State of the Inventory

The total inventory at the end of the four days is 60 piecesXdays ((0.5*5*1 + 5*1) + (0.5*5*1 + 10*1) + (0.5*5*1 + 15*1) + (0.5*5*1 + 20*1)) and the average inventory is equal to 15 (60 piecesXdays / 4 days) pieces. In this example it is obviously seen that if the production time gets longer (depending on that, the lifetime gets longer), the amount of WIP inventory will get longer.

What causes the longer lifetimes is basically weak communication. If the production of a company is composed of lots of production processes, besides one of the production processes is subcontractors, the planning of this production stages is very important. The communication is vital in this situation for the planning purpose. If the communication is week and tracking of the materials is not obtained, appropriately the production times get higher.

CHAPTER 4

MODELING OF THE PRINTED BOARD PRODUCTION PROCESS

In the previous part, the analysis of the current situation of the company is performed and it is found that the process times are very long. Moreover, the communication in the company and among subcontractors and the company is weak. Therefore, production flowtime is so long and this can cause high WIP inventory and stockout. In this part some approaches are introduced to decrease the flow time. Before the approaches, the causes of the problems should be investigated deeply and in this part it is performed by constructing the simulation of the current situation of the printed board production. Simulation technique is selected for this examination because this is the cheapest and detailed way of the investigation of this kind of case. Deterministic techniques can be used in this case; however the processes in the production are mostly stochastic. In other words, the lengths of the processes in the production are variable with respect to time. On the other hand, experiments can be made in the real situation and approaches can be tried in the real production area, however it is not acceptable for the management. Moreover trial of the approaches can be costly for the company. Furthermore in the Section 4.1, some other reasons are given about why the simulation technique is used in this study. After the construction of the simulation for the initial situation of the company's production, the results are examined and the approaches to improve the current situation are determined. After that the new simulation models for these approaches are constructed and the results of these simulations are examined. In the analysis part, the results of the approaches are compared.

The simulation technique used to analyze the situation of the company is the discrete event simulation. Below some information about this technique is given.

4.1. Discrete Event Simulation (DES)

In this part general information about the DES technique is given. In this technique, time is divided into small pieces like seconds, minutes or hours according to the length and type of the simulation. The events which represent the processes are ordered as a chronological sequence. In real life, all the processes are performed in sequence or in parallel and some time interval is required for the completion of these processes. These two main points can be easily simulated with DES. Moreover, in DES, the time of the processes can be analyzed statistically. This property is very important because most of the time, in real life actual process times are fluctuated according to some distributions and they can be guessed approximately by the sampling methods. Furthermore, this technique is very flexible to make some changes. The time and order of the processes can be changed easily, also some structural changes can be made in the simulation model. By the help of the easy changes, the optimal solution for the problem can be obtained. In addition, the capability of reflecting the real production processes is very high in discrete event simulation. In some situation, models which are same as the real situations can be constructed and with some changes the solution of the problem can be found easily. On the other hand, finding the solution with making changes in real situation can be so expensive. For instance, in some situations to find the optimal solution, changing layout can be required and making this layout changes in real situation two or more times can be costly however making changes in the simulation model which is constructed with DES technique can be done with no cost.

In the following section the initial case of the company's production and the approaches made for the improving the current situation in the production are simulated with the help of DES technique. All the simulations are constructed with the ARENA 4.0 software and Input Analyzer and Output Analyzer software packages of ARENA are used for analyzing inputs and outputs ("Arena Standard Edition," n.d.).

4.2. Simulation of the Current Situation

In the first simulation, the initial situation of the production in the company is modeled. This is the base line of the further improvements. Moreover, the model constructed in this level is the fundamental to the other simulation models made in this thesis because the main layout in the factory is not changed and it is assumed that changing the layout can very costly. Furthermore, the problems considered at the first place are not reasoned from the layout problems. In further simulation models, little constructional changes is made and most of them are logical and operational changes. The main foundation of the production of the company can be summarized below in Figure 16:

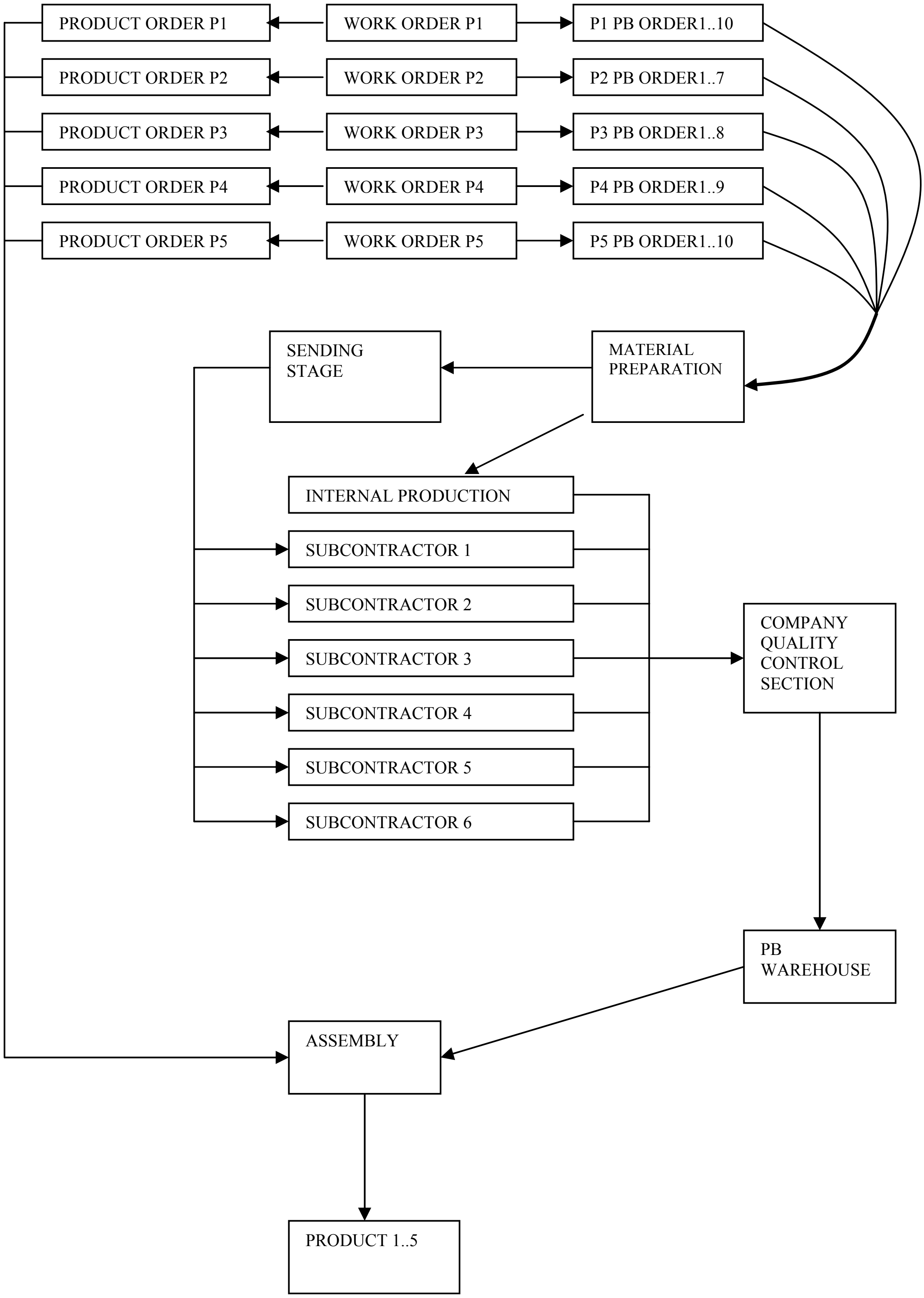

Figure 16. The Main Foundation of the Production of the Company

By introducing this model, it is assumed that the company produces five different products. Although dozens of different products are actually produced in the company, making simulation with this number of products is not easy. However, simulations for five different products will provide a good intuition for the company. Speaking more intuitively, why the simulation becomes impossible is related to the fact that if all the products are simulated, the number of the blocks will be very high so the construction of the model becomes very difficult. Moreover the size of the arrays which keeps the information of the entities and the statics in the simulation are restricted, therefore running this simulation will be impossible. On the other hand, thinking of the simulation constructed in this section as a good reflection of the system will be reasonable because the resource used in the simulation model in this section is arranged according to this number of the product so the effect of the improvements to the simulation model will be parallel to the effect of the improvements to the actual case.

The resources used by the products in the company are adjusted according to these five products. Moreover, most of the production processes run in parallel manner. Furthermore, in this model it is assumed that there are only six subcontractors for the printed boards of these products. In real case, the number of the subcontractor is more than six, however for this amount of the printed boards, the number of the subcontractor is enough. Lastly, statistical information of the five products is used for the simulations. First, second, third, fourth and fifth products are composed of ten, seven, eight, nine, and ten printed boards respectively. In the following parts, how the stages of the production in the company are simulated is explained.

4.2.1. Work Order

The flow diagram of work order process used in simulation of the initial situation is given below in Figure 17.

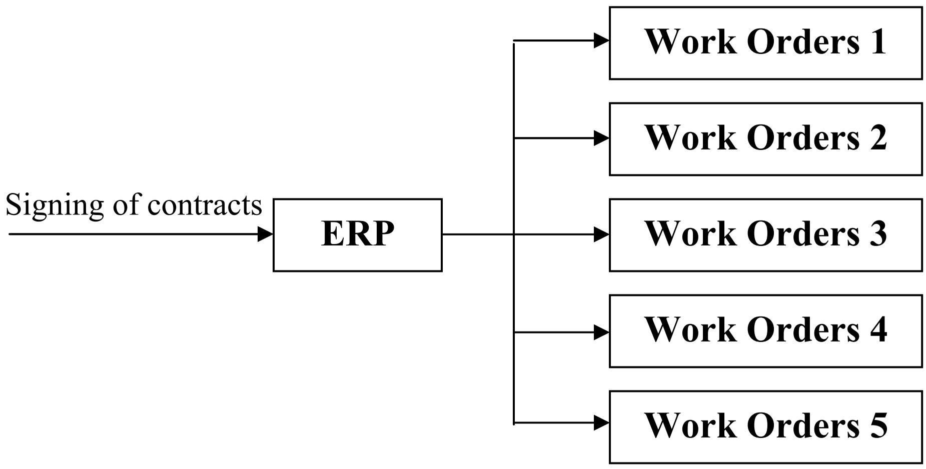

Figure 17. The Flow Diagram of Work Order Process

In the company, production is performed with the help of the Work Order (WO). When a contract is signed, orders are given to the ERP system to be produced according to this contract. In the simulation, it is assumed that the factory produces five different products and work orders are created for the production of these products. The model frame of this process constructed in the simulation is available in appendix A.2. Figure 68, Figure 69, Figure 70, Figure 71, and Figure 72.

In the simulation model created in this section for reflecting the initial situation of production in the company, first of all the work orders are created in a certain amount and with the certain frequency. The work order creation amounts and frequencies are given below in Table 11.

Table 11. WO Creation Amounts and Frequencies

Product	**WO amount**	**WO frequency**
P1	TRIA(30, 97.5, 255)	NORM(150, 17.9)
P2	5.5 + 40 * BETA(0.648, 0.825)	132 + 78 * BETA(0.632, 0.927)
P3	38 + 220* BETA(0.648, 0.825)	126 + 162 * BETA(0.675, 1.43)
P4	9.5 + WEIB(10.7, 2.02)	116 + 79 * BETA(1.36, 0.844)
P5	6 + 0.8*GAMM(118, 0.612)	TRIA(123, 157, 236)

In the table TRIA and NORM are used for abbreviations of triangular and normal distributions respectively. This notation is the notation of the ARENA software and triangular distribution is shown as TRIA(l,m,u). Characters l, m, u are used for lower bound, mode and upper bound respectively. On the other hand, normal distribution is shown as NORM(a,b). Characters a and b are used for mean and standard deviation of the distribution respectively.

In the simulation, creation processes are performed according to the work order frequencies. This means that the time between two consecutive creations is determined according to these distributions. Batch size of every creation is changed according to work order amount distributions. These distributions are determined by the examination of the previous data of the five products used in this simulation. Their work order amounts and work order frequencies are taken and fitted to the appropriate distribution by the help of ARENA Input Analyzer.

After that, work orders, product work orders (PWO) and printed board work orders for each product (PBWO) are created according to this distributions. The flow diagram of this process is given in Figure 18.

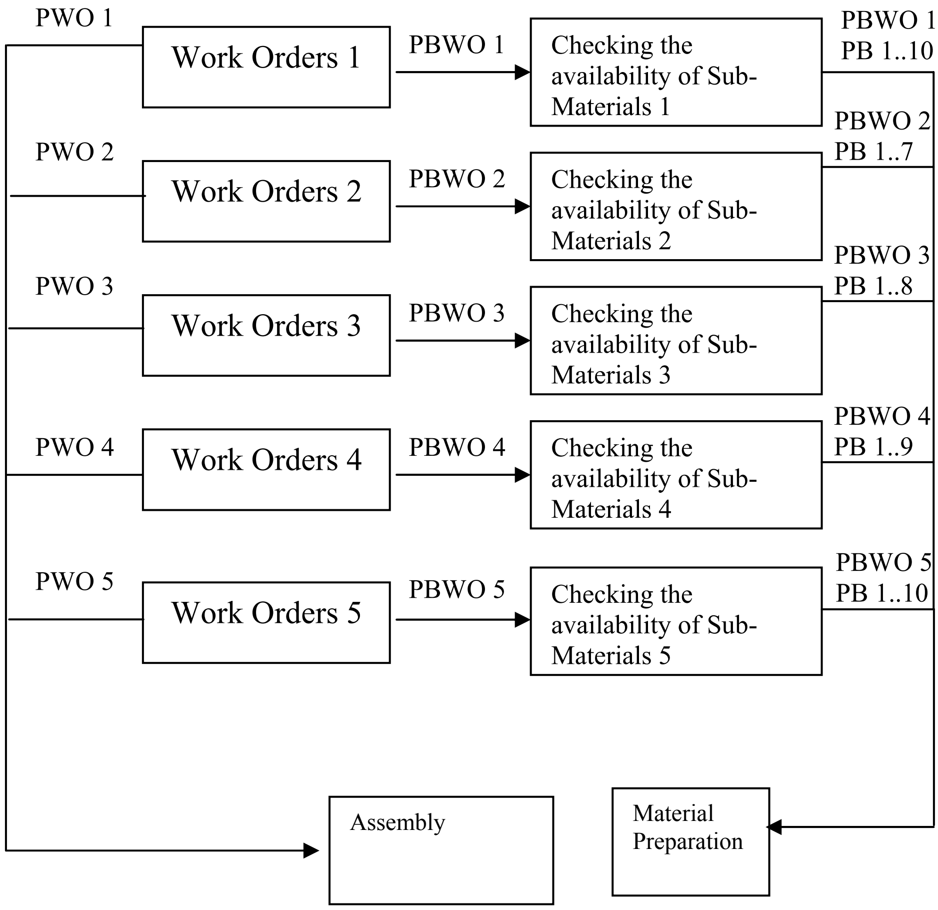

Figure 18. The Flow Diagram of the Creation of Product Work Orders and Printed Board Work Orders

Product work orders go to the assembly section and they are used as orders for the assembly operations. Printed board work orders of each product go to checking the availability of the simulation's sub-materials section and they are used as orders for production of printed boards. In availability of the sub-materials section, the availability of the sub-materials of a printed board is checked. The block diagram of this flow diagram can be seen in Figure 69.

Figure 19 shows the details of checking the availability of sub-materials 1 sub-model. Since the structure in all checking the availability of sub-materials models are the same, here only the structure of the first one is shown.

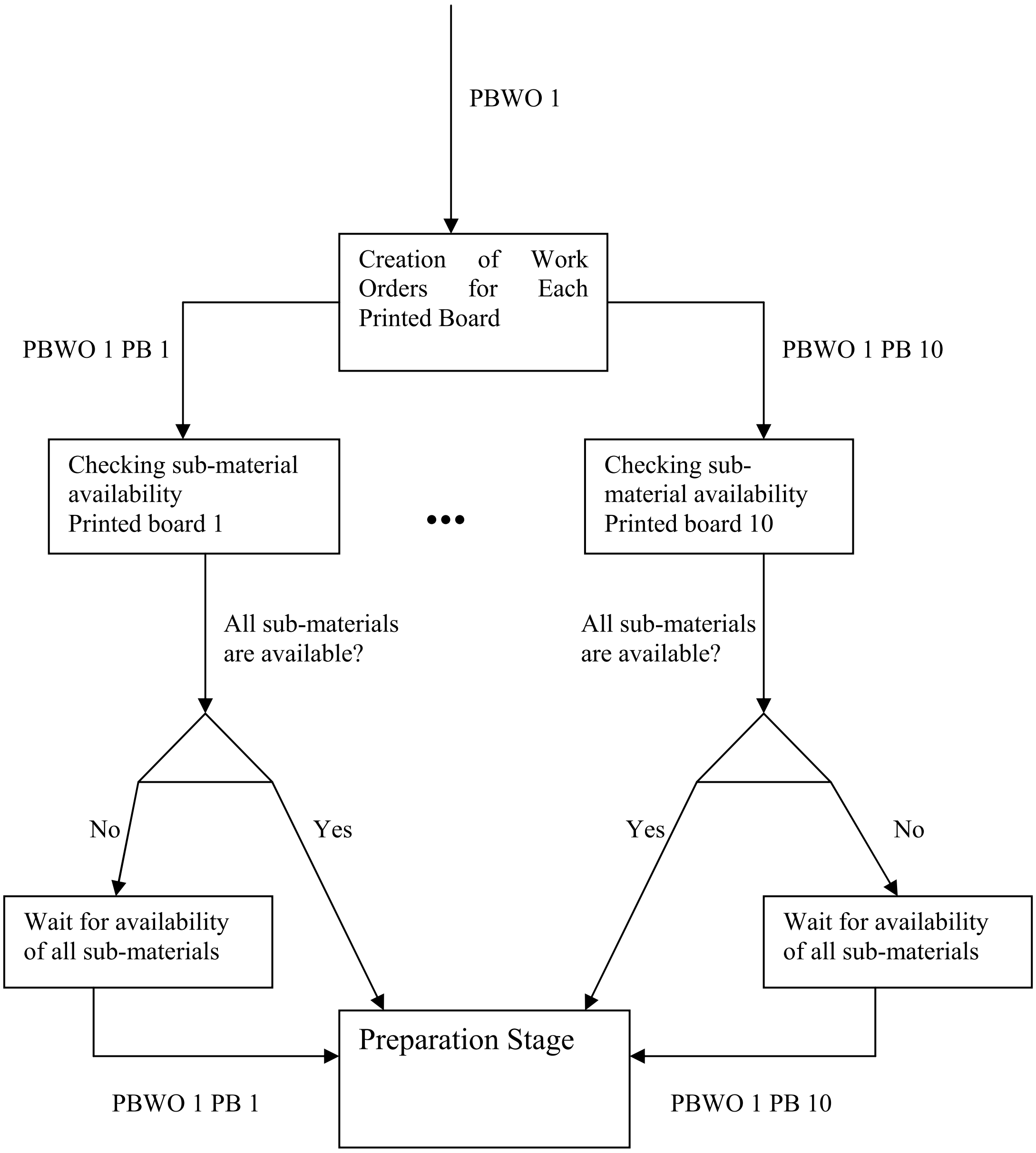

Figure 19. The Detail of the Checking the Availability of Sub-material

The product 1 is composed of ten printed boards. In this sub-model, first of all the printed board work orders for each printed board of the product one are created. Exactly ten printed board work orders for the printed boards are created however in the Figure 19, only the printed board work orders for the printed boards of one and ten are shown and they are called as PBWO 1 PB1 and PBWO 1 PB10 in the figure. After that, the availability of the materials used for the production of the printed boards is checked and this operation is shown in Figure 19 with triangle. Actually the operation is performed by the help of the ERP system. If all the materials of a printed board are available in the factory, printed board work orders are sent to the preparation stage. If some of the materials are absent, in some time intervals the worker checks the availability of the materials. When the materials are completed, the printed board work orders are sent to the preparation stage.

Generally the materials are available in the factory but for small time periods the materials are absent in the factory. For 2 months period, the amount of the materials are absent about 3-5 days in the company and the modeling of this section is performed according to these times.

4.2.2. Internal Printed Board Production

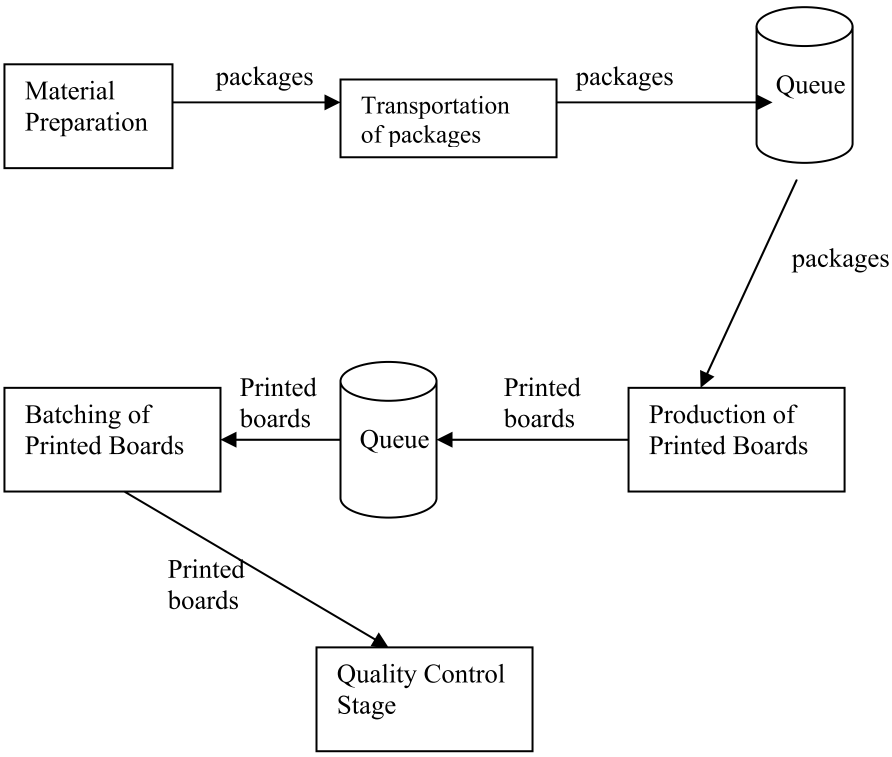

Figure 20. Flow Diagram of Internal Production

The flow diagram of the internal production stage is given in Figure 20. The packaged materials are sent to the internal printed board production section if the printed board is produced internally. There is a time lag for these transportation processes because of the awareness of the materials. This time lag is shown in the flow diagram as transportation of the packages. Most of the time the packed materials are not sent to the internal printed board production section immediately and it waits for at least 0.2 day. This delay is caused by the weak communication among the workers since there are not any automated work assigning on the ERP system that warn the workers to carry the packed materials to the next process and the communication entirely depends on the workers. This delay sometimes increases up to 1.5 days however mostly it is about 0.4 days. Therefore, the distribution used for this time in the simulation model is TRIA(0.2,0.4,1.5). When the packages come to the internal production, they enter a production queue and this queue works according to the first in first out rule. Unit production time is taken the same with the subcontractors in the internal production because the process flow of internal printed board production is the same with the one of subcontractors. The value of the unit production time is given in Section 4.2.3. The processes in the internal printed board production are mainly serial production and in the model it is assumed that there is only one resource.

After the internal printed board production process, printed boards wait in another queue and batching process is performed. The size of the batches changes around 5 to 30. After batching, printed board batches are sent to the quality control section. The block diagram of the simulation's internal production is available in appendix A.2. Figure 75 and Figure 76.

4.2.3. Subcontractors

Some of the printed boards are produced by the subcontractors instead of the company because the resource of the company is not sufficient to produce all of the printed boards. About seventy five percent of all the printed board production is performed by the subcontractors and the synergy between the company and the subcontractors are very important.

In the simulation model, there are six subcontractors. The production assignment of the printed boards to the subcontractors and internal production is given in the Table 12.

Table 12. The Assignment of the Printed Boards to the Subcontractors and Internal Production

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
Internal Production	PB1	PB1, PB2, PB3	PB1, PB2	PB2, PB3, PB4	PB1
Subcontractor 1	PB2, PB3		PB3	PB1	PB2
Subcontractor 2	PB4, PB5, PB6			PB5,PB6	PB3, PB4
Subcontractor 3	PB7	PB4	PB4,PB5	PB7	PB5
Subcontractor 4	PB8	PB5			PB6, PB7
Subcontractor 5	PB9	PB6	PB6,PB7	PB8, PB9	
Subcontractor 6	PB10	PB7	PB8		PB8, PB9, PB10

Actually the company works with the large number of subcontractors however in the simulation model there are six subcontractors. The number of the product is taken as five in the simulation model and the number of subcontractors which is six, is calculated proportionally with the actual case.

The process structure of all the six subcontractors are assumed the same and this is a fair assumption because after the interview with the production planning engineer the production processes of the all subcontractors are almost the same. Moreover, the aim of making this simulation model is to see the possible production problems in the overall production processes and constructing all the subcontractors with the same structure cannot cause the overlooking of the some problems. The flow chart of the subcontractors is seen in Figure 21.

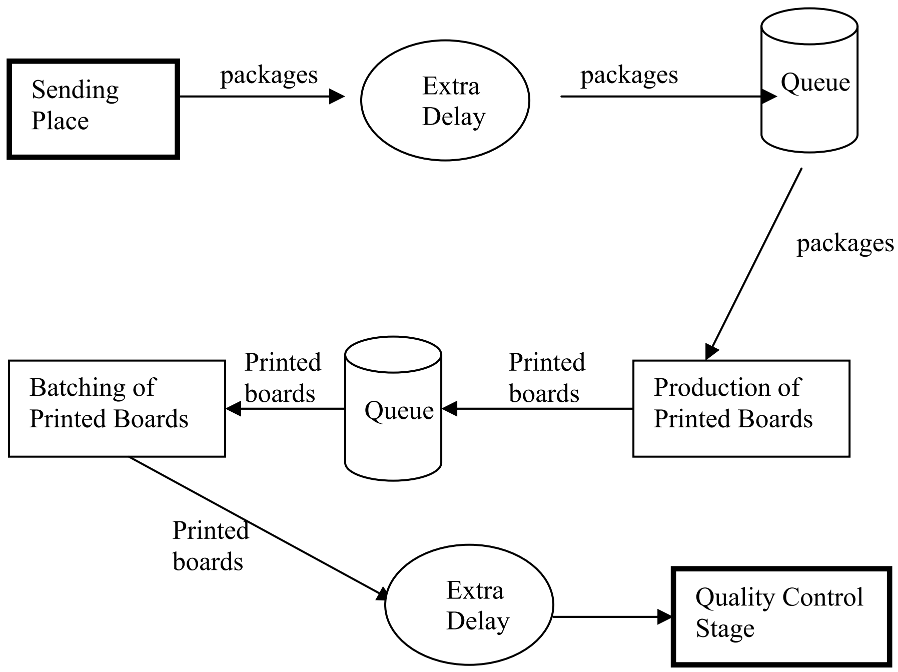

Figure 21. Flow Diagram of Subcontractor Section

The flow diagram of the subcontractors begins with an extra delay. This is the time between unloading process and registration of the packages to the system of the subcontractors. It is fluctuated between 0.2 day to 1 day and most likely the value of this time is about 0.4 days. In the simulation model this time is selected from the distribution of TRIA(0.2,0.4,1). After the registration of the packages, they enter a queue and wait for the production. Then a resource is allocated to process the materials. The unit processing time is taken from the distribution of TRIA(0.175,0.225,0.275) and this distribution is formed with the help of the review made with the engineer who deal with the subcontractors. This value can be a little different from the real distribution however as explained before, for the purpose of the simulation it is good enough, moreover when comparing some performance measure of the model with the real ones, it is seen that there is no significant difference.

After the production of the printed boars is completed, they enter a queue and wait for batching. The amount of the printed board in the queue reaches a certain number and then batching process is performed. This number fluctuates between about 5 and

50, and sipping batch size is taken from the distribution of TRIA(4.5, 19, 49.5). While examining the results of the simulations, it is seen that the sipping batch size affects the performance of the overall production hence this distribution is very important.

After finishing the printed board production in the subcontractors, the company informed about finishing of the production but this is not performed immediately. There is a delay caused from sending the information lately. Furthermore, when the company takes the information about the finishing of printed boards, the vehicle is not sent to the subcontractor immediately, there is also an extra delay. This extra time delay is approximately 2 days however some times this can increase up to half week or decrease to half day. The printed boards taken from the subcontractors are dropped off at a temporary acceptance area. This temporary acceptance area is counted as part of the quality control section and in this part the registration of the materials to ERP system is performed.

The block diagrams of the simulation's subcontractor part are given in the appendix A.2. Figure 77 and Figure 78.

4.2.4. Quality Control Section

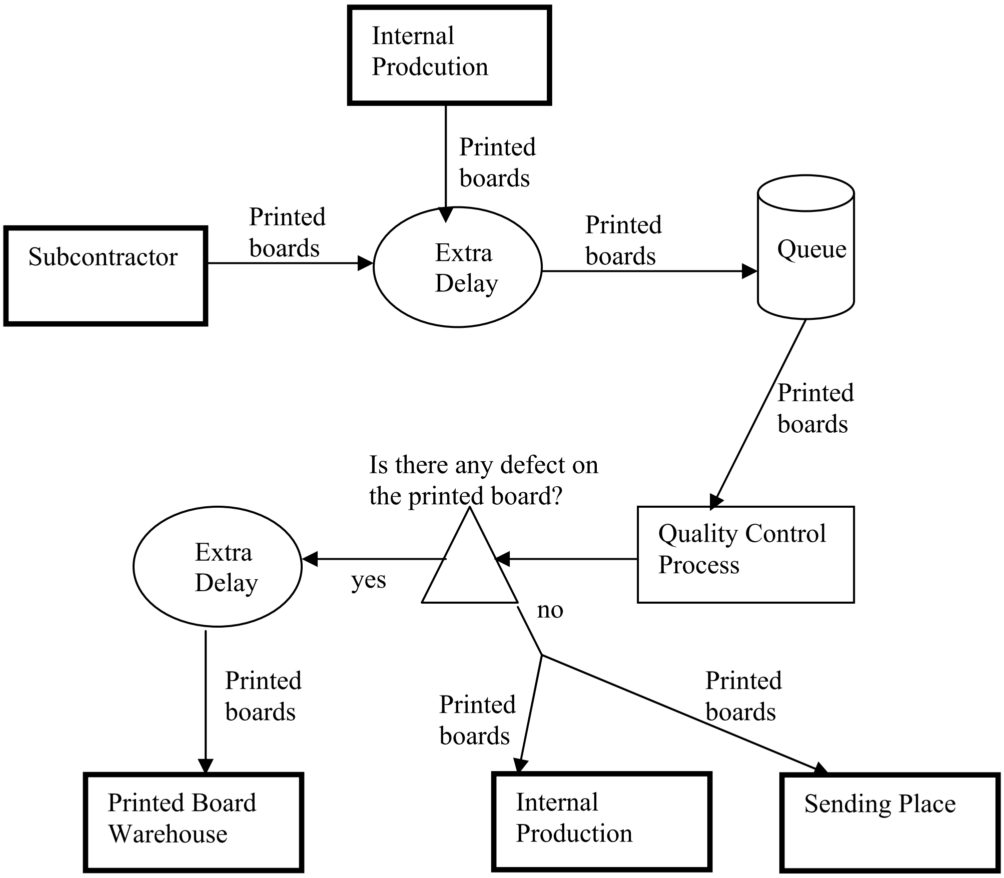

Figure 22. Flow Diagram of Quality Control Section

The flow diagram of the quality control section is given in Figure 22. In the quality control section, first of all, the produced printed boards come to the temporary acceptance area. In this area, the registration of the printed board production is made by the workers. Generally this registration process is not performed immediately and the workers in the quality control section cannot know the presence of the printed boards in the factory so the quality control process can not be started. Moreover, after the registration of the process, most of the time the materials are not taken to the quality control section without delay and this delay happens to be some times so high like two weeks. This place is the most problematic area of the factory and in this section the value of the extra delay can vary between 10 days to fifteen days. To simulate this extra delay in the model the distribution of TRIA(10,12.5,15) is used and the first extra delay in the flow diagram shows this one. The printed boards are taken to a queue and the quality control process is performed. The unit quality control time is about 0.15 day and this value can increase up to 0.18 day and decrease to 0.07 day. At the end of the quality control process, if the printed boards do not have any defects, they are sent to the warehouse but this does not happen immediately. Printed boards wait for going to the warehouse and if the workers are not warned, this process can last a couple of days. In the simulation, 2.25 days is used for this extra delay. On the other hand, if the printed boards have any defects, they are sent to the internal production or to the sending places according to the information of where it is produced.

The block diagram of simulation's quality control section is given in appendix A.2. Figure 79

4.2.5. Warehouse

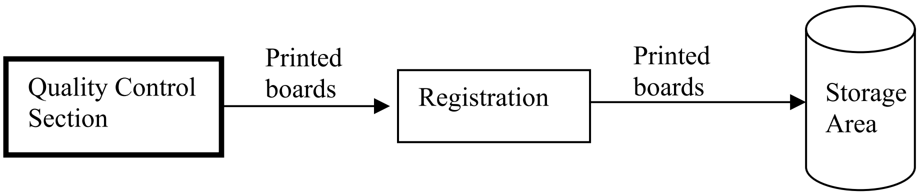

Figure 23. Flow Diagram of Warehouse

The printed boards are stored in the warehouse section of the factory and its flow diagram is shown in the Figure 23. Until the assembly stage, the printed boards are waits in this section and when the assembly of the products, the printed boards are drawn from the warehouse and carried to the assembly stage. Before the printed boards enter the warehouse, printed boards are registered to the ERP system as produced and available in the warehouse. The printed boards which enter the warehouse are counted and the appropriate number of the printed board is increased.

If all printed boards of a product are produced and available in the warehouse the number of the producible product (NPP) is increased. In the assembly section the availability of the all the printed boards of a product is checked by the inspection of this NPP number. If this number of a product is bigger than zero, it means that this product is producible and assembly operation of this product can be started.

In the simulation it is assumed that there is no shortage in the capacity of the warehouse. Actually it is a reasonable assumption because the company constructed two new warehouses in 2009 and this investment solves the storage problem of the company at least for five years.

The block diagram of simulation's warehouse section is given in appendix A.2. Figure 80 and Figure 81

4.2.6. Assembly

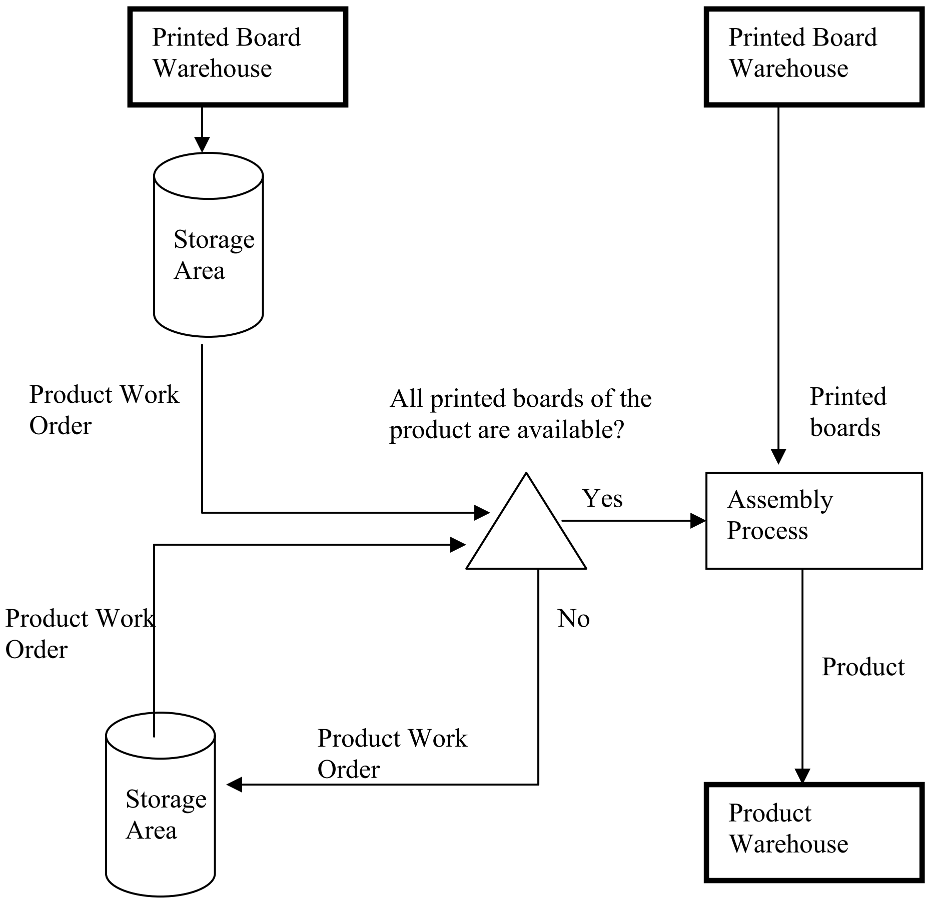

Figure 24. Flow Diagram of Assembly Stage

In Figure 82 the flow diagram of the assembly stage is given. Firstly, product work orders come to the assembly section from work order section or the assembly itself. Then the availability of the printed boards for the product is checked. If there is at least one printed board from each type of a product's printed board, the work order goes to the assembly process. In the real case, a product work order comes in front of a worker and the worker performs the checking operation via ERP system, if all the printed boards of a product are available in the warehouse, the product work order is sent to the assembly operation. However, if at least one of the printed boards is absent in the warehouse, the product work order is not sent to the assembly operation. This product work order become preferential and the availability of its printed boards are checked with some time interval. This time interval changes from 2 to 5 days and the average of this time interval is about 4 days. These values are used in the simulation model and in actual case the value of this time interval can be lower than 2 or bigger than five however the most likely values of this time interval are the values used in the model. Before the checking availability of printed boards, there are two queues in which product work orders wait. The work orders of which checking operation is not performed and which come from the work order section wait in the first queue. On the other hand, after printed boards of a product work order are checked and some of them are absent in the warehouse, within a period of time (mentioned above) re-check is performed until all the printed boards are available. When all printed boards are available, the product work order goes to the second queue. The second queue has priority over the first queue because the product work orders in the second queue are ordered before. Because of this priority, the model firstly checks the second queue, if there isn't any waiting product work order, it checks the first queue.

The work orders of which all printed boards are available in the warehouse go to the assembly process. When it comes to this process, the printed boards in the warehouse are transferred to the assembly area and then the joining and test operations are performed. In this section only one resource is available and the assembly operations of only one product are performed at a time. After the assembly operations are completed the resource becomes idle and the manufactured product is sent to the final product warehouse. Final product warehouse is the final examination point of this study and in this study the capacity is not taken as a constraint in the model. Because of the investment mentioned before there is enough space for the final products.

Assembly is the process in which all the combination processes to form the product are performed and all the assembly operations are performed in the company. Assembly process is basically composed of 2 processes which are joining of the printed boards, case, interconnects and other sub-materials for making the product and the acceptance test process (ATP). The joining operations are performed by the workers with manual ways. These operations consist of basically fitting the printed boards and other materials to the case and some screwing processes and it takes at most one or two hours. For the assembly process the workers are not scarce resource, there is enough amount of worker available for each product. On the other hand, the ATP is composed of some kind of tests like vibration tests, thermal test etc. These two processes are performed serially and the longest processes are the acceptance test process. The length of the acceptance test process constitutes the unit assembly time and as an average it is 0.75 day and can last 1 day at most however it can be performed in a half day.

The block diagram of the simulation's assembly part is given in the appendix A.2. Figure 82, Figure 83 and Figure 84.

4.2.7. Machine Breakdowns

As mentioned before, the tests in the assembly stage are performed by the machines and breakdowns in these machines are common. To reflect the real production processes, these breakdowns are constructed in the simulation model.

In this section two types of information are important; first one is the frequency of the breakdowns and the second one is the duration of the breakdowns. The statistics of these information is not kept in the factory however it is said that on average the frequency of breakdowns is about 30 days and the duration of this breakdown is about 3 days. These values are very rough and in the real case they will be different however to these average values are good enough to see the effect of the breakdowns. It is assumed that this average values can vary and distributions of TRIA(15,30,45) and TRIA(1,3,14) are used for the frequency and the duration in the model respectively. As a upper level of duration of breakdowns 14 days are used because the repair of some breakdowns can last 2 weeks. Generally this occurs because of the unavailable broken machine parts and they take time to acquire.

The block diagram of the simulation's machine breakdowns part is given in the appendix A.2. Figure 85

4.2.8. Verification and Validation of The Model

Until now, the simulation model of the production system's initial case is constructed and in the previous section, details of this model are explained. In this section, the validation and verification of this model is made and there will not be much discrepancy because the main approach in this study is the applicability of the solution obtained from the simulation model to the real case. Needless to say that the simulation model is not identical with the real case since every statistic, structure and information of the real case cannot be reflected to the simulation model hence it is impossible to construct an identical model. Even if one creates an identical simulation model, the additional gain obtained from that simulation model would be significantly low according to the effort spent. However, in some point the simulation model and the real case will be similar. If the behaviors of the simulation model and real case are similar and some measures are not different so much, it can be said that if the solution which is used in the simulation model improves the system, it will also improve the real system and the degree of improvement is alike.

To verify the model, the balance of the simulation model is examined. Balance is the most important required property of a simulation model and it shows that verification measures do not increase by time. If some of the verification measures increased with time, it would mean that there would be accumulation in the model and in real situation such a case does not exist.

After checking the balance of the simulation, some verification measures are determined and they are compared with the real values collected from the company.

Balance Analysis

In this section the balance analysis of the simulation model is made. First of all some verification measures will be determined. If a verification measure which is influenced by any unbalance in the model can be found, this analysis can be done easily. The production process starts with the ordering of the work orders and finishes with the completion of the assembly operations. This time period can be called as lifetime of a product and lifetime is affected from any unbalances in the model. For instance, if there is an accumulation in front of any subcontractor from any reason, the production time of the printed boards are produced in this subcontractor and this causes to have a longer lifetime of the product. If one product's lifetime gets longer, overall lifetime gets longer. In summary, any unbalance which causes trouble in any part of the production causes elongation in lifetime, because of this reason to detect the balance of the simulation model, lifetime is a good verification measure.

The simulation is run with a simulation length of 3000 days and 10 replications are done to see if it is in balance or not. 3000 days are a little more than 8 years and this length is good enough for the analysis because the analysis period is 3 years in this study. Below the lifetime graph of the first replication is given in Figure 25 and the moving average graphs of lifetime for other replications are similar to this graph. .

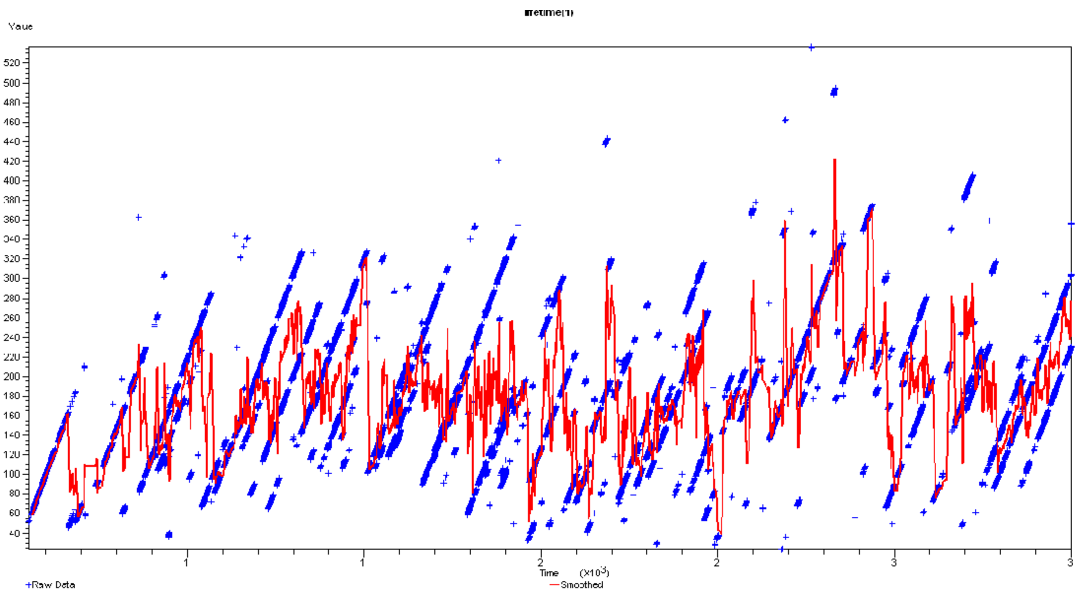

Figure 25. The Lifetime Graph of the Initial Case's First Replication

In the figures, x axis shows the time and y axis shows the lifetime, both in number of days. The points shown with the plus sign show the lifetimes for the corresponding days and the continuous line is the moving average of ten consecutive lifetime values. To see the general movement of the lifetime, moving average is a good indicator because it is not affected so much from instantaneous ups and downs in the lifetime values.

After the examination of the graphs, it is seen that the lifetime values are in balance because in most of the graphs lifetime does not increase with time. In last section of some graph the lifetime values increase. However in the period of three years which are the replication length used in the analysis all of them are seen in balance. In summary, it can be said that there is no accumulation in any part of the simulation model and it is in balance.

Verification Measures

Another verification technique is determining some verification measures and comparing them with the real statistical ones. First verification measure can be lifetime because it is affected from all the processes in the production and can be measured in simulation model and real life. The time lag between the time of ordering and the time of arrival of the printed boards from the subcontractor to the company can be a verification measure. This measure which can be called subcontractortime shows only the some period of the lifetime and if the value of subcontractortime is not very different from the one in the real case, the part of the simulation done for simulating from ordering stage to subcontractor is constructed well. Another verification measure can be orderingtime and this verification measure is the time interval between the ordering stage and the leaving of the printed boards from the company to subcontractors. This is a good measure to see if this part of the simulation is constructed well or not. Another three verification measures can be qualitytime, order-to-warehouse and assemblytime which show the time lasting between entering quality stage and leaving quality stage, ordering and entering of the printed boars to the warehouse and the entering assembly processes and leaving assembly processes respectively. All measure selected for some part of the production process and if this values are not very different from the real ones it means that these parts are constructed well. Below this performance measures received from the simulation is compared with the ones obtained from the real statistical data.

Lifetime

The lifetime obtained from the first simulation model is 183,9 days. The one obtained by averaging the actual data is 195,4. By comparing these values it can be seen that they are not so different from each other and according to lifetime criteria the model can be used as a reflection of the real case.

Orderingtime

The orderingtime obtained from the first simulation model is 9,3 days. The one obtained by averaging the actual data is 13,6. By comparing these values it can be seen that they are a little different from each other and this difference affects the impacts of the improvements a little. The comparison at the Analysis Chapter is made by the help of the simulation and this difference exists in simulation of all approaches and initial case. Because of this reason, this difference does not affect the chosen of the best approach.

Qualitytime

The qualitytime obtained from the first simulation model is 13 days. The one obtained by averaging the actual data is 15,5. By comparing these values it can be seen that they are a little different from each other and this difference affects the impacts of the improvements a little. The comparison at the Analysis Chapter is made by the help of the simulation and the this difference exists in simulation of all approaches and initial case. Because of this reason, this difference does not affect the chosen of the best approach method.

Subcontractortime

The subcontractortime obtained from the first simulation model is 49,3 days. The one obtained by averaging the actual data is 51,4. By comparing these values it can be seen that they are not so much different from each other and according to subcontractortime criteria the model can be used as a reflection of the real case.

Order-to-warehouse

The order-to-warehouse time obtained from the first simulation model is 67,2 days. The one obtained by averaging the actual data is 75,3. By comparing these values it can be seen that they are a little different from each other and this difference affects the impacts of the improvements a little. The comparison at the Analysis Chapter is made by the help of the simulation and the this difference exists in simulation of all approaches and initial case. Because of this reason, this difference does not affect the chosen of the best approach method.

Assemblytime

The assemblytime obtained from the first simulation model is 117,45 days. The one obtained by averaging the actual data is 121,3. By comparing these values it can be seen that they are not so different from each other and according to assemblytime criteria the model can be used as a reflection of the real case.

4.2.9. The Performance Measures

In this part of the study the performance measures are determined. The performance measures are the measures used to judge the affectivity of the improvements made over the system. They are like verification measures however they also have property of direct impact on the gain and lost. If one of the performance measures gets worse the company loses some workforce, product or money. For example, the number of product produced in a certain time is a performance measure. If this number increases the total profit will also increase, on the contrary if this number decreases total profit will also decrease. The result of the approaches will be measurable for comparison with the initial case and other approaches. Because of this purpose some performance measure can be determined.

As mentioned before the number of the produced product in a certain time is the one of the performance measure because it affects the total profit and lost of the company. With the increase of this performance measure the total profit increases as directly proportional. It means that if the number of the product in a certain time is increased twice, the amount of the total profit will be doubled as well.

Amount of the work in process (WIP) inventory can be used as another performance measure. WIP inventory is the inventory which is not assembled and turned into the product. WIP inventory is a cost item because the cost of WIP inventory could not be used in any other investment and the value of the opportunity cost is lost by the company. Mainly opportunity cost is the best alternative investment if the company does not make this business with its assets. To clarify the opportunity cost concept, a simple example can be given. A company has 100 units of money and the profit margin of the company getting in the business is 15 percent per year. It means that the company gains 15 units of money in a year. On the other hand the best alternative of the investment other than its business would be depositing this amount of money in a bank and interest rate of this bank would be 12 percent. When the company runs its business with a profit margin of 15 percent, it loses the 12 percent of the interest given by the bank and 12 units of the money is the opportunity cost of the company. Similarly if the company increases the amount of WIP inventory, it loses the opportunity cost of this amount of WIP inventory. Because if any changes made in the production system increase the WIP inventory, the total cost will also increase with the value of WIP inventory's opportunity cost. Opportunity cost is a good performance measure.

The company is running the business based on the contract as said before and in the contract delivery dates are determined and if the company cannot deliver the products on time, it should pay penalty and this cost is calculated over the number of the late product and amount of delay. To be more specific, the number of the late product is divided with the amount of delay and lateness can be obtained in type of productXday. After that productXday value is divided by a rate which is determined in the contract and this final value forms the penalty cost. Because the number of the late product and the amount of delay are directly proportional with the penalty cost, they are perfect candidate for the performance measures.

Furthermore, the number of the transportation can also be a performance measure because it is directly proportional to the cost of the production. If the number of the transportation between subcontractors increases, the cost of the total transportation will also increase. Secondly, the approaches in the system affect the number of the transportation made. Therefore, the number of the transportation made between the subcontractors should be a performance measure.

The installation cost of the approaches is the final performance measure to evaluate the results of the simulation models.

4.2.10. Results

Below the performance measures determined in the section 4.2.9 of the initial case's simulation model are exhibited. The summary of the result of the initial case's simulation is shown below in Table 13.

Table 13. The Summary of the Result of the Initial Case's Simulation

Number of Product (pieces)	2459,6
Lifetime (days)	183,9
Work-in-Process Inventory (PBs)	1163,1
Amount of Stockouts (times)	49,6
Average value of Stockouts (days)	33
Number of the Transportation (times)	1569
Installation Cost ($)	0

The detail of the WIP inventory for each product and the detail of produced products are given in Table 14 and

Table 15 respectively.

Table 14. The Detail of the WIP inventory for Each Product in the Initial Case

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	84,1	10,6	67,1	6,4	38,1
PB2 (PBs)	58,9	9,1	59,8	10,5	24,3
PB3 (PBs)	46,8	10,6	38,8	10,7	16,1
PB4 (PBs)	55,3	3,9	31	10,1	10,1
PB5 (PBs)	32,9	8,8	18,9	4,2	20,4
PB6 (PBs)	20,9	5,5	38,4	3,6	28,7
PB7 (PBs)	45,8	4,9	24,7	6,3	23
PB8 (PBs)	66		37,6	8	24
PB9 (PBs)	50,7			5,4	18,8
PB10 (PBs)	51,7				11,9

Table 15. The Detail of the Produced Products in the Initial Case

Product	**Number of Product** (pieces)
Product 1	954,5
Product 2	131,7
Product 3	869,3
Product 4	128,6
Product 5	375,5

4.3. Approach1: Changing The Lot Size Came from Subcontractor

After the examination of the model, it can be seen that the ratio of the assembly lines' busy times to the total times are not so close to the 100 percent. The average ratios of the ten replication are given below in Table 16.

Table 16. Assembly Line's Average Usage in Initial Case

Assembly Line	**Ratio** (%)
Assembly line 1	81,6
Assembly line 2	27,0
Assembly line 3	71,2
Assembly line 4	25,4
Assembly line 5	40,6

This low ratio may be caused by the lot size of the printed boards which are shipped from the subcontractor. The graphs of the subcontractor one's shipping queue in which produced printed boards waiting until shipping are given Figure 26 below. In the graph size of the queue is shown, the x axis shows the time and the y axis shows the length of the queue.

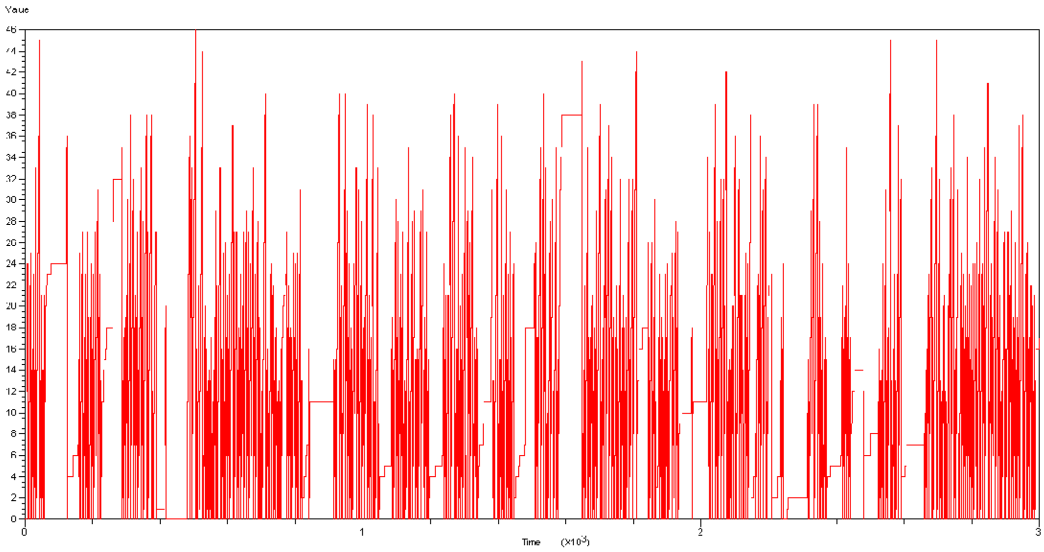

Figure 26. The Graph of the Subcontractor One's Shipping Queue

After the examination of this graph, it can be seen that the average number of printed boards waiting in this queue is high and there are lots of up and downs in the graph. The average values of these queues' lengths are given below in Table 17.

Table 17. The Average Values of the Queues' Lengths in the Initial Case

Subcontractor	**Average lot size** (PBs)
Subcontractor 1	13,1
Subcontractor 2	13,3
Subcontractor 3	13,1
Subcontractor 4	13,9
Subcontractor 5	13,2
Subcontractor 6	13,5

If the up and downs in the model can be reduced then the shipped amount can be smoothed. Furthermore, the lot sizes can be reduced to a smaller amount. By this arrangement, the utilization of the assembly lines may be increased and the number of the production can be increased. In this section the lot size is varied and the result of these changes are examined.

4.3.1. Changes in the Model

In this section the lot size of the shipments from subcontractors are changed with the increment of 10. Firstly, the lot size of the shipment is selected as 5 and results of this simulation are examined. Then the lot size of the shipment is selected as 15, 25, 35, 45 and the results of all these simulations are recorded and tabulated below in section 4.3.3.

4.3.2. Verification and Validation of the Approach1's Simulation Model

The verification of the model should be made and below it is done with the same method used in the initial simulation model in section 4.2.8. However, the verification measures method is not applicable here because this is not the same model with the initial case. Only the balance analysis is performed for this simulation model.

Balance Analysis

The balance of the simulation can be examined by using the lifetime graph of the simulation. In this part the approach which has lot size of 25 is examined, because the results of all the approaches constructed in this section are similar and the best results occur in the Approach1 when the lot size is 25. The improvement rates of Approach1 for different lot sizes are given in tables 48, 49 and 50 in Chapter 5. According to these tables almost for every situation best improvement occurs when the lot size is 25 for the Approach1. The lifetime graph of the Approach1's first replication is given in Figure 27 and the moving average graphs of the other replication are similar.

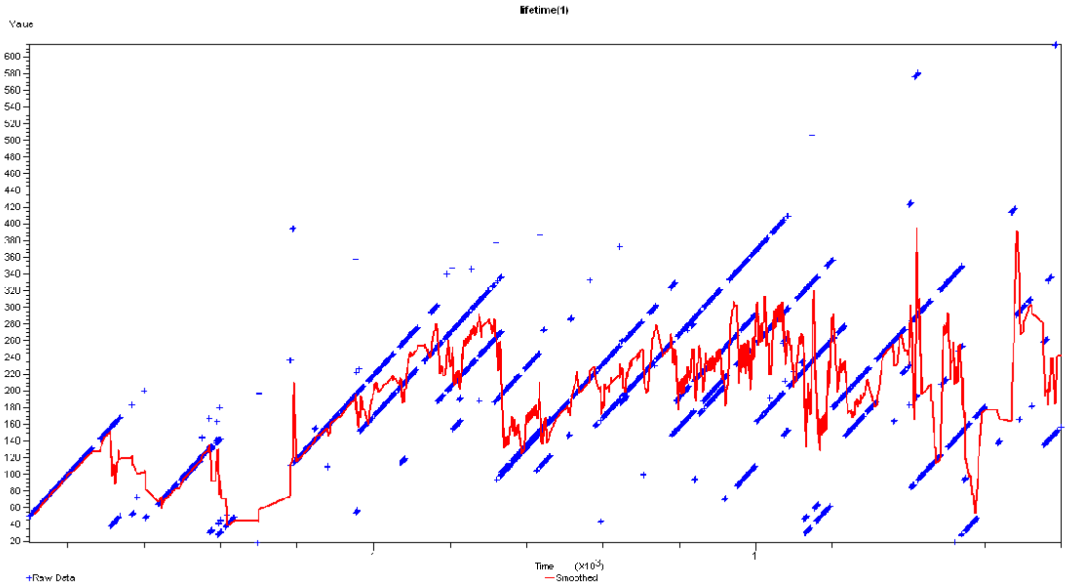

Figure 27. The Lifetime Graph of the Approach1's First Replication

After the examination of this graphs, it is seen that the simulation of the Approach1 is in balance.

4.3.3. Results

The results of the alternatives are given below in Table 18.

Table 18. The Results of the Approach1

Lot size	**5**	**15**	**25**	**35**	**45**
Number of Product (pieces)	2476,8	2414,1	2468,2	2470	2475,8
Lifetime (days)	185,2	188,7	184,3	199,5	199,5
Work-in-Process Inventory (PBs)	1287,4	1262,7	1176,4	1347,2	1274
Amount of Stockouts (times)	44,1	45,4	50,2	86,3	111
Average value of Stockouts (days)	28,7	31,1	33,2	38,3	45,2
Number of the Transportation (times)	4966,8	2188,1	1521,2	1229,1	1031,3
Installation Cost ($)	0	0	0	0	0

The details of the product are given in Table 19.

Table 19. The Detail of the Products in the Approach1

Lot size	**5**	**15**	**25**	**35**	**45**
Product 1 (pieces)	948,6	939,9	908	938,3	963,6
Product 2 (pieces)	163,3	157,1	178,2	147,8	136,7
Product 3 (pieces)	808,9	880	880	785,3	868,3
Product 4 (pieces)	130,1	127,3	130	125	129,2
Product 5 (pieces)	425,9	309,8	372	473,6	378

The detail of the WIP inventory is given in Table 20.

Table 20. The Detail of the WIP Inventory in the Approach1

Lot size		5	15	25	35	45
Product 1	**PB1** (PBs)	100,3	96,4	82,2	107,4	100,3
	PB2 (PBs)	70,4	72,4	62,1	77,4	70,4
	PB3 (PBs)	59,7	53,1	48,8	62,6	59,7
	PB4 (PBs)	54,8	46,6	46,9	50,3	54,8
	PB5 (PBs)	30,1	38,9	32,6	30,7	30,1
	PB6 (PBs)	16,4	19,1	18,2	19,7	16,4
	PB7 (PBs)	67	60,1	54,3	69,2	67
	PB8 (PBs)	77,4	78,1	63,1	83,4	77,4
	PB9 (PBs)	70,6	61,3	55,6	72,2	70,6
	PB10 (PBs)	66,2	64,2	52,2	66	66,2
Product 2	**PB1** (PBs)	9,2	11,8	10,9	12,4	9,2
	PB2 (PBs)	9,1	9	10	10,3	9,1
	PB3 (PBs)	8	8,2	11,3	9,6	8
	PB4 (PBs)	3,6	5,1	5,1	5,5	3,6
	PB5 (PBs)	7,4	7	7,1	5,1	7,4
	PB6 (PBs)	5,6	4,8	4,6	5,5	5,6
	PB7 (PBs)	4,1	4,6	4,6	5,1	4,1
Product 3	**PB1** (PBs)	58,9	73,4	58,2	60,1	58,9
	PB2 (PBs)	48	57,3	53,2	49,2	48
	PB3 (PBs)	33,6	39,7	38,7	34	33,6
	PB4 (PBs)	33,1	40,4	39,3	28,8	33,1
	PB5 (PBs)	18,9	19	17,1	19,5	18,9
	PB6 (PBs)	34,6	43,2	36	36,6	34,6
	PB7 (PBs)	19,3	22,2	18,4	16,1	19,3
	PB8 (PBs)	32,1	34,5	28,3	29,7	32,1
Product 4	**PB1** (PBs)	7,9	6,7	8	8,2	7,9
	PB2 (PBs)	11,2	10,9	12,5	13,7	11,2
	PB3 (PBs)	12,6	11,1	11,3	11,6	12,6
	PB4 (PBs)	12,4	10,9	12,5	12,2	12,4
	PB5 (PBs)	2,8	2,9	5	3,7	2,8
	PB6 (PBs)	2,4	2,7	3,5	3,1	2,4
	PB7 (PBs)	7,9	6,5	6,8	6,5	7,9
	PB8 (PBs)	8,7	7,5	8,2	8,4	8,7
	PB9 (PBs)	9,5	7,1	7,2	7,6	9,5
Product 5	**PB1** (PBs)	43,4	39,5	42	54	43,4
	PB2 (PBs)	32,6	25,7	29,3	34,9	32,6
	PB3 (PBs)	14,5	14,8	19,2	18,7	14,5
	PB4 (PBs)	12,7	10,3	12,6	10,3	12,7
	PB5 (PBs)	33,5	23,5	29,1	33,7	33,5
	PB6 (PBs)	37,9	31,9	24,9	43,8	37,9
	PB7 (PBs)	30,1	25,5	27,2	32,8	30,1
	PB8 (PBs)	30,7	26,3	29,6	31,7	30,7
	PB9 (PBs)	24	15,2	14,2	22	24
	PB10 (PBs)	14,1	13,4	14,5	23,9	14,1

4.4. Approach2: Using RFID Systems in the Production

RFID technologies are one of the best tools used for providing good communication in the supply chain of a company. As mentioned before, there is no need to the human intervention and the speed of the communication via RFID is very fast.

In section 3.3.2 the weakness of the communication in the company is mentioned and some of the time loses caused by this absence are specified. These time loses can be called awareness loses because they are caused from late realization. For instance after the materials of a printed board are prepared and packed, the package waits a time period until it is carried to sending place. The worker that makes the preparation works send the information about the finishing of the packaging operation to the worker in the sending place and the sending worker comes and takes the package. This information sending operation is performed via e-mail and the preparation worker may not be able to send the e-mail immediately. This causes an awareness delay in this section as mentioned before, the value of this delay changes according to the distribution of TRIA(0.2,1,2). If RFID technologies are used in the company, the system checks the finishing of the packaging operation and sends warning to the sending worker immediately, so the awareness time does not occur. However, currently there is not any system like RFID technologies in the company and this awareness delay occurs. Moreover, there are other delays mentioned before and the list of these average delays can be seen below in Table 21

Table 21. The List of Average Delays

Place of the Delay	Average Delay
Before the internal production	0.4 day
After the material preparation	1 day
Before the subcontractor	0.4 day
After the subcontractor	2 days
In the quality control section	12,5 days
After the quality control section	2.25 days

Moreover, the checking operation of the availability of the printed boards in the warehouse in assembly stage is made by the workers and if all the printed boards are not available, the worker waits for some time period and at the end of this time period, the worker rechecks the availability of the printed boards. If some of the printed boards are absent, the worker waits again. If the worker waits for 5 days and all the printed boards become available in the warehouse at 3rd days, 2 days are lost because of the lack of communication. If RFID technologies are used in the company, the system checks the availability of the printed boards in the warehouse and sends a warning to the assembly worker immediately. Because of this improvement this type of time loses is eliminated.

In this approach, Approach2, it is assumed that RFID technologies are used in the company for the tracking of the materials. First of all the places where RFID readers are placed are determined. The first place is in front of the material preparation section. When a printed board work order comes to the this section the worker takes the printed boards with RFID tag, RFID reader reads this tag. At the end of the preparation stage there should be an RFID reader also, this reader is used for determining the finishing of the preparation process. At the sending place in the loading door there should be an RFID reader because of determining the arrival time of the sub-materials. There should be two pairs of RFID reader for each subcontractor and internal production, one is for the beginning of the subcontractor and internal production and the other is for the end of the subcontractor and internal production. Furthermore, there should be an information flow between the subcontractors and the company. At the beginning and end of the quality control section there should be RFID readers for the control of this process. Last four RFID readers should be in door of the printed board warehouse, the beginning of the assembly section, the end of the assembly section, and the door of the product warehouse. Below the places of RFID readers are shown in the Figure 28. RFID readers are shown as rhomboids.

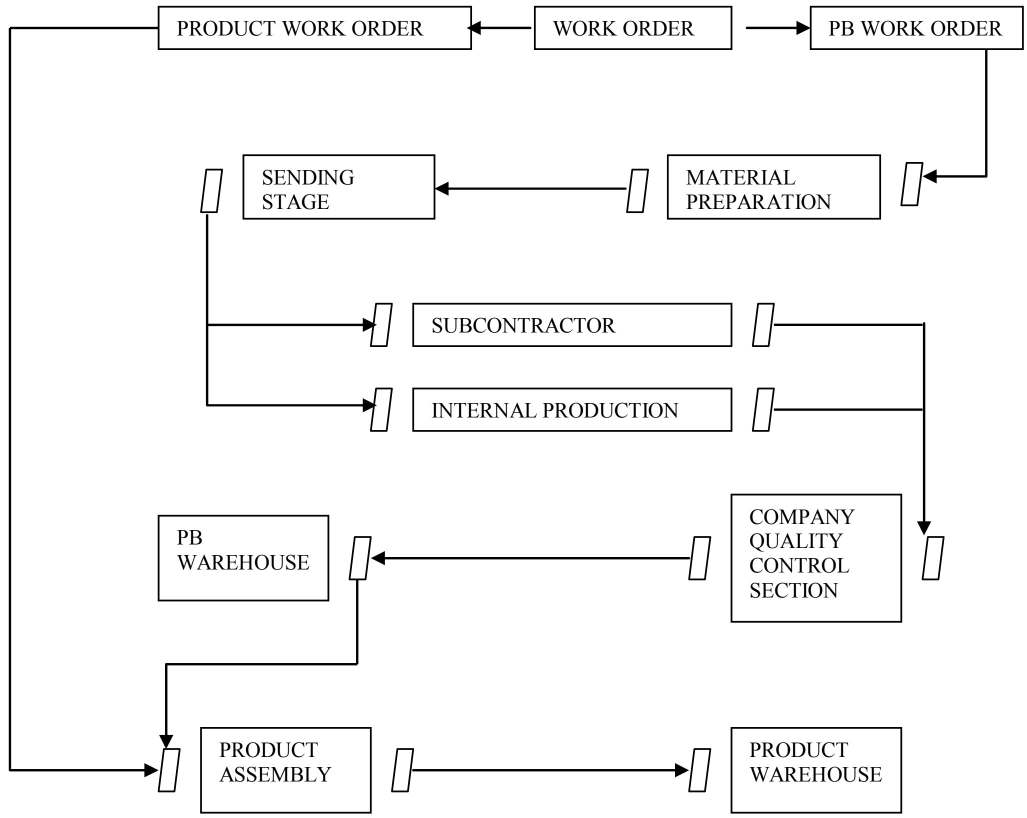

Figure 28. The Places of RFID Readers

4.4.1. Changes in the Model

In this section, the improvements about the issues which are explained above are made in the simulation model. First of all the awareness delays which are shown in the flow diagrams as extra delays are taken out from the model, then the model is modified for usage of RFID technologies. In this approach, the lot size in the simulation of initial situation as shown in Section 4.2.3 is used. Moreover the assembly sub-model of the simulation is changed. In this case, the amount of the printed boards is checked periodically. With this modification, the periodic checks are removed and continuous tracking of the printed boards' availability is performed. The modification made in the block diagram of the simulation's assembly part is given in appendix A.2. Figure 86.

4.4.2. Verification and Validation of the Approach2's Simulation Model

Balance Analysis

The balance of the simulation can be examined by using the lifetime graph of the simulation. The lifetime graph of the Approach2's first replication is given in Figure 29 and the moving average graphs of the other replication are similar.

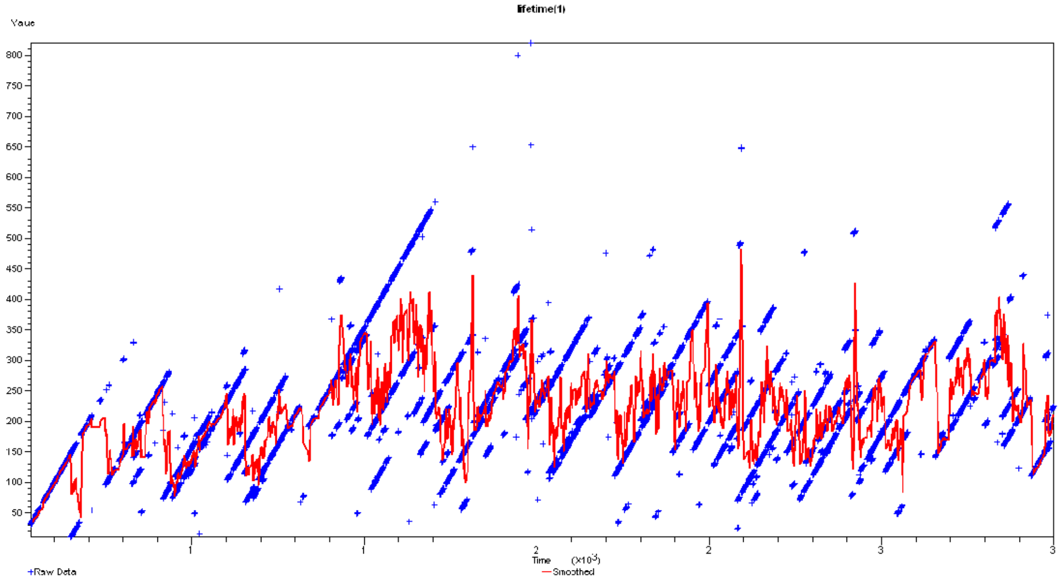

Figure 29. The Lifetime Graph of the Approach2's First Replication

After the examination of these graphs it is seen that the simulation of the Approach2 is in balance.

4.4.3. Results

The results of the Approach2's simulation model is shown in Table 22.

Table 22. The Results of the Approach Two

Number of Product (pieces)	2532,7
Lifetime (days)	170,6
Work-in-Process Inventory (PBs)	1149,5
Amount of Stockouts (times)	43,4
Average value of Stockouts (days)	27,4
Number of the Transportation (times)	2090,3
Installation Cost ($)	300.000

The details of the produced product are given in Table 23.

Table 23. The Detail of the Produced Product in Approach2

Product 1 (pieces)	934,2
Product 2 (pieces)	157,4
Product 3 (pieces)	878,2
Product 4 (pieces)	128,5
Product 5 (pieces)	434,4

The detail of the WIP inventory is given in Table 24.

Table 24. The Detail of the WIP Inventory in Approach Two

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	77,4	10,7	66,2	5,9	41,9
PB2 (PBs)	56,4	10,3	55	9,5	31
PB3 (PBs)	43	10,1	42,2	9,6	22,6
PB4 (PBs)	55,5	4,6	40,6	8,6	18
PB5 (PBs)	29	8,5	13,1	5,1	28,6
PB6 (PBs)	10,4	5,7	39,5	4,8	36,7
PB7 (PBs)	46,8	4,1	13,9	6,2	25,4
PB8 (PBs)	57,3		33,4	4	34
PB9 (PBs)	47,1			6,7	19,4
PB10 (PBs)	41,3				8,8

4.5. Approach3: Using RFID Systems for Decision Support

In this part, in addition to the improvement made in the section **Hata! Başvuru kaynağı bulunamadı.**, the way of increasing the total achievement with the help of RFID systems is considered. In the section 4.2.9, the performance measures are determined and these performance measures affect the total achievement. For instance, the number of the product produced in 3 years period is directly proportional to the total achievement because the number of the total product increases the total profit and this increases the total achievement if the other things are held up. On the other hand, the amount of the WIP inventory, the number of stockouts, and the number of shipment are directly proportional to the total achievement. If an improvement which gets better all these performance measures with the help of RFID systems can be found, it can be applied to the factory.

However, finding this kind of improvement is not possible because the performance measures are not independent from each other. It means that some approaches get better some performance measures but some others get worse. On the other hand, an approach makes better the total achievement resulting from the improvement and the deterioration of the performance measures can be found.

The number of the total production is very important for the company because the demand of the factory is very high according to the production capacity of the company. In the Table 25 below, the ratio of the budget of the production to the amount of deliveries to be made in three consecutive years .

Table 25. The Ratio of The Budget of the Production to the Amount of Mandatory Deliveries to be Made in Three Consecutive Years

	Year 1	**Year 2**	**Year 3**
Budget/Mandatory Deliveries	0,719	0,801	0,739

From this table it can be seen that the capacity of the production is below the demand and the production of the company is bottleneck. Because of this situation the number of the production is the first point of concern. The number of the production made in a certain time can be increased by decreasing lifetime. If the lifetime of the products decreases, in a certain time more products can be produced.

In this simulation, all the production time is taken as the same because production times of the products are nearly the same in the company's real production environment. However, if the content of the warehouse is examined in a certain time it can be seen that all the printed boards of some products are not available in the warehouse. The Table 26 below shows the snap shot of the warehouse taken in a certain time given.

Table 26. The Snap Shot of the Warehouse Taken in a Certain Time

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	4	0	182	2	11
PB2 (PBs)	0	3	15	4	9
PB3 (PBs)	0	2	42	0	7
PB4 (PBs)	13	14	69	0	12
PB5 (PBs)	36	10	22	1	0
PB6 (PBs)	14	11	58	3	4
PB7 (PBs)	16	9	0	4	10
PB8 (PBs)	15		69	0	19
PB9 (PBs)	14			5	7
PB10 (PBs)	16				0

In this time some printed boards of some products are absent in the warehouse. If this table is examined deeply, the product 1 has 2, product 2 has 1, product 3 has 1, product 4 has 3 and product 5 has 2 type of printed boards absent. The product 2 and product 3 have the lowest number of printed board absence. If the required time to produce the absent printed boards is ordered, the printed boards of the products 2 and 3 have the lowest because they have the lowest number of absence. Because of this reason, to produce products 2 and 3 firstly is a good approach to decrease the average lifetime. However, the system in the factory works according to the first in first out rule and does not check this type of issues.

In this section, the lifetime will be tried to be reduced. In the factory, the process which has the longest total production time is the assembly process and in the initial case its average total production time is 117.45 days. On the other hand, the unit production of the assembly time is much lower than this value. If this average total production time of the assembly process can be reduced the total production time of the factory happens to decrease. For the company, the assembly process can be thought as a single machine because all the processes in the assembly process are performed serially. To produce the products which have the shortest process time (SPT) first is the best way of lowering the lifetime in a single machine production (Biskup, 1999). This can be explained better with a simple example. A simple single machine production is taken for examination and three products which have different production times are processed in this production. The Figure 30 below shows this production.

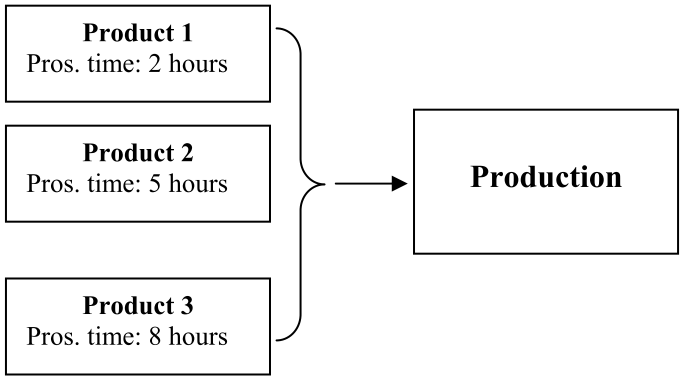

Figure 30. An Example About the Flowtime

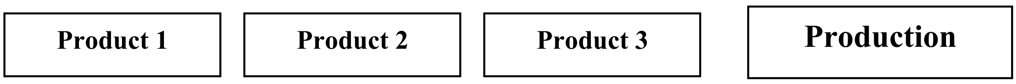

Figure 31. Arrangement of a Production According to the Longest Process Time Rule

Firstly the order of the production of this products is arranged as the longest process time (LPT) first. According to this ordering product 3 needs 8 hours for the production, however the product 2 waits for the production of product 3 and the total production time of the product 2 is 13 (8 + 5) hours. Moreover the product 1 waits for the production of the other products and its total production time is 15 (2 + 5 + 8) hours. The total production times in this situation are the flowtime (lifetime) of the products. The average flowtime of these products is 12 days ((8+13+15)/3). On the other hand the production order can be arranged as the rule of SPT.

Figure 32. Arrangement of a Production According to the Shortest Process Time Rule

According to this ordering, the flowtime of the products are 2 hours, 7 hours and 15 hours for the products 1, 2 and 3 respectively. The average flowtime is 8 ((2 + 7 + 15)/3) hours for these three products. With the help of these small example the effects of making the production according to the SPT rule over the average flowtime is seen easily. This is performed in the company by ordering the entities in front of the subcontractor, quality control stage and the material preparation stage. Absent printed boards of the products which has the lowest number of the printed board absence are put the first place of the queues in these stages. Because of this improvement, it is expected that the lifetime will get lower; the number of the product will increase.

4.5.1. Changes in the Model

Ordering in the Material Preparation Stage

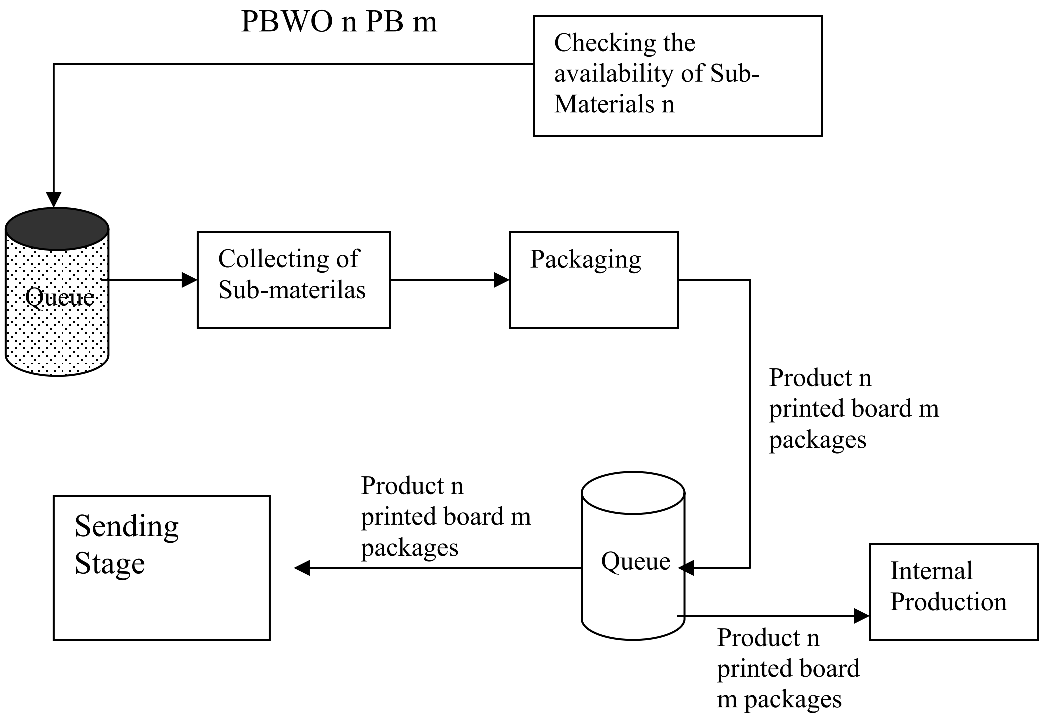

Figure 33. Detail of Material Preparation Section

In initial case of material preparation section, seen in Figure 33, printed board work orders are collected in the queue which is shown with the dots in the figure and the preparation of orders are made according to the first in first out rule. In this stage, in order to decrease the lifetime, the materials are prepared according to the rule determined above. A new sub-model is added to the simulation model to be able to change the ordering rule of the queue before the material preparation stage. The flow diagram of this added part is shown in Figure 34.

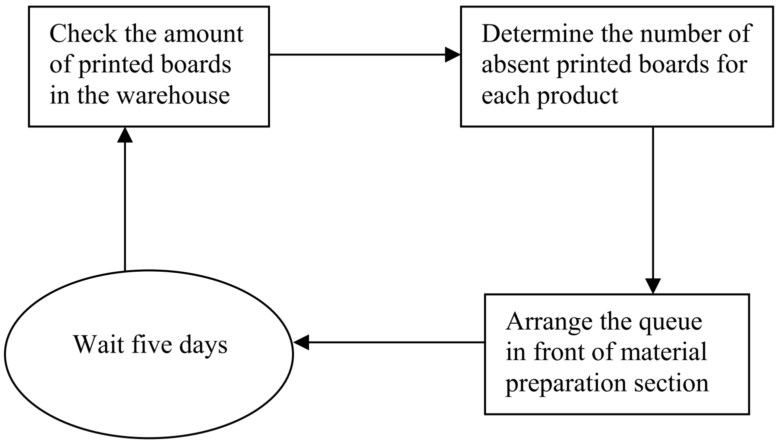

Figure 34. Flow Diagram of Material Preparation's Ordering Part

First of all, the amount of the printed boards in the warehouse is checked and after that all the products which have the minimum absence are determined with some checking operation. Finally, the absent printed boards of the product which has least absence are sent to the in front of the appropriate queue then this operation is performed for the other products in order of having less absence of printed boards. All absent printed boards are placed to the in front of the queue so they are processed firstly. This processes continue until the end of the simulation.

The block diagrams of the simulation's this part are given in the appendix A.2. Figure 87, Figure 88, and Figure 89.

Ordering in the Subcontractors

Changes done in the subcontractor stage are same with the changes done in the material preparation stage. The queue reordered in the subcontractor section is the first queue found in front of the process. This queue is shown in the flow diagram of the subcontractor section with dots in Figure 35.

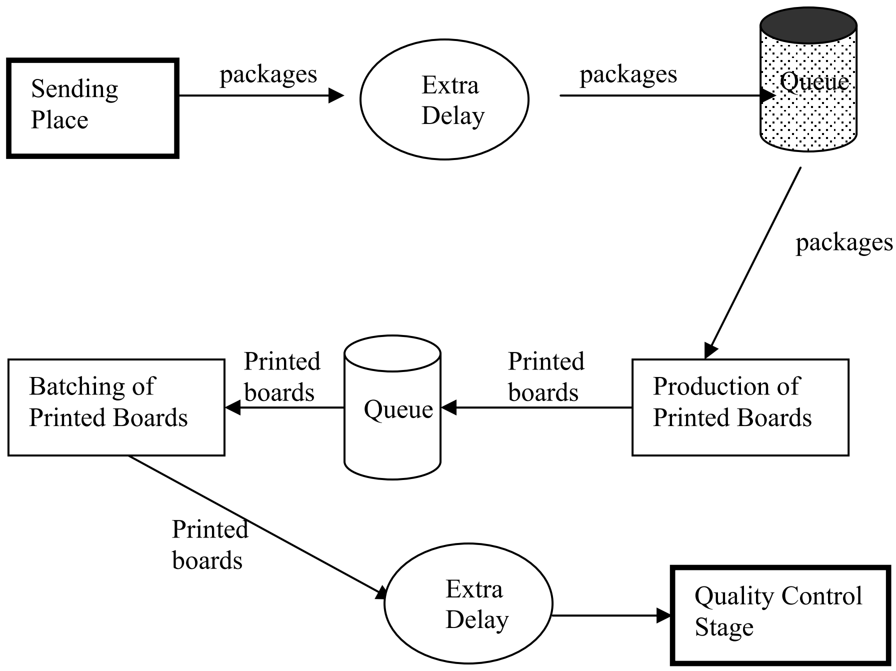

Figure 35. Flow Diagram of Subcontractor Section

Ordering in the Quality Control Stage

Changes made in the quality control stage are same with the changes made in the material preparation and subcontractor stages. The queue reordered in the quality control section is the queue found in front of the process. This queue shown in the flow diagram of the quality control section with dots in Figure 36.

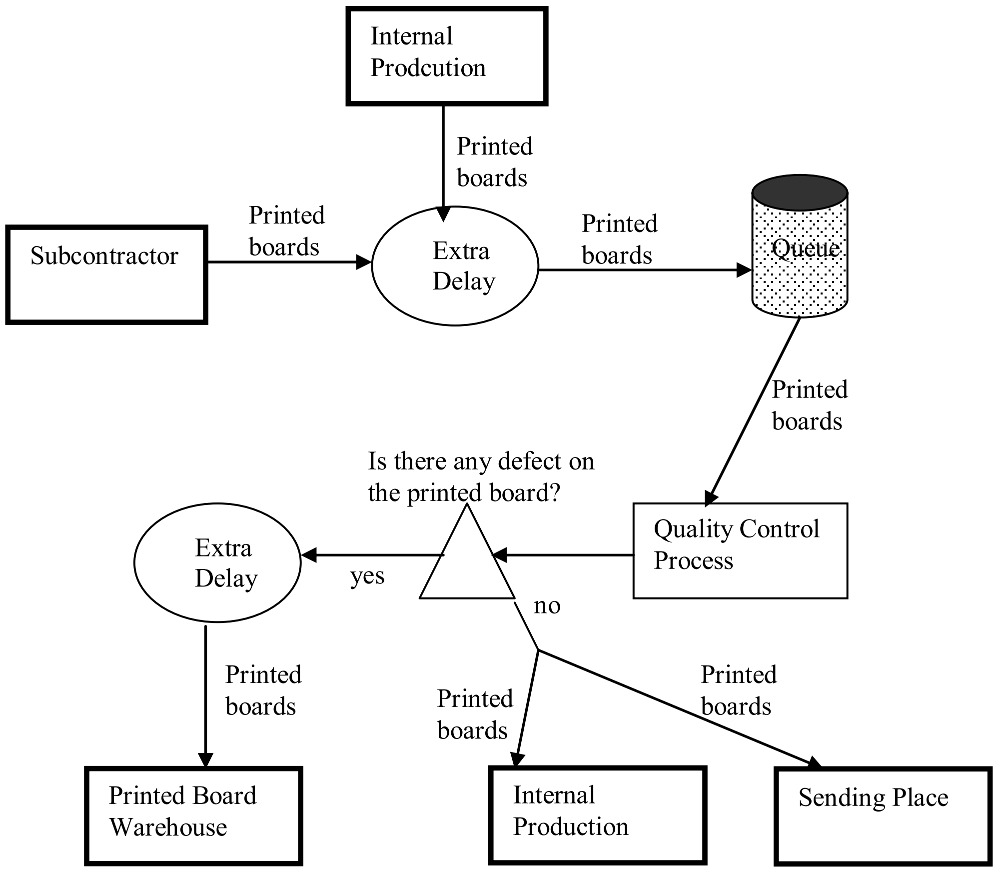

Figure 36. Flow Diagram of Quality Control Section

Changes made in the Assembly Stage

The flow diagram of the new assembly section is given in Figure 37.

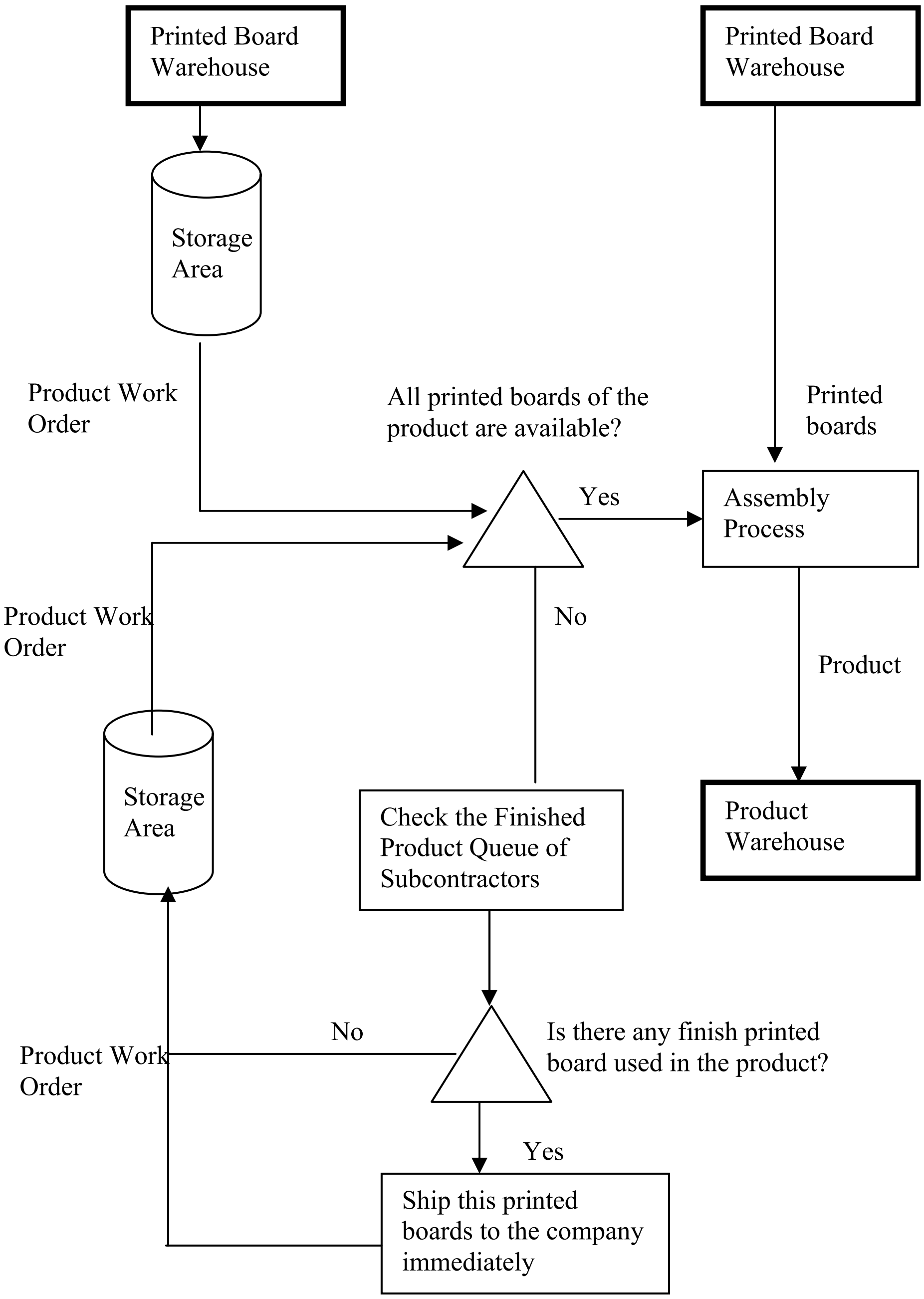

Figure 37. Flow Diagram of Assembly Section After the Changes

In the assembly stage, a change is made in the model. As mentioned before the produced printed boards wait in a queue until the determined lot size is reached in subcontractor. The lot sizes used in the simulation of the initial situation are used in this approach. After the required lot size is reached, the produced printed boards are shipped. However, if some of the printed boars are absent in the warehouse and they are available in the finishing product queue of the subcontractor, the shipment of these printed boards without waiting the lot size is a good approach to decrease the lifetime. In this part, this improvement is modified to the simulation model.

In this sub-model every subcontractor is searched for the absent printed boards and if some of the absent printed boards are found they are shipped to the company without waiting the lot size.

The block diagrams of the simulation's this part are given in the appendix A.2. Figure 91, Figure 92, and Figure 93.

4.5.2. Verification and Validation of the Approach3's Simulation Model

Balance Analysis

The balance of the simulation can be examined by using the lifetime graph of the simulation. The lifetime graph of the Approach3's first replication is given in Figure 38 and the moving average graphs of the other replication are similar.

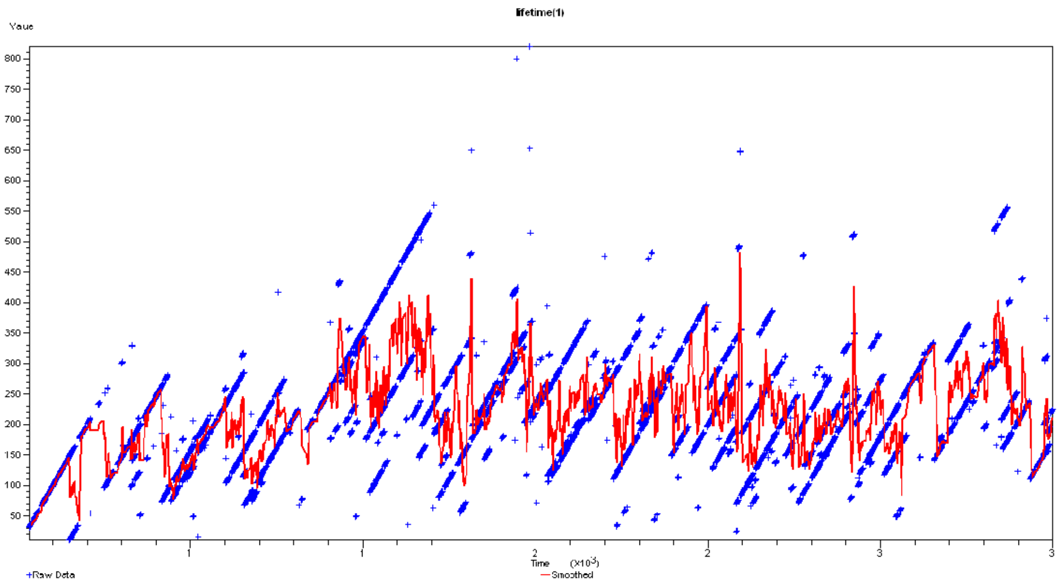

Figure 38. The Lifetime Graph of the Approach3's First Replication

After the examination of this graphs it is seen that the simulation of the Approach3 is in balance.

4.5.3. Results

The result of the Approach3 is given in Table 27.

Table 27. The Result of the Approach Three

Number of Product (pieces)	2506,6
Lifetime (days)	140
Work-in-Process Inventory (PBs)	957,04
Amount of Stockouts (times)	15,6
Average value of Stockouts (days)	26,9
Number of the Transportation (times)	1923,7
Installation Cost ($)	300.000

The detail of the produced product is given below in Table 28.

Table 28. The Detail of the Produced Product in Approach Three

Product 1 (pieces)	973,7
Product 2 (pieces)	176,4
Product 3 (pieces)	836,6
Product 4 (pieces)	128,6
Product 5 (pieces)	391,3

The detail of the WIP inventory is given below in Table 29

Table 29. The Detail of the WIP Inventory in Approach Three

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	78,4	7	47,8	6,1	49,6
PB2 (PBs)	44,1	6,2	44,1	7,2	35,9
PB3 (PBs)	36,7	7,3	29,3	6,9	13,7
PB4 (PBs)	19,2	4,6	16,8	6,7	13,3
PB5 (PBs)	14,6	4,5	15,4	3,9	30
PB6 (PBs)	14,6	3,3	18,9	3,4	38,8
PB7 (PBs)	39,9	4,5	17,1	5,9	30,7
PB8 (PBs)	52,3		24,2	6	24,7
PB9 (PBs)	42,5			5,7	17,9
PB10 (PBs)	39,5				17,5

4.6. Forcing The Simulation Models

In the previous sections, three approaches are tried and their results are examined. From these examinations, it is seen that lifetimes of the some approaches are short according to the lifetime in the initial case, especially the lifetime in the Approach3 is much shorter than the initial case. Furthermore, number of stockouts and the amount of the stockouts are also shorter than one in the initial case in the approaches. All these results mean that the capacity of the production is increased and more products can be produced. From this point, the improved situations are forced by increasing the frequency of the ordering. Moreover, the demand of the company is assumed infinite; the company can sell all produced products and may increase the total profit because if the number of the total product in a certain time increases, the amount of the profit will increase. However there is a condition that is other performance measures should not be deteriorated more.

In this part, the simulation of the approaches are forced by increasing their ordering frequency. In order to increase the ordering frequency the ordering distributions are multiplied by some coefficient. Firstly, inter arrival times between work orders in Approach2 and Approach3 are multiplied by 0.95 and the average lifetime of this simulations are checked and after that the simulations of which lifetime is lower than the initial one are multiplied by the coefficient of 0.90 and then the average lifetime of this simulations are rechecked. The stopping criterion is the average lifetime because the average lifetime affects the number of products, amount of stockouts. The limit of the lifetime is the lifetime of the initial case. Approach1 is not forced because lifetime of all cases of the Approach2 is not lower than the initial case.

4.6.1. Forcing the Approach2

In this section, the Approach2 is forced with the lower coefficients and the ordering rate of the Approach2 increases by this way. First of all, inter arrival times between work orders is multiplied by 0.95 for increasing the ordering rate with respect to the initial case. To differentiate this forced simulation, it is called Approach2 Forced

Version 1. The results of this forced version, Approach2 Forced Version 1, is given below in tables Table 30, Table 31, and Table 32.

The result of the Approach2 Forced Version 1 is given in Table 30.

Table 30. The Result of the Approach Two Forced Version

Number of Product (pieces)	2608,1
Lifetime (days)	188,7
Work-in-Process Inventory (PBs)	1317,8
Amount of Stockouts (times)	73,7
Average value of Stockouts (days)	39,2
Number of the Transportation (times)	2130,5
Installation Cost ($)	300.000

The detail of the produced product is given below in Table 31

Table 31. The Detail of the Produced Product in Approach2 Forced Version

Product 1 (pieces)	1007,4
Product 2 (pieces)	164,5
Product 3 (pieces)	933,5
Product 4 (pieces)	138,8
Product 5 (pieces)	363,9

The detail of the WIP inventory is given below in Table 32

Table 32. The Detail of the WIP Inventory in Approach2 Forced Version

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	105,13	12	68,3	7	40,1
PB2 (PBs)	80,4	13,2	55,2	13,2	28,4
PB3 (PBs)	58,4	11,6	31,8	13,2	16,3
PB4 (PBs)	55,9	5,8	36,1	11,1	10,9
PB5 (PBs)	34,5	7,3	12,3	3	22,2
PB6 (PBs)	10,9	7,4	45	4,8	33,8
PB7 (PBs)	69	4,2	17,2	7,5	25,8
PB8 (PBs)	87,6		34,5	8,4	26
PB9 (PBs)	74,5			7,3	19
PB10 (PBs)	69				13

As seen in Table 32, the amount of the production increases unsurprisingly, because of the increase of the ordering rate. However, at the same time, the amount of WIP inventory, number of stockouts, length of average stockouts time and number of transportation also increases. This situation causes a tradeoff between gain obtained from the increase of the production and loses caused from the increase of the WIP inventory, stockouts and transportation. This issue is examined in the analysis chapter which is chapter six. Besides, increase of the production and cost items the length of the average lifetime is also increases and its value reached to the 188.7 days. Since this value is higher than the lifetime of the initial case's average lifetime, the Approach2 is not forced any more with the lower coefficients and the name of the Approach2 Forced Version 1 is changed as Approach2 Forced Version.

4.6.2. Forcing the Approach3

In this section, the Approach3 is forced with the coefficients. First of all, inter arrival times between work orders in Approach3 is multiplied with the coefficient of 0.95 as in the section 4.6.1. Then the result of this forced simulation is examined and according to the value of the average lifetime, inter arrival times between work orders in Approach3 is multiplied with the lower coefficient values or not. Below in the Table 33, Table 34, and Table 35 results of the Approach3 forced with the coefficient of 0.95 and here it is called Approach3 forced version 1.

The result of the Approach3 Forced Version 1 is given in Table 33.

Table 33. The Result of the Approach Three Forced Version 1

Number of Product (pieces)	2681,8
Lifetime (days)	155,2
Work-in-Process Inventory (PBs)	1024,6
Amount of Stockouts (times)	63,6
Average value of Stockouts (days)	40,1
Number of the Transportation (times)	2100,9
Installation Cost ($)	300.000

The detail of the produced product is given below in Table 34

Table 34. The Detail of the Produced Product in Approach3 Forced Version 1

Product 1 (pieces)	1009,2
Product 2 (pieces)	156,7
Product 3 (pieces)	998,6
Product 4 (pieces)	134,1
Product 5 (pieces)	383,2

The detail of the WIP inventory is given below in Table 35

Table 35. The Detail of the WIP Inventory in Approach3 Forced Version 1

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	75	6,8	70,8	7,2	43,1
PB2 (PBs)	43,8	5,7	56,3	8,1	30,8
PB3 (PBs)	36,5	4,4	31,8	8,7	12,1
PB4 (PBs)	18,4	2,6	20,9	8,5	10,5
PB5 (PBs)	16,7	3,6	16,8	3,8	24,8
PB6 (PBs)	16,4	3,1	19,3	3,9	37,5
PB7 (PBs)	39,3	4,2	19,6	7,3	31,2
PB8 (PBs)	56,1		42,9	5,8	27,2
PB9 (PBs)	38			6,6	25,4
PB10 (PBs)	52,8				20,2

In the tables it is easily seen that the number of production, WIP inventory, stockouts and transportation increases. Moreover, the lifetime value also increases to the value of 155.19 days, because of that inter arrival times between work orders in Approach3 is multiplied with the coefficient of 0.9 and this forced version is called the Approach3 Forced Version 2. The outputs of the Approach3 Forced Version 2 is given below in Table 36, Table 37, and Table 38.

The result of the Approach3 Forced Version 2 is given in Table 36.

Table 36. The Result of the Approach Three Forced Version 2

Number of Product (pieces)	2810,2
Lifetime (days)	166,7
Work-in-Process Inventory (PBs)	1402,7
Amount of Stockouts (times)	91
Average value of Stockouts (days)	57,6
Number of the Transportation (times)	2209,2
Installation Cost ($)	300.000

The detail of the produced product is given below in Table 37

Table 37. The Detail of the Produced Product in Approach3 Forced Version 2

Product 1 (pieces)	1115,1
Product 2 (pieces)	193,2
Product 3 (pieces)	977,3
Product 4 (pieces)	136,5
Product 5 (pieces)	388,1

The detail of the WIP inventory is given below in Table 38

Table 38. The Detail of the WIP Inventory in Approach3 Forced Version 2

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	103	7,3	69,4	12,8	81,7
PB2 (PBs)	66,2	7,9	50	14,7	57,9
PB3 (PBs)	50,7	4,8	37,2	13,3	10,6
PB4 (PBs)	17,8	4,5	19,9	15,1	9,6
PB5 (PBs)	14,8	6,3	16,3	4,5	45,3
PB6 (PBs)	15,1	3,3	22,4	4,1	72,5
PB7 (PBs)	51,4	3,5	16,2	11,1	66,1
PB8 (PBs)	79,8		30,4	11,8	58
PB9 (PBs)	64,7			11,7	43,3
PB10 (PBs)	60,2				35,7

In this forced version of the Approach3, the values of the production, WIP inventory, stockouts and transportations are higher than the other forced version of the Approach3 and the lifetime value of this approach is 166.7. This value still lower than the lifetime of the initial case and inter arrival times between work orders in Approach3 is multiplied with the coefficient of 0.85. The Approach3 Forced Version 3 is given to this approach as a name and its outputs are given in Table 39, Table 40, and Table 41.

The result of the Approach3 Forced Version 3 is given in Table 39.

Table 39. The Result of the Approach Three Forced Version 3

Number of Product (pieces)	2856,3
Lifetime (days)	181,8
Work-in-Process Inventory (PBs)	1705,6
Amount of Stockouts (times)	146,3
Average value of Stockouts (days)	80,8
Number of the Transportation (times)	2250,5
Installation Cost ($)	300.000

The detail of the produced product is given below in Table 40.

Table 40. The Detail of the Produced Product in Approach3 Forced Version 3

Product 1 (pieces)	1101,8
Product 2 (pieces)	183,5
Product 3 (pieces)	1013,9
Product 4 (pieces)	137
Product 5 (pieces)	420,1

The detail of the WIP inventory is given below in Table 41

Table 41. The Detail of the WIP Inventory in Approach3 Forced Version 3

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**
PB1 (PBs)	108,43	7,7	63,9	12,7	132
PB2 (PBs)	65,5	7,1	52,5	14,8	108,3
PB3 (PBs)	46,8	6,2	35,4	14,9	15,6
PB4 (PBs)	16,9	3,9	21,3	14,9	12
PB5 (PBs)	13,9	4,5	17,7	3,6	100,2
PB6 (PBs)	14,9	5,1	21,9	3,9	118,3
PB7 (PBs)	51,1	3,9	16,7	11,2	108
PB8 (PBs)	85,2		32,8	11,6	58,7
PB9 (PBs)	63,6			10,4	70,9
PB10 (PBs)	60,7				56

In this approach the amount of production does not increase very much but the WIP inventory and stockouts increase considerably. Because the lifetime of this forced version of the Approach3 reaches the lifetime value of the initial case, this multiplication process is not performed any more with lower coefficients. All the outputs obtained are examined in Chapter 5.

CHAPTER 5

ANALYSIS

In the previous section, the performance items are determined as total production, total WIP inventory, amount of transportation, number and average length of the stockouts and the cost of the investment done for the approaches. The reason for the selection of these as performance measures is that they directly affect the total profit of the company.

In this section, the analysis of the alternative approaches explained in section 4 is made and the best alternatives are determined for given cases. First of all, sample cases are created with some parameters. In this part all approaches are examined according to 81 possible cases. A case can be defined as a scenario determined with some parameters:

- **Value of the first product's first printed board (P1PB1V)**: To simplify the calculations all printed boards' values of the all products are divided the value of the first product's first printed board (P1PB1V). By the help of this operation to know P1PB1V is enough to calculate the value of the other printed boards. Furthermore, if the values of the products are divided by P1PB1V; the calculation of the products' values will also get simpler. In Table 42 the ratio of the printed boards' value are given and in Table 43 the ratio of the products' value to P1PB1V is given below.

Table 42. The Ratio of the Printed Boards

Product 1	Printed Boards	PB1	PB2	PB3	PB4	PB5	PB6	PB7	PB8	PB9	PB10
	PB / P1PB1V	1	1,2	1,5	3	0,7	1,2	0,9	1,3	2,1	2
Product 2	Printed Boards	PB1	PB2	PB3	PB4	PB5	PB6	PB7			
	PB / P1PB1V	3	3,2	1,5	2,5	2,8	1,4	3,2			
Product 3	Printed Boards	PB1	PB2	PB3	PB4	PB5	PB6	PB7	PB8		
	PB / P1PB1V	1,2	1,1	1,5	1,2	1,4	1,1	1,4	1,3		
Product 4	Printed Boards	PB1	PB2	PB3	PB4	PB5	PB6	PB7	PB8	PB9	
	PB / P1PB1V	3,1	1,7	3,6	5,7	2	3,8	2,5	2,3	3,2	
Product 5	Printed Boards	PB1	PB2	PB3	PB4	PB5	PB6	PB7	PB8	PB9	PB10
	PB / P1PB1V	1,5	1,4	2,4	2,4	1,1	1,2	2,3	1,4	3,4	3,2

Table 43. The Ratio of the Products to the First Product's First Printed Board

Product	P1	P2	P3	P4	P5
Product / P1BB1V	20	125	25	90	50

The values in the tables are rounded. Cost of the total WIP inventory and the value of the all products can be controlled by changing P1PB1V. As a value of this printed board $1.000, $10.000 and $30.000 are used for representing various value products and for seeing the effects of the approaches in the various sizes of products. With the help of the tables 15 and 43, the weighted average value of the products can be calculated. This calculation is performed by summing the multiplication of the production in Table 15 with the coefficients in the Table 43 and the value of the first product's first printed board then dividing this sum by the total production. According to this formulation the weighted average values of the products are about $35.600, $356.000, and $1.070.000 when the value of the first product's first printed board is $1.000, $10.000, and $30.000 respectively.

- **Profit margin**: Total profit of the company is directly proportional with the profit margin of the company and if the profit margin increases the total profit will also increase when the other parameters are fixed. In this analysis part, three values is determined as profit margin and they are 5%, 15%, and 25%.
- **Opportunity cost**: Opportunity cost determines the total cost of the WIP inventory to the company. The opportunity cost is explained in the section 3.3.5 and with the increase of the opportunity cost the total cost of the WIP

inventory increases. The total opportunity cost of WIP inventory can be found by multiplying the value of the WIP inventory with the opportunity cost rate. For the analysis the opportunity cost rate is used one of the 0.15, 0.20 and 0.25 for a sample case in this part.

- **Penalty rate**: Penalty rate is used for the calculation of the punishment cost. The punishment cost is found by the multiplying the value of the late products with the average late days and the penalty rate. The penalty rates used in this section are 0.0003, 0.001 and 0.003.

In Table 44 the values of the parameters chosen to represent the sample cases are shown.

Table 44. The Values of the Parameters Chosen to Represent the Sample Cases

	Name	**Possible Values**
Parameter1	P1PB1V	\$1.000, \$10.000, \$30.000
Parameter2	Profit Margin	0,05, 0,1, 0,15
Parameter3	Oppor. Cost Rate	0,15, 0,20, 0,25
Parameter4	Penalty Rate	0,0003, 0,001, 0,003

The installation and transportation costs are independent from the value of the products and they are important for the analysis. First of all, the cost of RFID system's implementation is applicable for the Approach2 and Approach3 and composed of the software, hardware labor cost for the installation processes. In this study a value for the installation cost is crucial and below Figure 39 initial installation cost of the some companies are given (Vijayaraman, & Osyk,, 2006).

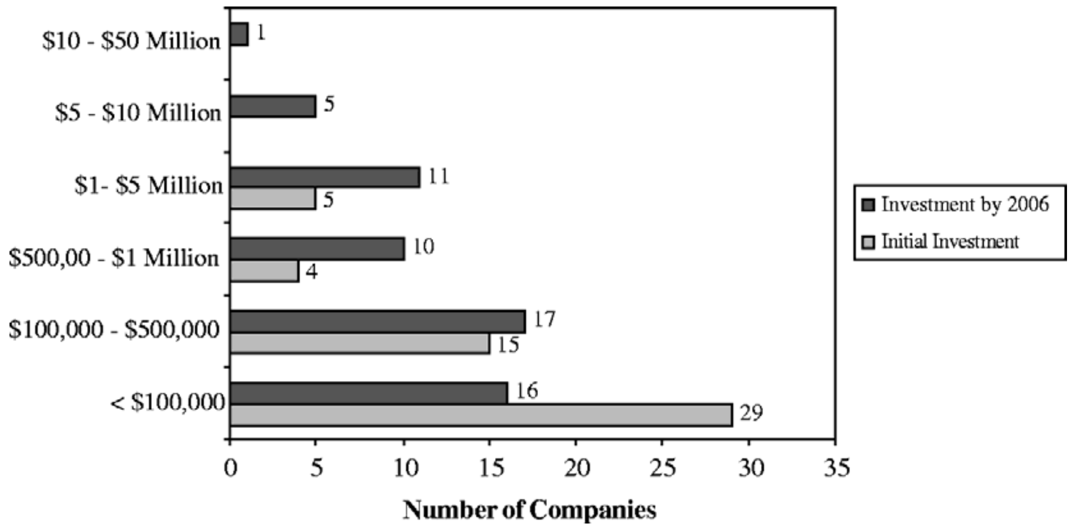

Figure 39. Initial Installation Cost of the Some Companies (Vijayaraman, & Osyk,,, 2006).

In this figure the initial RFID investments and the investments made in 2006 are shown. The initial investment ranges and the companies made initial investment in this ranges are given in the figure. The information in this figure can be expressed in different way in Table 45.

Table 45. The Information in the Figure 40

Initial Investment Range	Mean of Range (MR)	Number of Company (NC)	Total Initial Investment for Each Range (MR*NC)
$1-$5 million	$3 million	5	$15 million
$500.000-$1milion	$750.000	4	$3 million
$100.000-$500.000	$300.000	15	$4,5 million
<$100.000	taken as $100.000	29	$2,9 million

In this table the ranges, mean of each ranges, number of companies made initial investments and the total initial investments for each range is given. The total initial investments made in each investment range is $25,4 million (15+3+4,5+2,9) and total number of company made investment in the table is 53 (5+4+15+29). In the light of this information, the average initial investment is calculated as $479.245 ($25,4 million / 53) and used in the analysis as rounding up $500.000. In the company the computer hardware and software are depreciated in 5 years with the straight line depreciation method. The analysis in this study is made for three years and the initial investment used in this analysis is determined as $300.000 ((3/5)*$500.000).

In the analysis, made in this part it is assumed that there is no expenditure made for RFID systems other than initial investment. The variable cost made every year is mainly composed of cost of RFID tags and in this study for each printed boards a passive RFID tag is used. For approaches and initial situation more or less 25.000 tags are required and the price of a passive RFID tag is about $0,1. The total cost for the company is calculated approximately $2.500 and this value is very small compared with other costs.

Another cost used in the analysis is the cost of one transportation. One transportation is composed of a going and coming and depreciation of vehicle, used fuel and salary of the worker constitute the cost of a transportation. In this part of the analysis cost of a transportation is determined as $50.

By changing the values of the four determined parameters, 81 sample case can be obtained and the analysis is made over these 81 sample cases. Firstly, all loses caused from WIP inventory, stockouts, opportunity cost, transportation and installation will be calculated for all approaches and after that the rise in the profit caused from the increase of the production is calculated and the total gain of the approach is calculated by taking difference of profit and loses result from the changes in the performance measures. Finally the differences of the approaches' gains are compared with the initial case. Below in the Table 46 and Table 47 the formulas of the profits and loses are shown. Before these tables, some definitions should be given to interpret the formulations.

P_i : Amount of i^{th} produced product; given in
Table 15, Table 19
Table 23, Table 28, Table 31, Table 34, Table 37, and Table 40.

RP_i : Ratio of i^{th} product's cost to the cost of the first product's first printed board; given in Table 43.

PjPBi : Amount of jth product's ith printed board in the warehouse; given in Table 14, Table 20, Table 24, Table 29, Table 32, Table 35, Table 38, and Table 41.

RPBji : Ratio of the cost of the jth product's ith printed board to the cost of the first product's first printed board; given in Table 42.

NSO : Number of stockouts; given in
Table 15, Table 19, Table 23, Table 28, Table 31, Table 34, Table 37, and Table 40

ASOL : Average stockouts length; given in
Table 15, Table 19, Table 23, Table 28, Table 31, Table 34, Table 37, and Table 40

P_1PB_1V :Value of the first product's first printed board; case parameter

OCR : Opportunity cost rate; case parameter

COT : Average cost of one transportation; $50.

GI_i : Gain from approach i

DGI_i : Difference of the gains from the approach i and the initial case

PR : Penalty rate; case parameter

Table 46. Formulas I

Name	**Symbol**	**Formula**
Total Relative Production	RP	$(\sum P_i*RP_i)$
Total Relative WIP inventory	RW	$(\sum\sum P_jPB_i*RPB_{ji})$
Total Stockouts	SO	NSO*ASOL
One Relative Production	ORP	$(\sum P_i*RP_i)/(\sum P_i)$
Number of Transportation	T	T

Table 47. Formulas II

Name	**Symbol**	**Effect to the Profit**	**Formula**
Sales	S	Positive	RP*P1PB1V
Cost of WIP inventory	CW	negative	RW*P1PB1V*OCR
Cost of Stockouts	CSO	negative	SO*ORP*PR
Cost of Transportation	CT	negative	T*COT
installation cost	IC	negative	IC

$GI_i = (S\text{-}CW\text{-}CSO\text{-}CT\text{-}IC)_i$

The difference of the gains obtained from the approaches from the initial case can be calculated as:

$DGI_i = GI_i - GI_0$ (zero represents the values of the initial case)

The Table 48, Table 49, and Table 50 below show percentage of the approaches' DGI which is called improvement rate.

Table 48. Percentage of the Approaches' DGI (P1PB1V=$1.000)

Index	Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Initial case ($)	A1 (%)					A2 (%)	A2FV (%)	A3 (%)	A3FV1 (%)	A3FV2 (%)	A3FV3 (%)
							LS5	LS15	LS25	LS35	LS45						
1	1	1000	0,05	0,15	0,0003	3.999.097	1,24	-1,47	6,28	3,99	0,34	-0,52	-0,61	1,13	2,88	**7,65**	5,17
2	2	1000	0,05	0,15	0,001	3.958.274	1,45	-1,36	**6,27**	2,89	-1,80	-0,27	-1,44	1,89	2,33	5,38	-1,33
3	3	1000	0,05	0,15	0,003	3.841.638	2,06	-1,03	**6,24**	-0,38	-8,16	0,47	-3,91	4,17	0,69	-1,39	-20,67
4	4	1000	0,05	0,2	0,0003	3.903.545	0,99	-1,66	6,40	3,69	0,14	-0,51	-0,95	1,60	3,26	**7,25**	4,03
5	5	1000	0,05	0,2	0,001	3.862.722	1,20	-1,55	**6,39**	2,56	-2,06	-0,25	-1,80	2,39	2,69	4,91	-2,65
6	6	1000	0,05	0,2	0,003	3.746.086	1,82	-1,21	**6,35**	-0,80	-8,59	0,51	-4,35	4,75	1,02	-2,04	-22,52
7	7	1000	0,05	0,25	0,0003	3.807.992	0,73	-1,86	6,51	3,38	-0,08	-0,49	-1,30	2,11	3,65	**6,82**	2,82
8	8	1000	0,05	0,25	0,001	3.767.169	0,94	-1,74	**6,50**	2,22	-2,33	-0,23	-2,18	2,92	3,07	4,42	-4,03
9	9	1000	0,05	0,25	0,003	3.650.533	1,57	-1,40	**6,48**	-1,25	-9,05	0,55	-4,80	5,35	1,37	-2,72	-24,47
10	10	1000	0,1	0,15	0,0003	8.380.797	3,56	-0,85	6,04	4,39	0,74	3,31	3,94	4,08	6,35	**12,56**	12,03
11	11	1000	0,1	0,15	0,001	8.339.974	3,67	-0,80	6,03	3,87	-0,28	3,45	3,57	4,46	6,10	**11,51**	8,97
12	12	1000	0,1	0,15	0,003	8.223.338	3,99	-0,63	6,02	2,36	-3,23	3,85	2,49	5,56	5,39	**8,44**	0,09
13	13	1000	0,1	0,2	0,0003	8.285.245	3,47	-0,93	6,09	4,26	0,64	3,36	3,84	4,34	6,56	**12,43**	11,57
14	14	1000	0,1	0,2	0,001	8.244.422	3,58	-0,88	6,09	3,73	-0,38	3,50	3,46	4,73	6,31	**11,36**	8,48
15	15	1000	0,1	0,2	0,003	8.127.786	3,90	-0,71	6,07	2,19	-3,37	3,90	2,36	5,84	5,59	**8,25**	-0,52
16	16	1000	0,1	0,25	0,0003	8.189.692	3,38	-1,02	6,14	4,12	0,55	3,41	3,73	4,61	6,78	**12,29**	11,09
17	17	1000	0,1	0,25	0,001	8.148.869	3,49	-0,96	6,14	3,58	-0,49	3,55	3,35	5,00	6,53	**11,21**	7,97
18	18	1000	0,1	0,25	0,003	8.032.233	3,81	-0,79	6,12	2,03	-3,51	3,96	2,24	6,13	5,81	**8,06**	-1,15
19	19	1000	0,15	0,15	0,0003	12.762.497	4,29	-0,66	5,97	4,52	0,86	4,51	5,37	5,01	7,43	**14,10**	14,17
20	20	1000	0,15	0,15	0,001	12.721.674	4,36	-0,62	5,96	4,18	0,20	4,61	5,13	5,26	7,27	**13,42**	12,18
21	21	1000	0,15	0,15	0,003	12.605.038	4,58	-0,51	5,95	3,19	-1,73	4,88	4,44	5,99	6,82	**11,43**	6,41
22	22	1000	0,15	0,2	0,0003	12.666.945	4,23	-0,71	6,00	4,43	0,80	4,55	5,31	5,19	7,58	**14,03**	13,89
23	23	1000	0,15	0,2	0,001	12.626.122	4,31	-0,67	5,99	4,09	0,13	4,65	5,07	5,44	7,42	**13,34**	11,88
24	24	1000	0,15	0,2	0,003	12.509.486	4,52	-0,56	5,98	3,09	-1,81	4,92	4,37	6,17	6,97	**11,33**	6,06
25	25	1000	0,15	0,25	0,0003	12.571.392	4,18	-0,76	6,03	4,34	0,74	4,60	5,25	5,37	7,73	**13,95**	13,60
26	26	1000	0,15	0,25	0,001	12.530.569	4,25	-0,72	6,03	3,99	0,07	4,69	5,01	5,62	7,57	**13,25**	11,57
27	27	1000	0,15	0,25	0,003	12.413.933	4,47	-0,62	6,01	2,99	-1,89	4,97	4,31	6,36	7,11	**11,23**	5,71

Table 49. Percentage of the Approaches' DGI (P1PB1V=$10.000)

Index	Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Initial case ($)	A1 (%)					A2 (%)	A2FV (%)	A3 (%)	A3FV1 (%)	A3FV2 (%)	A3FV3 (%)
							LS5	LS15	LS25	LS35	LS45						
1	28	10000	0,05	0,2	0,0003	40.697.021	4,97	-0,76	6,12	3,55	-0,26	6,70	6,65	8,13	10,06	**14,86**	12,47
2	29	10000	0,05	0,2	0,001	40.288.793	5,22	-0,65	6,11	2,46	-2,37	7,02	5,91	8,96	9,59	**12,70**	6,16
3	30	10000	0,05	0,2	0,003	39.122.430	5,93	-0,30	6,07	-0,76	-8,64	7,96	3,70	**11,40**	8,19	6,28	-12,61
4	31	10000	0,05	0,2	0,0003	39.741.496	4,82	-0,93	6,23	3,24	-0,47	6,89	6,50	8,77	10,59	**14,64**	11,52
5	32	10000	0,05	0,2	0,001	39.333.268	5,07	-0,81	6,22	2,13	-2,64	7,22	5,74	9,62	10,12	**12,42**	5,04
6	33	10000	0,05	0,2	0,003	38.166.905	5,80	-0,46	6,18	-1,19	-9,07	8,19	3,47	**12,15**	8,70	5,83	-14,23
7	34	10000	0,05	0,3	0,0003	38.785.971	4,66	-1,10	6,34	2,92	-0,70	7,08	6,34	9,44	11,16	**14,40**	10,52
8	35	10000	0,05	0,3	0,001	38.377.743	4,91	-0,98	6,33	1,78	-2,92	7,42	5,55	10,32	10,68	**12,13**	3,88
9	36	10000	0,05	0,3	0,003	37.211.380	5,65	-0,63	6,30	-1,64	-9,53	8,42	3,22	**12,94**	9,24	**5,36**	-15,93
10	37	10000	0,1	0,2	0,0003	84.514.021	5,34	-0,52	5,97	4,17	0,44	6,76	7,40	7,43	9,77	**15,99**	15,48
11	38	10000	0,1	0,2	0,001	84.105.793	5,46	-0,46	5,96	3,66	-0,56	6,91	7,05	7,82	9,55	**14,96**	12,47
12	39	10000	0,1	0,2	0,003	82.939.430	5,80	-0,29	5,94	2,15	-3,49	7,35	6,03	8,96	8,89	**11,97**	3,71
13	40	10000	0,1	0,2	0,0003	83.558.496	5,27	-0,59	6,01	4,04	0,35	6,85	7,34	7,73	10,02	**15,90**	15,07
14	41	10000	0,1	0,2	0,001	83.150.268	5,39	-0,54	6,01	3,51	-0,67	7,00	6,98	8,13	9,80	**14,86**	12,02
15	42	10000	0,1	0,2	0,003	81.983.905	5,73	-0,37	5,99	1,99	-3,64	7,45	5,95	9,28	9,13	**11,83**	3,15
16	43	10000	0,1	0,3	0,0003	82.602.971	5,20	-0,67	6,06	3,90	0,25	6,94	7,27	8,03	10,28	**15,81**	14,64
17	44	10000	0,1	0,3	0,001	82.194.743	5,32	-0,61	6,06	3,37	-0,78	7,09	6,91	8,43	10,05	**14,75**	11,56
18	45	10000	0,1	0,3	0,003	81.028.380	5,67	-0,44	6,04	1,82	-3,78	7,55	5,86	9,61	9,38	**11,68**	2,57
19	46	10000	0,15	0,2	0,0003	128.331.021	5,46	-0,44	5,92	4,37	0,67	6,77	7,64	7,21	9,68	**16,35**	16,44
20	47	10000	0,15	0,2	0,001	127.922.793	5,53	-0,40	5,91	4,03	0,01	6,87	7,41	7,47	9,53	**15,68**	14,46
21	48	10000	0,15	0,2	0,003	126.756.430	5,76	-0,29	5,90	3,05	-1,91	7,16	6,75	8,21	9,10	**13,72**	8,75
22	49	10000	0,15	0,2	0,0003	127.375.496	5,41	-0,49	5,95	4,28	0,61	6,83	7,60	7,40	9,85	**16,30**	16,17
23	50	10000	0,15	0,2	0,001	126.967.268	5,49	-0,45	5,94	3,94	-0,06	6,93	7,37	7,66	9,70	**15,61**	14,18
24	51	10000	0,15	0,2	0,003	125.800.905	5,71	-0,34	5,93	2,95	-1,99	7,23	6,70	8,41	9,26	**13,65**	8,42
25	52	10000	0,15	0,3	0,0003	126.419.971	5,37	-0,54	5,98	4,19	0,55	6,89	7,56	7,60	10,01	**16,24**	15,90
26	53	10000	0,15	0,3	0,001	126.011.743	5,44	-0,50	5,98	3,85	-0,13	6,99	7,33	7,86	9,86	**15,55**	13,89
27	54	10000	0,15	0,3	0,003	124.845.380	5,67	-0,39	5,96	2,85	-2,07	7,29	6,65	8,62	9,43	**13,56**	8,09

Table 50. Percentage of the Approaches' DGI (P1PB1V=$30.000)

Index	Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Initial case ($)	A1 (%)					A2 (%)	A2FV (%)	A3 (%)	A3FV1 (%)	A3FV2 (%)	A3FV3 (%)
							LS5	LS15	LS25	LS35	LS45						
1	55	30000	0,05	0,15	0,0003	122.247.962	5,25	-0,71	6,11	3,51	-0,30	7,23	7,18	8,64	10,58	**15,38**	13,00
2	56	30000	0,05	0,15	0,001	121.023.280	5,49	-0,59	6,10	2,43	-2,41	7,55	6,45	9,47	10,11	**13,23**	6,70
3	57	30000	0,05	0,15	0,003	117.524.191	6,21	-0,24	6,06	-0,79	-8,67	8,51	4,26	**11,93**	8,73	6,83	-12,02
4	58	30000	0,05	0,2	0,0003	119.381.387	5,10	-0,88	6,22	3,21	-0,52	7,43	7,04	9,29	11,13	**15,17**	12,07
5	59	30000	0,05	0,2	0,001	118.156.705	5,35	-0,76	6,20	2,10	-2,68	7,76	6,28	10,15	10,66	**12,97**	5,60
6	60	30000	0,05	0,2	0,003	114.657.616	6,09	-0,40	6,17	-1,22	-9,10	8,75	4,04	**12,69**	9,26	6,40	-13,62
7	61	30000	0,05	0,25	0,0003	116.514.812	4,94	-1,05	6,33	2,89	-0,75	7,63	6,89	9,97	11,70	**14,95**	11,08
8	62	30000	0,05	0,25	0,001	115.290.130	5,20	-0,93	6,32	1,74	-2,96	7,97	6,12	10,86	11,23	**12,69**	4,45
9	63	30000	0,05	0,25	0,003	111.791.041	5,95	-0,57	6,28	-1,66	-9,56	9,00	3,80	**13,49**	9,81	5,95	-15,31
10	64	30000	0,1	0,15	0,0003	253.698.962	5,47	-0,49	5,96	4,16	0,42	7,01	7,66	7,68	10,02	**16,25**	15,74
11	65	30000	0,1	0,15	0,001	252.474.280	5,59	-0,43	5,95	3,64	-0,58	7,16	7,31	8,07	9,80	**15,22**	12,73
12	66	30000	0,1	0,15	0,003	248.975.191	5,93	-0,27	5,93	2,14	-3,51	7,61	6,29	9,21	9,14	**12,23**	3,98
13	67	30000	0,1	0,2	0,0003	250.832.387	5,40	-0,57	6,01	4,02	0,33	7,10	7,60	7,98	10,28	**16,16**	15,32
14	68	30000	0,1	0,2	0,001	249.607.705	5,52	-0,51	6,00	3,50	-0,69	7,26	7,24	8,37	10,05	**15,12**	12,28
15	69	30000	0,1	0,2	0,003	246.108.616	5,87	-0,34	5,98	1,97	-3,66	7,71	6,21	9,53	9,39	**12,09**	3,42
16	70	30000	0,1	0,25	0,0003	247.965.812	5,33	-0,65	6,06	3,88	0,23	7,19	7,53	8,28	10,54	**16,06**	14,90
17	71	30000	0,1	0,25	0,001	246.741.130	5,45	-0,59	6,05	3,35	-0,80	7,35	7,17	8,69	10,31	**15,01**	11,82
18	72	30000	0,1	0,25	0,003	243.242.041	5,80	-0,42	6,03	1,81	-3,80	7,81	6,13	9,86	9,65	**11,95**	2,85
19	73	30000	0,15	0,15	0,0003	385.149.962	5,54	-0,42	5,91	4,36	0,65	6,94	7,81	7,37	9,85	**16,52**	16,61
20	74	30000	0,15	0,15	0,001	383.925.280	5,62	-0,38	5,91	4,02	-0,01	7,04	7,58	7,63	9,70	**15,85**	14,63
21	75	30000	0,15	0,15	0,003	380.426.191	5,84	-0,27	5,89	3,04	-1,92	7,33	6,91	8,37	9,27	**13,89**	8,92
22	76	30000	0,15	0,2	0,0003	382.283.387	5,50	-0,47	5,94	4,27	0,59	7,00	7,77	7,57	10,01	**16,46**	16,34
23	77	30000	0,15	0,2	0,001	381.058.705	5,58	-0,43	5,94	3,93	-0,07	7,10	7,54	7,83	9,86	**15,78**	14,35
24	78	30000	0,15	0,2	0,003	377.559.616	5,80	-0,32	5,93	2,94	-2,00	7,40	6,87	8,58	9,43	**13,82**	8,59
25	79	30000	0,15	0,25	0,0003	379.416.812	5,45	-0,52	5,98	4,18	0,53	7,06	7,73	7,76	10,18	**16,40**	16,07
26	80	30000	0,15	0,25	0,001	378.192.130	5,53	-0,48	5,97	3,84	-0,14	7,16	7,50	8,02	10,03	**15,72**	14,07
27	81	30000	0,15	0,25	0,003	374.693.041	5,76	-0,37	5,96	2,84	-2,08	7,46	6,82	8,78	9,60	**13,74**	8,26

5.1. Examination of Approach1

In the Approach1, the lot sizes are changed and the best improvement occurs when the lot size is 25. The changes of the improvement rates according to the cases are given in Figure 40. In this figure, there are three line which shows the cases when P1PB1V is $1.000, $10.000, and $30.000.

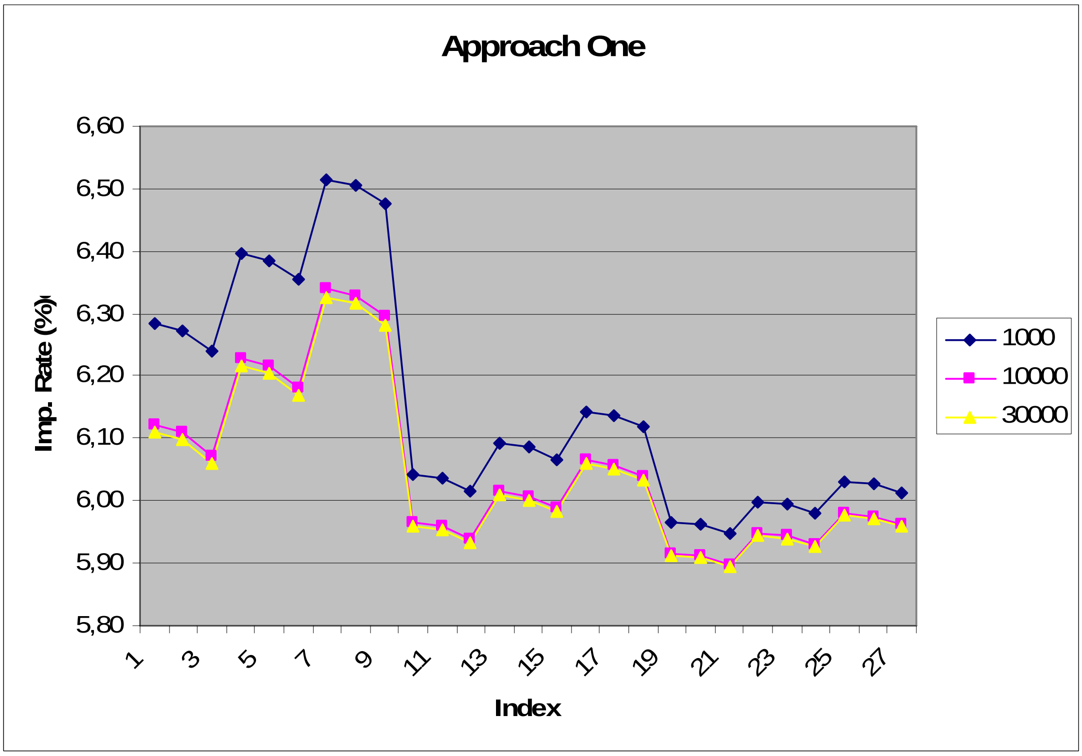

Figure 40. The Changes of the Improvement Rates According to the Indexes in Approach1

The best case for the Approach1 is the case 7 and for this case P1PB1V, the profit margin, the opportunity cost rate and the penalty rate are $1.000, 0.05, 0.25 and 0.0003 respectively. For the Approach1, the improvement rates in the table do not fluctuate much with respect to the cases, the maximum, average and minimum improvement rates are 6.51, 6.08 and 5.89 respectively. The reason of this stability is that WIP inventory, stockout and transportation characteristic of the Approach1 is nearly same with the initial situation. The information of the best and the worst case of the Approach1 is given below in Table 51 and Table 52.

Table 51. Information of the Best Case of the Approach1

Case 7			
Improvement Rate (%)	6,51	**Sales** ($)	4.636.750
P1PB1V	$1.000	**WIP inventory Cost** ($)	485.882
Profit Margin	0,05	**Stockouts Cost** ($)	18.786
OCR	0,25	**Transportation Cost** ($)	76.060
Penalty Rate	0,0003	**Installation Cost** ($)	0

Table 52. Information of the Worst Case of the Approach1

Case 75			
Improvement Rate (%)	5,89	**Sales** ($)	417.307.500
P1PB1V	$30.000	**WIP inventory Cost** ($)	8.745.885
Profit Margin	0,15	**Stockouts Cost** ($)	5.635.697
OCR	0,15	**Transportation Cost** ($)	76.060
Penalty Rate	0,003	**Installation Cost** ($)	0

In the best case of the Approach1, case 7:

- The penalty rate takes its lowest value because the stockouts of the Approach1 is higher than the initial situation.
- Although the production and WIP inventory of the Approach1 is higher than the initial situation, P1PB1V, profit margin takes their lowest and OCR value takes its highest value. The reason of this is that in lower total profit values, the improvements have more effect over the improvement rates. This can be explained with a small example. For instance, there are two situations with sales values of 200 and 250, the second situation is 25 percent higher than the first one. Subtractions of 20 and 21 are made from first and second situations respectively and new values of the sales are 180 and 229. Although a higher value, 21, is subtracted from the second situation, in new case the second situation is 27.2 percent higher than the first one because in lower values, rates are more sensitive.

Because of these reason the best situation occurs in the case 7 and worst one occurs in case 75 in Approach1.

5.2. Examination of Approach2

The changes in improvement rates of Approach2 according to the cases are given in Figure 41.

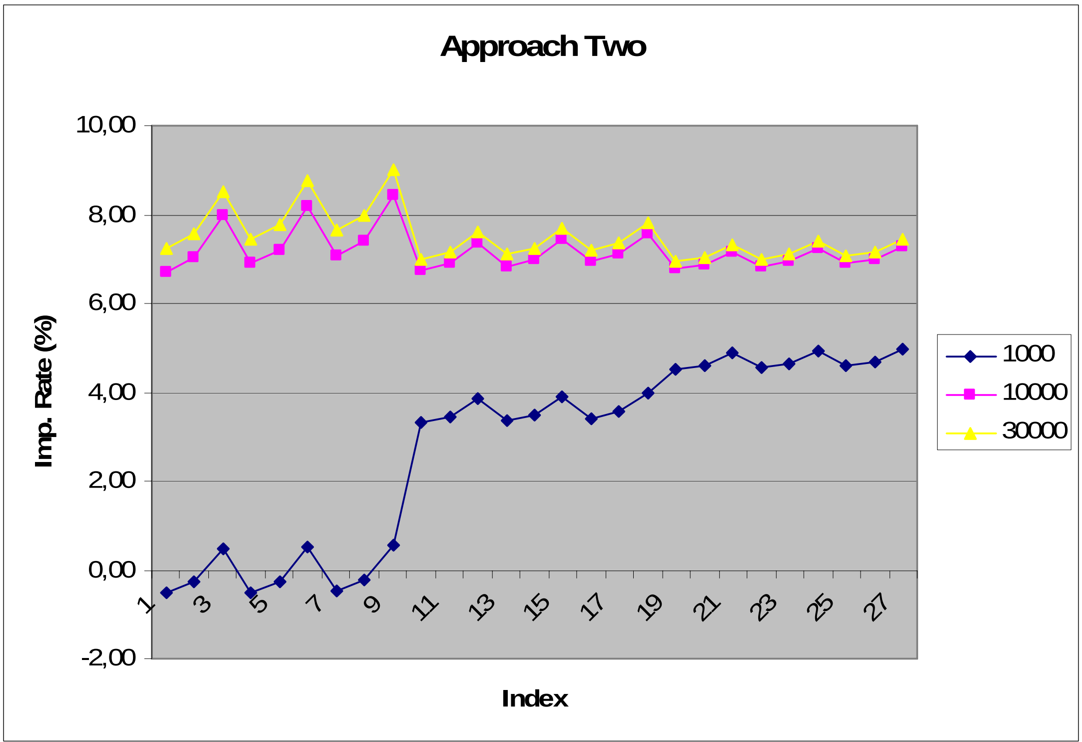

Figure 41. The Changes of the Improvement Rates According to the Indexes in Approach2

Best improved case is the case 63 with the improvement rate of the 9,00 percent, on the other hand, the worst improved case is the case 1 with the improvement rate of -0,52 percent. The case parameters, the value of the costs and sales for these cases are given in Table 53 and Table 54.

Table 53. The Information of the Best Case of the Approach2

Case 63			
Improvement Rate (%)	9,00	**Sales** ($)	140.398.500
P1PB1V	$30.000	**WIP inventory Cost** ($)	14.191.125
Profit Margin	0,05	**Stockouts Cost** ($)	3.955.216
OCR	0,25	**Transportation Cost** ($)	104.515
Penalty Rate	0,003	**Installation Cost** ($)	300.000

Table 54. The Information of the Worst Case of the Approach2

Case 1			
Improvement Rate (%)	-0.52	**Sales** ($)	4.679.950
P1PB1V	$1.000	**WIP inventory Cost** ($)	283.823
Profit Margin	0,05	**Stockouts Cost** ($)	13.184
OCR	0,15	**Transportation Cost** ($)	104.515
Penalty Rate	0,0003	**Installation Cost** ($)	300.000

Best case occurs in case 63:

- Since in Approach2, the amount of WIP inventory and stockouts are lower than the initial case, in the best case, case 63, P1PB1V, OCR and penalty values take their highest values to maximize the improvement rate.
- The profit margin takes the lowest value because in the small sales values the impact of the costs to the improvement rate will be higher.

The case parameters in the case 1 take the opposite values of the case parameters except profit margin in the case 63:

- The profit margin takes the lowest value because the improvement rate is below zero. The improvement rates of the Approach2 is below the zero when the profit margin is 0.05, P1PB1V is $1.000 and penalty rate is 0.0003 or 0.001. For all other cases improvement rates are higher than the zero.

Furthermore when the P1PB1V is higher than the value of $1.000, the Approach2 is better than the Approach1 for all cases. The WIP inventory, stockouts and production value of the Approach2 is better than the Approach1 but in the Approach2 there is an extra initial investment cost. If the company produces higher value products, the total gain obtained from increase of product and decrease on WIP inventory and stockouts will be higher than the loses caused from the initial investment. The comparison of the Approach1 with the Approach2 is given in Figure 42 below.

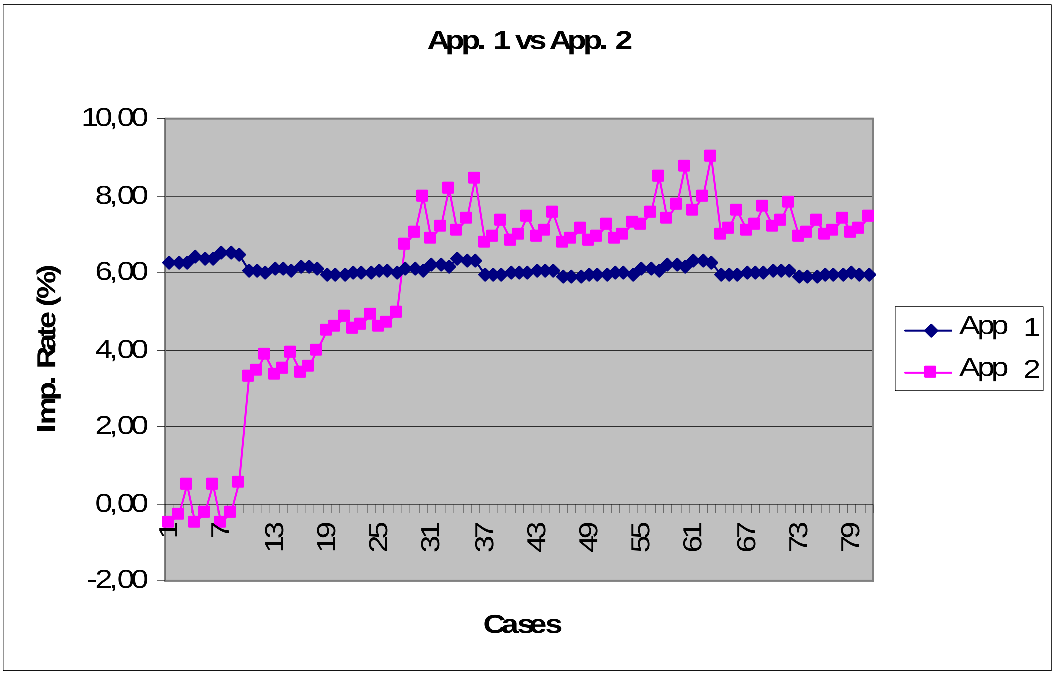

Figure 42. The Comparison of the Approach1 with the Approach2

To summarize, it can be said that because the amount of the stockouts and WIP inventory in the Approach2 is lower than the initial case and Approach1 but in the Approach2 there is an investment cost, the best improvement rate occurs in high P1PB1V.

5.3. Examination of Approach3

The improvement rates of the Approach3 fluctuates according to the cases because the patterns of the WIP inventory, stockouts, production and transportation are not similar with the initial situation. The changes in improvement rates of Approach3 according to the cases are given in Figure 45.

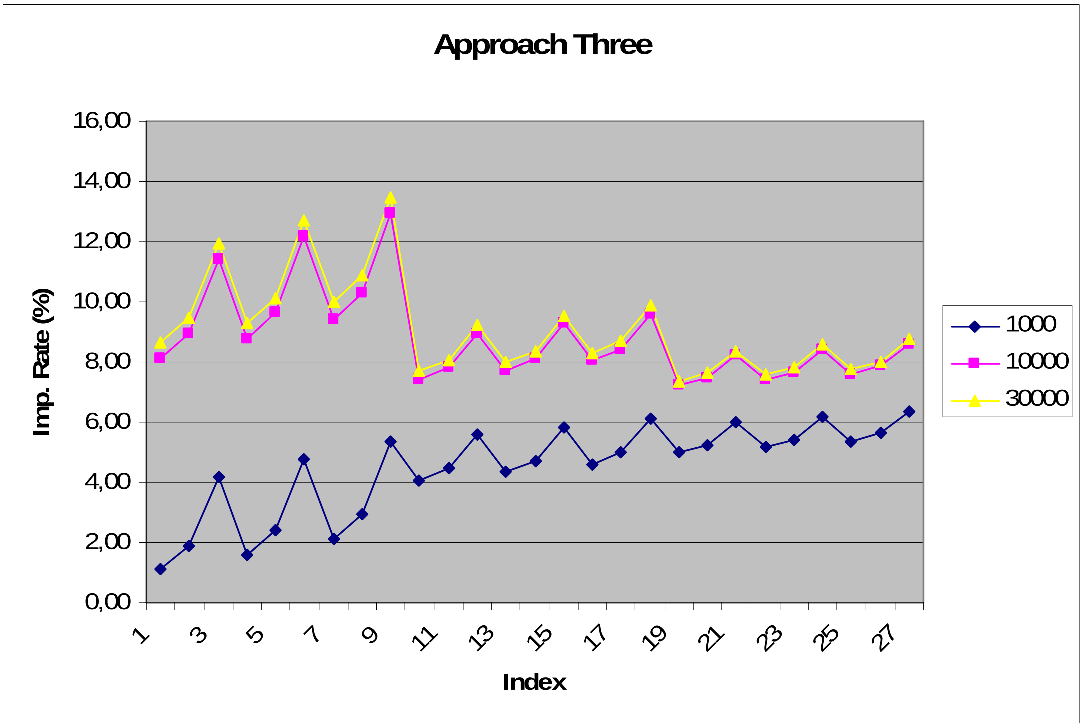

Figure 43. The Changes of the Improvement Rates According to the Cases in Approach3

After the examination of the improvement rates' inclination, it can be said that with the increase of the OCR and penalty rate the improvement rates get better. The reason behind this is that the stockout and WIP inventory values of Approach3 are much better than the ones of the initial case and with the increase of OCR and penalty rate the net profit of the initial cases gets worse. For Approach3, the best improved case is the case 63 with the improvement rate of the 13.49 percent, on the other hand, the worst improved case is the case 1 with the improvement rate of 1.13 percent. The case parameters and the value of the costs and sales for these cases are given in Table 55 and Table 56.

Table 55. The Information of the Best Case of the Approach3

Case 63			
Improvement Rate (%)	13,49	**Sales** ($)	140.367.000
P1PB1V	$30.000	**WIP inventory Cost** ($)	11.694.450
Profit Margin	0,05	**Stockouts Cost** ($)	1.409.964
OCR	0,25	**Transportation Cost** ($)	96.185
Penalty Rate	0,003	**Installation Cost** ($)	300.000

Table 56. The Information of the Worst Case of the Approach3

Case 1			
Improvement Rate (%)	1,13	**Sales** ($)	4.678.900
P1PB1V	$1.000	**WIP inventory Cost** ($)	233.889
Profit Margin	0,05	**Stockouts Cost** ($)	4.700
OCR	0,15	**Transportation Cost** ($)	96.185
Penalty Rate	0,0003	**Installation Cost** ($)	300.000

Best case occurs in case 63:

- P1PB1V, OCR and penalty values take their highest values to maximize the improvement rate because the amount of WIP inventory and stockouts are much lower than the initial case,.
- The profit margin takes the lowest value because in the small sales values the impact of the costs to the improvement rates will be higher.

The case parameters of the costs in the case 1 take the opposite values of the case parameters in the case 63 because the improvement rate of case 1 is lowest.

Furthermore, the improvement rate of the Approach3 is better than Approach1 for all cases when the P1PB1V is higher than $1.000. However, most of the cases when the value of the P1PB1V is $1.000 the Approach1 is better than the Approach3 because of the initial investment cost. The comparison of the Approach3 with the Approach1 is given in Figure 44 below.

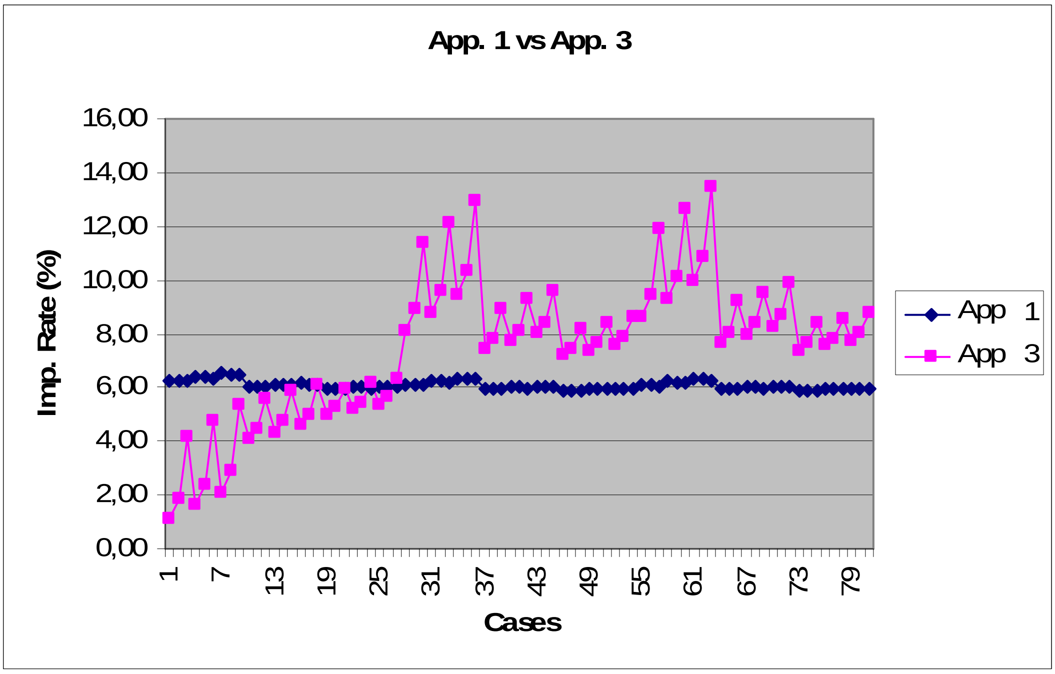

Figure 44. The Comparison of the Approach3 with the Approach1

On the other hand, the improvement rates of the Approach3 is better than the Approach2 for all cases. The reason of this is that although the production of the Approach2 is better than the Approach3, the WIP inventory, stockouts and transportation of the Approach3 are much better than the ones of the Approach2. Moreover, the relative production of two approaches is nearly same. The comparison of the Approach3 with the Approach2 is given in Figure 45 below.

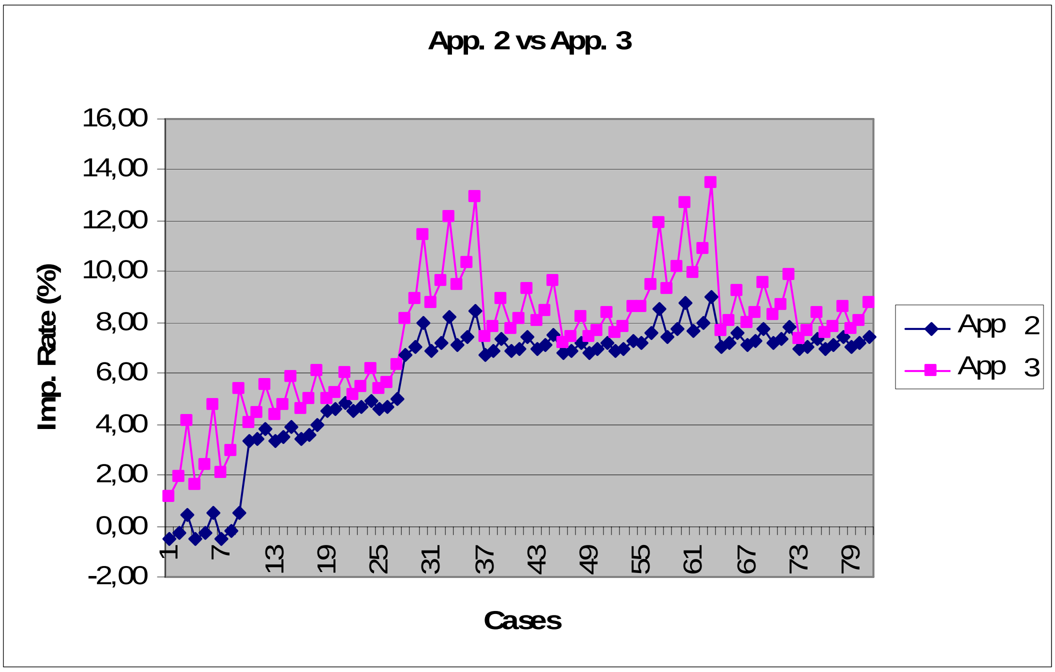

Figure 45. The Comparison of the Approach3 with the Approach2

To summarize, it can be said that because the amount of the stockouts and WIP inventory in the Approach3 is lower than the initial case and there is an investment cost in the Approach3, the best improvement rate occurs in the case which has higher penalty rate, OCR, and P1PB1V.

5.4. Examination of Approach2 Forced Version

The improvement rates of the Approach2 Forced Version fluctuate according to the cases because the patterns of the WIP inventory, stockouts, production and transportation are not similar with the initial situation. The changes in the improvement rates of Approach2 Forced Version according to the cases are given in Figure 46.

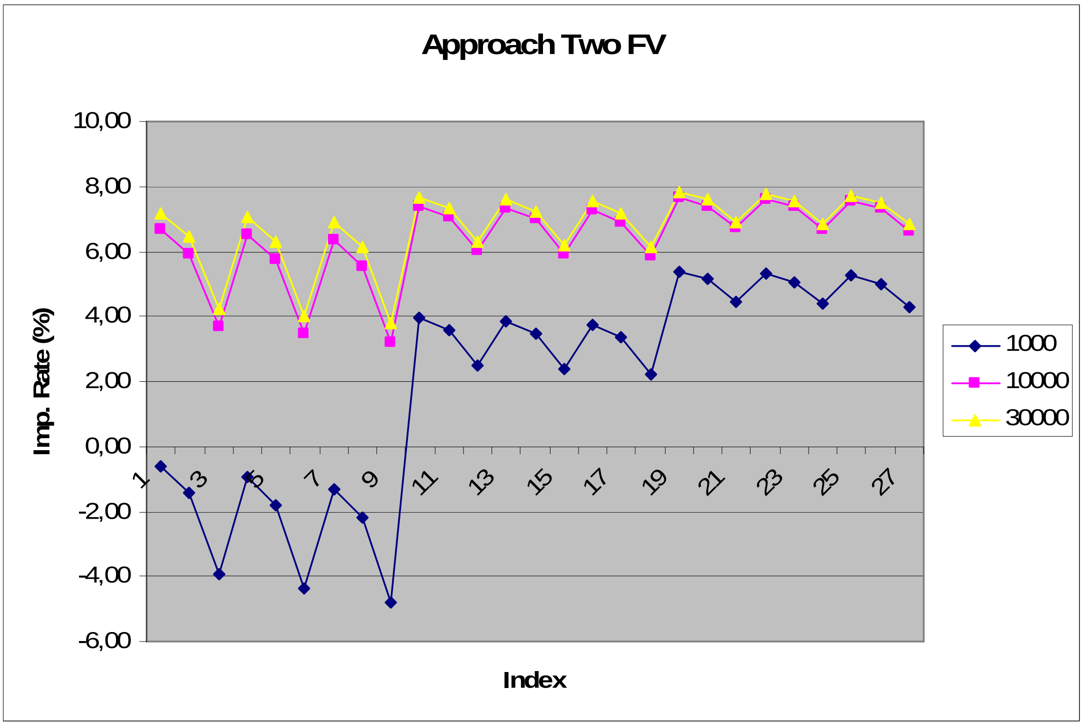

Figure 46. The Changes of the Improvement Rates According to the Cases in Approach2 Forced Version

After the examination of the improvement rates' inclination, it can be said that with the decrease of the OCR and penalty rate, the improvement rates get better. The reason behind this is that the stockout and WIP inventory values of Approach2 Forced Version are worse than the ones of the initial case and with the increase of OCR and penalty rate, the net profit of the Approach2 Forced Version decreases more with respect to the initial case. Furthermore, the amount of transportation made is worse than the transportation made in the initial cases. For Approach2 forced version, the best improved case is the case 73 with the improvement rate of the 7.81 percent. On the other hand, the worst improved case is the case 9 with the improvement rate of -4,80 percent. The case parameters and the value of the costs and sales for these cases are given in Table 57, Table 58.

Table 57. The Information of the Best Case of the Approach2 Forced Version

Case 73			
Improvement Rate (%)	7,81	**Sales** ($)	426.307.500
P1PB1V	$30.000	**WIP inventory Cost** ($)	9.724.545
Profit Margin	0,15	**Stockouts Cost** ($)	944.457
OCR	0,15	**Transportation Cost** ($)	106.525
Penalty Rate	0,0003	**Installation Cost** ($)	300.000

Table 58. The Information of the Worst Case of the Approach2 Forced Version

Case 9			
Improvement Rate (%)	-4,80	**Sales** ($)	4.736.750
P1PB1V	$1.000	**WIP inventory Cost** ($)	540.252
Profit Margin	0,05	**Stockouts Cost** ($)	314.819
OCR	0,25	**Transportation Cost** ($)	106.525
Penalty Rate	0,003	**Installation Cost** ($)	300.000

Best improvement rate occurs in the case 73:

- The OCR and penalty values take their lowest values to maximize the improvement rate because the amount of WIP inventory and stockouts are much higher than the initial case.
- The profit margin takes the highest value because in the high sales values, the impact of the costs to the improvement rate will be lower.
- The P1PB1V gets its maximum value to minimize the effect of the initial investment cost.

The case parameters of the costs in the case 9 take the opposite values of the case parameters in the case 73 because of the improvement rate of case 9 is lowest.

The parameters of the cases in which the Approach2 Forced Version is worse than the Approach1 are given below in Table 59.

Table 59. The Parameters of the Cases in Which the Approach2 Forced Version is Worse than the Approach1

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 1 (%)	Imp. 2 Forced (%)
1	1000	0,05	0,15	0,0003	6,28	-0,61
2	1000	0,05	0,15	0,001	6,27	-1,44
3	1000	0,05	0,15	0,003	6,24	-3,91
4	1000	0,05	0,2	0,0003	6,40	-0,95
5	1000	0,05	0,2	0,001	6,39	-1,80
6	1000	0,05	0,2	0,003	6,35	-4,35
7	1000	0,05	0,25	0,0003	6,51	-1,30
8	1000	0,05	0,25	0,001	6,50	-2,18
9	1000	0,05	0,25	0,003	6,48	-4,80
10	1000	0,1	0,15	0,0003	6,04	3,94
11	1000	0,1	0,15	0,001	6,03	3,57
12	1000	0,1	0,15	0,003	6,02	2,49
13	1000	0,1	0,2	0,0003	6,09	3,84
14	1000	0,1	0,2	0,001	6,09	3,46
15	1000	0,1	0,2	0,003	6,07	2,36
16	1000	0,1	0,25	0,0003	6,14	3,73
17	1000	0,1	0,25	0,001	6,14	3,35
18	1000	0,1	0,25	0,003	6,12	2,24
19	1000	0,15	0,15	0,0003	5,97	5,37
20	1000	0,15	0,15	0,001	5,96	5,13
21	1000	0,15	0,15	0,003	5,95	4,44
22	1000	0,15	0,2	0,0003	6,00	5,31
23	1000	0,15	0,2	0,001	5,99	5,07
24	1000	0,15	0,2	0,003	5,98	4,37
25	1000	0,15	0,25	0,0003	6,03	5,25
26	1000	0,15	0,25	0,001	6,03	5,01
27	1000	0,15	0,25	0,003	6,01	4,31
29	10000	0,05	0,15	0,001	6,11	5,91
30	10000	0,05	0,15	0,003	6,07	3,70
32	10000	0,05	0,2	0,001	6,22	5,74
33	10000	0,05	0,2	0,003	6,18	3,47
34	10000	0,05	0,25	0,0003	6,34	6,34
35	10000	0,05	0,25	0,001	6,33	5,55
36	10000	0,05	0,25	0,003	6,30	3,22
42	10000	0,1	0,2	0,003	5,99	5,95
45	10000	0,1	0,25	0,003	6,04	5,86
57	30000	0,05	0,15	0,003	2,99	1,24
60	30000	0,05	0,2	0,003	6,17	4,04
62	30000	0,05	0,25	0,001	6,32	6,12
63	30000	0,05	0,25	0,003	6,28	3,80

For the all cases of which P1PB1V value is equal to $1.000, the improvement rate of the Approach2 Forced Version is worse than the one of the Approach1 because of initial investment. For the value of $10.000 and $30.000, when the profit margin is lower and OCR and penalty rates are higher, the Approach2 Forced Version is worse. One of this reason is the initial investment cost as said before and the other reason is that the WIP inventory and stockouts of the Approach2 Forced Version is higher than the Approach1. The comparison of the Approach2 Forced Version with the Approach1 is given in Figure 47 below.

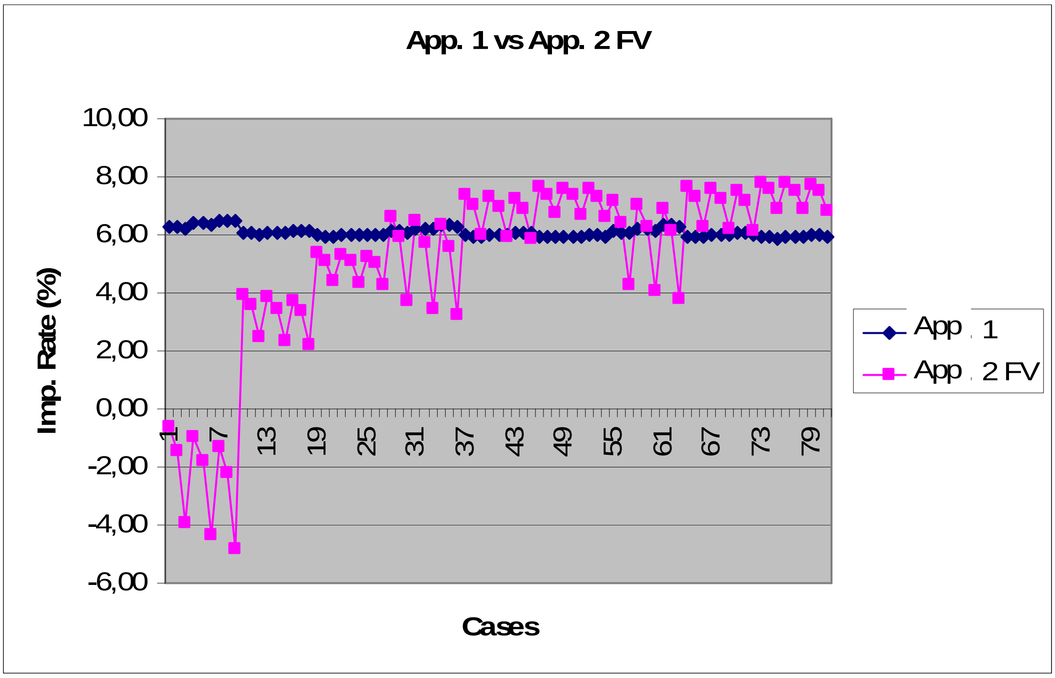

Figure 47. The Comparison of the Approach2 Forced Version with the Approach1

On the other hand, the parameters of the cases in which the Approach2 Forced Version is better than the Approach2 are given below in Table 60.

Table 60. The Parameters of the Cases in Which the Approach2 Forced Version is Better than the Approach2

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 2 (%)	Imp. 2 Forced (%)
10	1000	0,1	0,15	0,0003	3,31	3,94
11	1000	0,1	0,15	0,001	3,45	3,57
13	1000	0,1	0,2	0,0003	3,36	3,84
16	1000	0,1	0,25	0,0003	3,41	3,73
19	1000	0,15	0,15	0,0003	4,51	5,37
20	1000	0,15	0,15	0,001	4,61	5,13
22	1000	0,15	0,2	0,0003	4,55	5,31
23	1000	0,15	0,2	0,001	4,65	5,07
25	1000	0,15	0,25	0,0003	4,60	5,25
26	1000	0,15	0,25	0,001	4,69	5,01
37	10000	0,1	0,15	0,0003	6,76	7,40
38	10000	0,1	0,15	0,001	6,91	7,05
40	10000	0,1	0,2	0,0003	6,85	7,34
43	10000	0,1	0,25	0,0003	6,94	7,27
46	10000	0,15	0,15	0,0003	6,77	7,64
47	10000	0,15	0,15	0,001	6,87	7,41
49	10000	0,15	0,2	0,0003	6,83	7,60
50	10000	0,15	0,2	0,001	6,93	7,37
52	10000	0,15	0,25	0,0003	6,89	7,56
53	10000	0,15	0,25	0,001	6,99	7,33
64	30000	0,1	0,15	0,0003	7,01	7,66
65	30000	0,1	0,15	0,001	7,16	7,31
67	30000	0,1	0,2	0,0003	7,10	7,60
70	30000	0,1	0,25	0,0003	7,19	7,53
73	30000	0,15	0,15	0,0003	6,94	7,81
74	30000	0,15	0,15	0,001	7,04	7,58
76	30000	0,15	0,2	0,0003	7,00	7,77
77	30000	0,15	0,2	0,001	7,10	7,54
79	30000	0,15	0,25	0,0003	7,06	7,73
80	30000	0,15	0,25	0,001	7,16	7,50

For all P1PB1V, the better cases occur in the higher profit margins because the stockouts of the Approach2 Forced Version are much higher than the stockouts of the Approach2. To compensate this difference, the profit margin will be high to get high revenue because the total production of the Approach2 Forced Version is higher than the production of the Approach2. The comparison of the Approach2 Forced Version with the Approach2 is given in Figure 48 below.

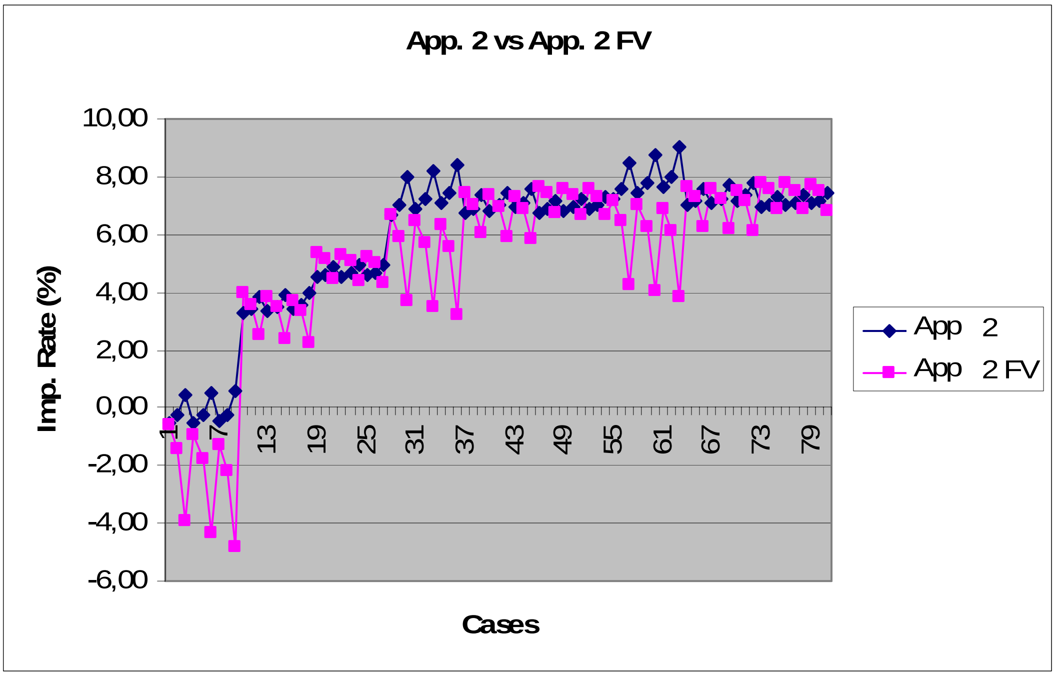

Figure 48. The Comparison of the Approach2 Forced Version with the Approach2

Finally the parameters of the cases in which the Approach2 Forced Version is better than the Approach3 is given below in Table 61.

Table 61. The Parameters of the Cases in Which the Approach2 Forced Version is Better than the Approach3

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 2 Forced (%)	Imp. 3 (%)
19	1000	0,15	0,15	0,0003	5,37	5,01
22	1000	0,15	0,2	0,0003	5,31	5,19
46	10000	0,15	0,15	0,0003	7,64	7,21
49	10000	0,15	0,2	0,0003	7,60	7,40
73	30000	0,15	0,15	0,0003	7,81	7,37
76	30000	0,15	0,2	0,0003	7,77	7,57

Only in the cases which have high profit margin, low OCR and penalty rate the Approach2 Forced Version is better than the Approach3, because the WIP inventory and stockouts of the Approach2 Forced Version are higher than the Approach3, on the other hand, the total production in Approach2 Forced Version is higher than the Approach3. The comparison of the Approach2 Forced Version with the Approach3 is given in Figure 49 below.

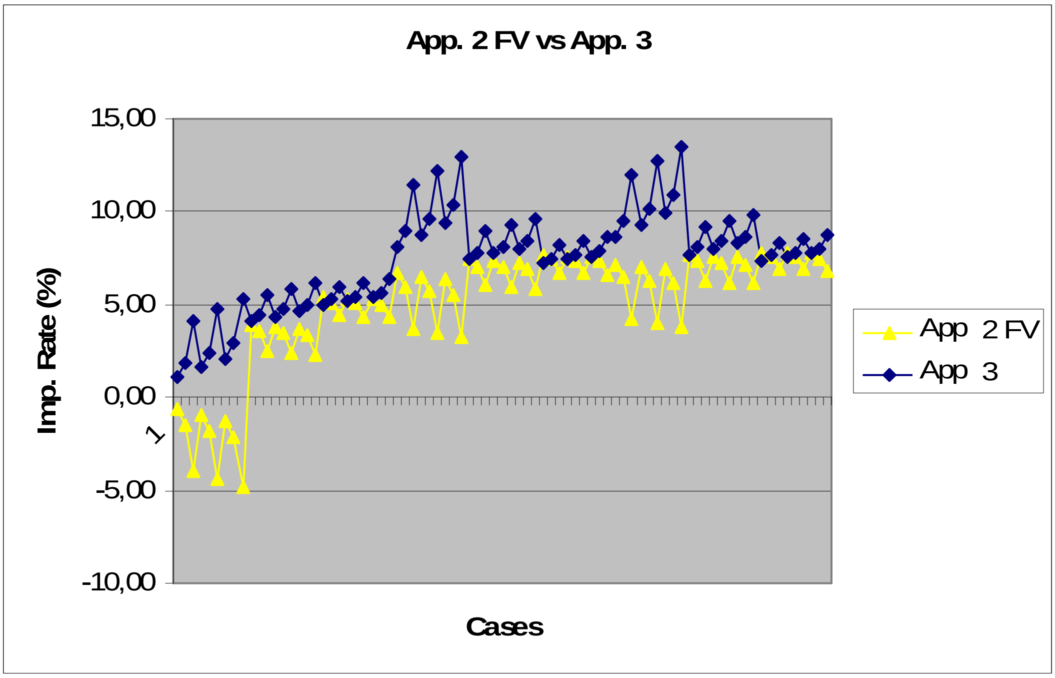

Figure 49. The Comparison of the Approach2 Forced Version with the Approach3

To summarize, it can be said that because the amount of the stockouts, WIP inventory and the amount of production made in the forced version two are higher than the initial case, the best improvement rate occurs in the case which has lower penalty rate, OCR and lower P1PB1V.

5.5. Examination of Approach3 Forced Versions

In this part the forced versions of the Approach3 are compared with the other approaches.

5.5.1. Approach3 Forced Versions 1

The improvement rates of the Approach3 Forced Version 1 fluctuate according to the cases because the patterns of the WIP inventory, stockouts, production and transportation are not similar with the initial situation. The improvement rates of Approach3 Forced Version 1 according to the cases are given in Figure 50.

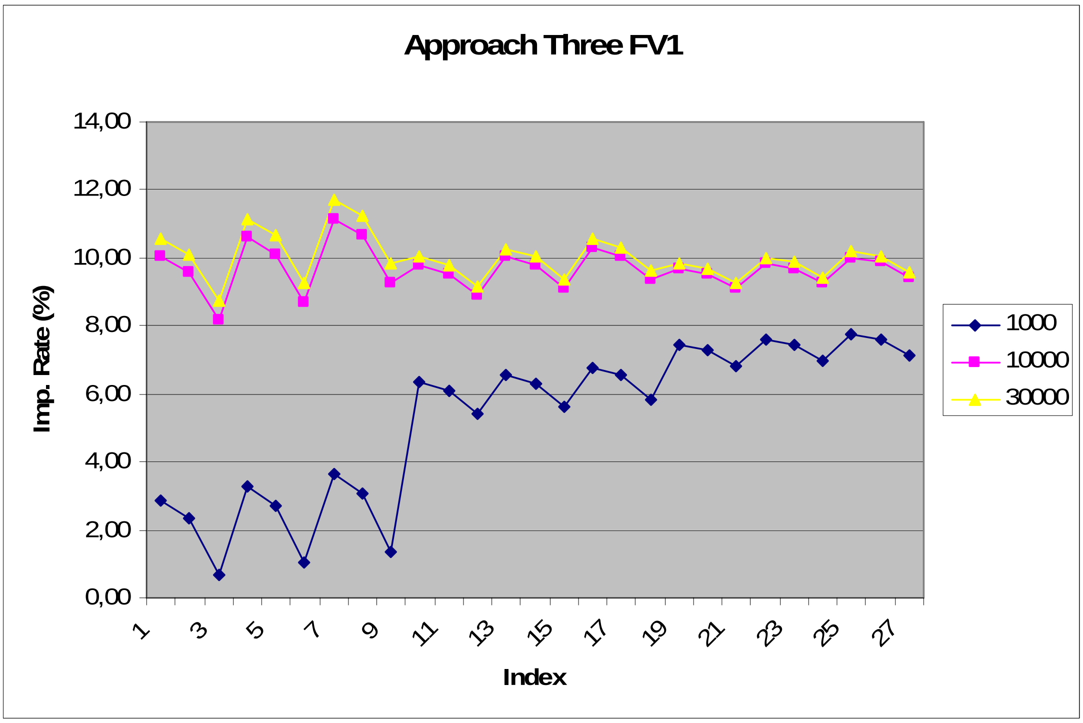

Figure 50. The Improvement Rates According to the Cases in Approach3 Forced Version 1

After the examination of the improvement rates' inclination, it can be said that with the decrease of the penalty rate the improvement rates get better. The reason behind this is that stockouts of Approach3 Forced Version 1 are worse than the ones of the initial case and with the decrease of penalty rate, the net profit of the Approach3 Forced Version 1 increases more with respect to the initial case. On the other hand, with the increase of the OCR the improvement rate of the Approach3 Forced Version 1 gets better, because the amount of WIP inventory in this approach is lower than the one in the initial case. Furthermore, the amount of transportation made is worse than the transportation made in the initial cases. In high P1PB1V, the improvement rates are better, because the effects of the transportation cost and initial investment are minimum in high sales values. For Approach3 Forced Version 1, the best improved case is the case 61 with the improvement rate of the 11,70 percent and on the other hand the worst improved case is the case 3 with the improvement rate of 0,69 percent. The case parameters and the value of the costs and sales for these cases are given in Table 62 and Table 63

Table 62. The Information of the Best Case of the Approach3 Forced Version 1

Case 61			
Improvement Rate (%)	11,70	**Sales** ($)	143.948.250
P1PB1V	$30.000	**WIP inventory Cost** ($)	12.569.475
Profit Margin	0,05	**Stockouts Cost** ($)	821.358
OCR	0,25	**Transportation Cost** ($)	105.045
Penalty Rate	0,0003	**Installation Cost ($)**	300.000

Table 63. The Information of the Worst Case of the Approach3 Forced Version 1

Case 3			
Improvement Rate (%)	0,69	**Sales** ($)	4.798.275
P1PB1V	$1.000	**WIP inventory Cost** ($)	273.786
Profit Margin	0,05	**Stockouts Cost** ($)	91.262
OCR	0,15	**Transportation Cost** ($)	105.045
Penalty Rate	0,003	**Installation Cost** ($)	300.000

Best improvement case occurs in case 61:

- Penalty rate takes their lowest value to maximize the improvement rate because the stockouts are much higher than the initial case.
- OCR value takes the highest value, because amount of the WIP inventory in Approach3 Forced Version 1 are lower than the one of the initial case.
- The profit margin takes its minimum value because of maximizing the impact of the improvement in the WIP inventory to the improvement rate. In the low sales, the impact of the improvements over the improvement rates is more visible so in the best case the profit margin gets its lowest value.
- P1PB1V gets its maximum value for minimizing the effect of the transportation cost.

The case parameters of the costs in the case 3 take the opposite values except the value of profit margin of the case parameters in the case 61:

- In case 3, the profit margin gets also its lowest value to increase effect of transportation and initial investment in the worst case, because in worst case the impact of the transportation and investment costs are more visible when the sales are lower.

The parameters of the cases in which the Approach3 Forced Version 1 is worse than the Approach3 are given below in Table 64.

Table 64. The Parameters of the Cases in Which the Approach3 Forced Version 1 is Worse than the Approach3

Case	**P1PB1V** ($)	**Profit Margin**	**OCR**	**Penalty Rate**	**Imp. 3** (%)	**Imp. 3 Forced V.1** (%)
3	1000	0,05	0,15	0,003	4,17	0,69
6	1000	0,05	0,2	0,003	4,75	1,02
9	1000	0,05	0,25	0,003	5,35	1,37
12	1000	0,1	0,15	0,003	5,56	5,39
15	1000	0,1	0,2	0,003	5,84	5,59
18	1000	0,1	0,25	0,003	6,13	5,81
30	10000	0,05	0,15	0,003	11,40	8,19
33	10000	0,05	0,2	0,003	12,15	8,70
36	10000	0,05	0,25	0,003	12,94	9,24
39	10000	0,1	0,15	0,003	8,96	8,89
42	10000	0,1	0,2	0,003	9,28	9,13
45	10000	0,1	0,25	0,003	9,61	9,38
57	30000	0,05	0,15	0,003	11,93	8,73
60	30000	0,05	0,2	0,003	12,69	9,26
63	30000	0,05	0,25	0,003	13,49	9,81
66	30000	0,1	0,15	0,003	9,21	9,14
69	30000	0,1	0,2	0,003	9,53	9,39
72	30000	0,1	0,25	0,003	9,86	9,65

For all value of P1PB1V and OCR, the worse cases of the Approach3 Forced Version 1 occur when the value of profit margin is 0.05 or 0.1 and the penalty rate is 0.003. The reason is that the difference between the WIP inventory is not very high for these two approaches however the difference between stocks out is very high. The change of the OCR does not affect the improvement rates so much but the change of the penalty rate affects the improvement rate. The comparison of the Approach3 Forced Version 1 with the Approach3 is given in Figure 51 below.

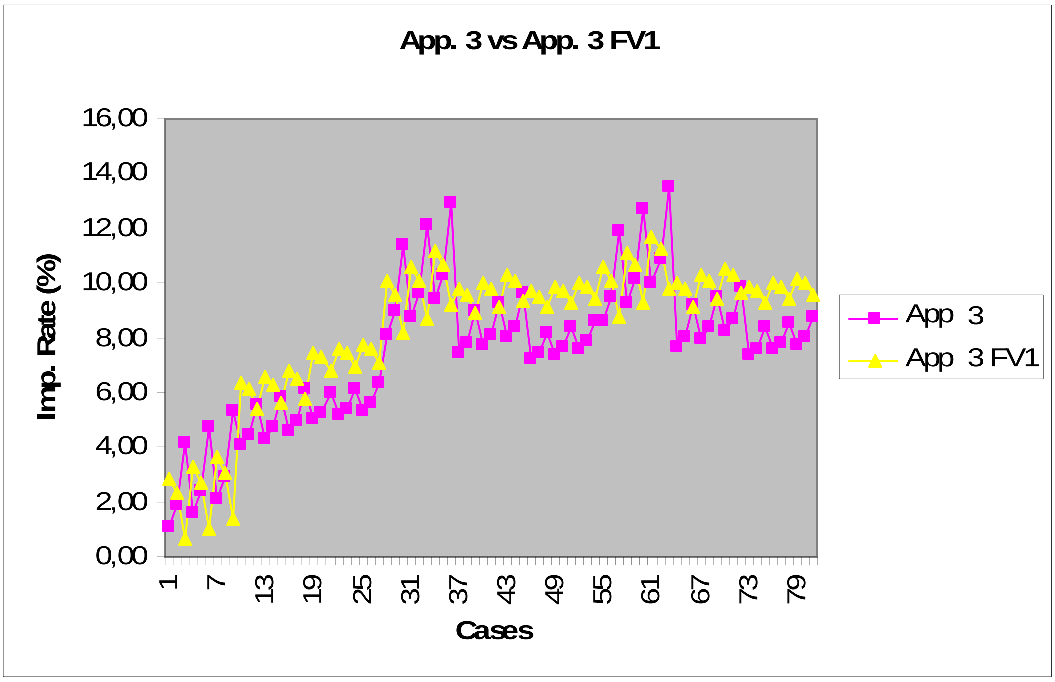

Figure 51. The Comparison of the Approach3 Forced Version 1 with the Approach3

For all cases of which P1PB1V is higher than $1.000, the Approach3 Forced Version 1 is better than the Approach1. However for the cases which have lowest P1PB1V and higher OCR and penalty values, the Approach1 is better than the Approach3 Forced Version 1 because of the initial investment. The comparison of the Approach3 Forced Version 1 with the Approach1 is given in Figure 52 below.

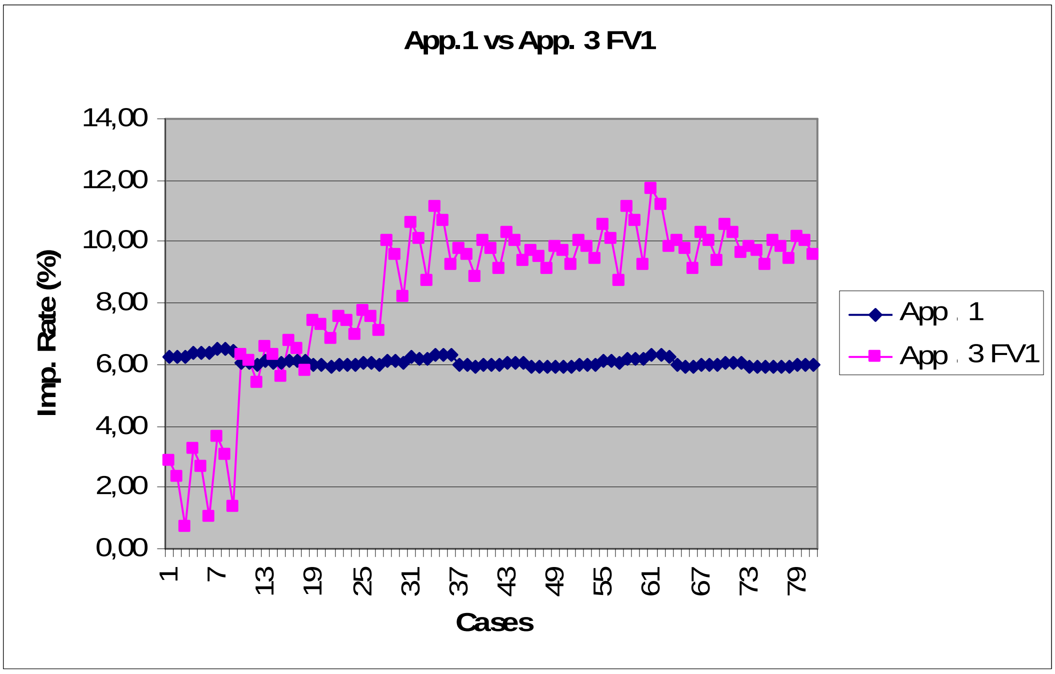

Figure 52. The Comparison of the Approach3 Forced Version 1 with the Approach1

For all cases, the Approach3 Forced Version 1 is better than the Approach2 and the Approach2 Forced Version. The reason behind this situation is that WIP inventory and amount of production in Approach3 Forced Version 1 are much better than the Approach2 and Approach2 Forced Version, although the stockouts of the Approach3 Forced Version 1 is worse than these approaches. The comparison of the Approach3 Forced Version 1 with the Approach2 and Approach2 Forced Version is given in graphs Figure 53 and Figure 54 respectively below.

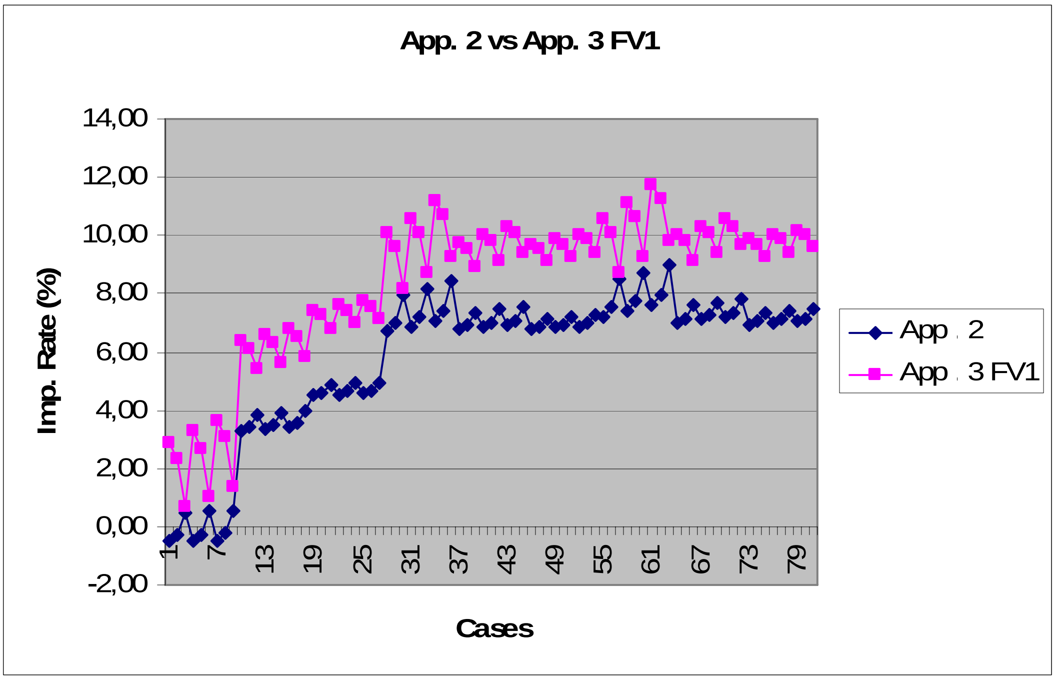

Figure 53. The Comparison of the Approach3 Forced Version 1 with the Approach2

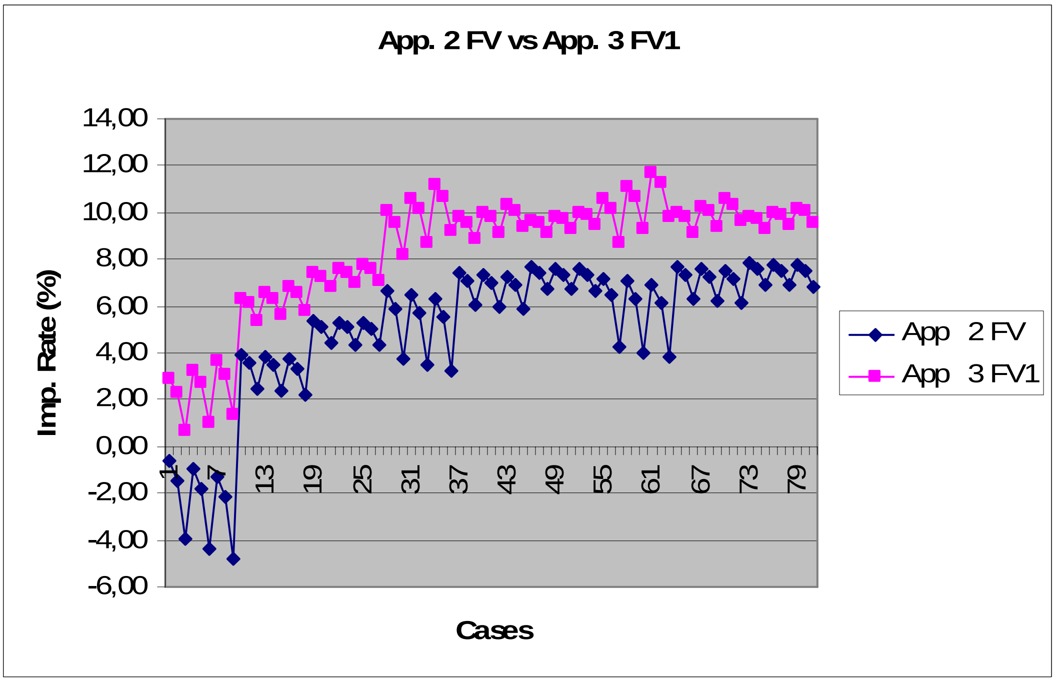

Figure 54. The Comparison of the Approach3 Forced Version 1 with Approach2 Forced Version

To summarize, it can be said that the best improvement rate occurs in the case which has lower penalty rate and profit margin and higher P1PB1V value and OCR for this approach, because the amount of the stockouts, amount of transportation and the amount of production made in the Approach3 Forced Version 1 is higher than the initial case and the Approach3 Forced Version 1 has initial investment.

5.5.2. Approach3 Forced Versions 2

The improvement rates of the Approach3 Forced Version 2 fluctuate according to the cases, because the patterns of the WIP inventory, stockouts, production and transportation are not similar with the initial situation. The changes in the improvement rates of Approach3 Forced Version 2 according to the cases are given in Figure 55.

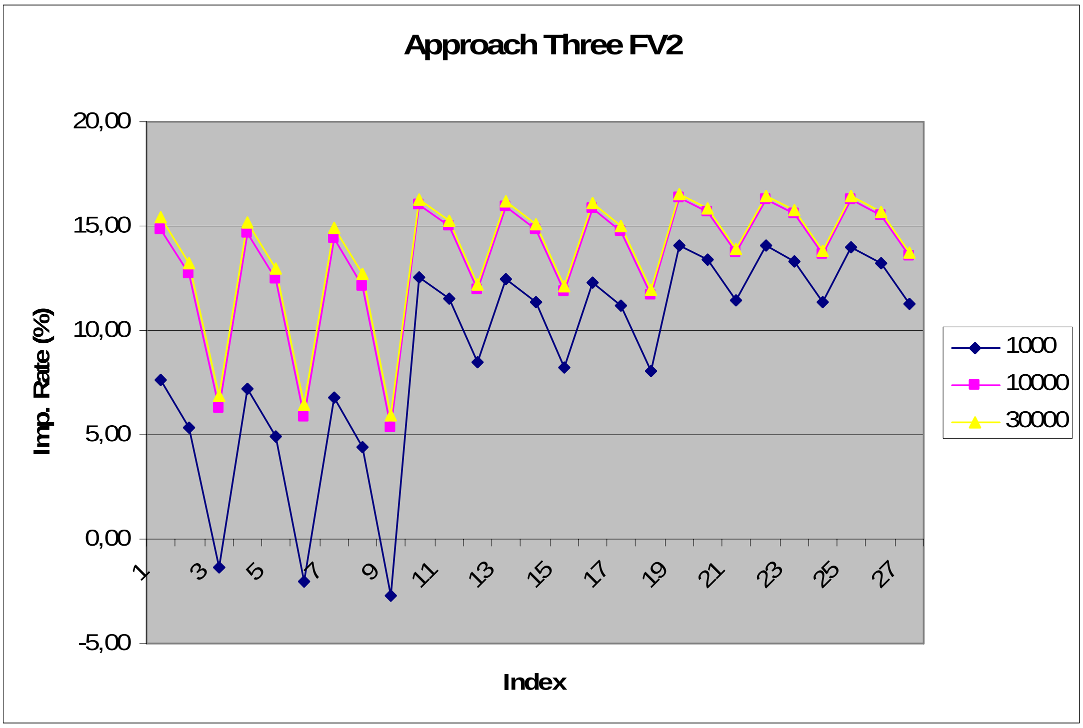

Figure 55. The Changes of the Improvement Rates According to the Cases in Approach3 Forced Version 2

After the examination of the improvement rates' inclination, it can be said that with decrease of the penalty rate and OCR, the improvement rates get better. The reason behind this is that stockouts and WIP inventory of Approach3 Forced Version 2 are worse than ones of the initial case and with the decrease of penalty rate and OCR, the net profit of the Approach3 Forced Version 2 increases more with respect to the initial case. Furthermore, the amount of transportation made is worse than the transportation made in the initial cases. In high P1PB1V, the improvement rates are better, because the effects of the transportation and initial investment are minimum in high sales values. For Approach3 Forced Version 2, the best improved case is the case 73 with the improvement rate of the 16.52 percent and on the other hand the worst improved case is the case 9 with the improvement rate of -2,72 percent. The case parameters and the value of the costs and sales for these cases are given in Table 65 and Table 66.

Table 65. The Information of the Best Case of the Approach3 Forced Version 2

Case 73			
Improvement Rate (%)	16,52	**Sales** ($)	461.565.250
P1PB1V	$30.000	**WIP inventory Cost** ($)	10.676.205
Profit Margin	0,15	**Stockouts Cost** ($)	1.721.903
OCR	0,15	**Transportation cost** ($)	110.460
Penalty Rate	0,0003	**Installation Cost** ($)	300.000

Table 66. The Information of the Worst Case of the Approach3 Forced Version 2

Case 9			
Improvement Rate (%)	-2,72	**Sales** ($)	5.128.725
P1PB1V	$1.000	**WIP inventory Cost** ($)	593.123
Profit Margin	0,05	**Stockouts Cost** ($)	573.968
OCR	0,25	**Transportation Cost** ($)	110.460
Penalty Rate	0,003	**Installation Cost** ($)	300.000

Best improvement rate occurs in case 73:

- Penalty rates and OCR take their lowest values to maximize the improvement rate, the stockouts and WIP inventory are much higher than the initial case.
- The profit margin takes its maximum value because of minimizing effect of the increase in the production.
- P1PB1V gets its maximum value for minimizing the effect of the transportation cost and initial investment.

The case parameters of the costs in the case 9 take the opposite values of the case parameters in the case 73 because improvement rate of case 9 is lowest.

The parameters of the cases in which the Approach3 Forced Version 2 is worse than the Approach1 is given below in Table 67.

Table 67. The Parameters of the Cases in Which the Approach3 Forced Version 2 is Worse than the Approach1

Case	**P1PB1V** ($)	**Profit Margin**	**OCR**	**Penalty Rate**	**Imp. One** (%)	**Imp. 3 Forced V.2** (%)
2	1000	0,05	0,15	0,001	6,27	5,38
3	1000	0,05	0,15	0,003	6,24	-1,39
5	1000	0,05	0,2	0,001	6,39	4,91
6	1000	0,05	0,2	0,003	6,35	-2,04
8	1000	0,05	0,25	0,001	6,50	4,42
9	1000	0,05	0,25	0,003	6,48	-2,72
33	10000	0,05	0,2	0,003	6,18	5,83
36	10000	0,05	0,25	0,003	6,30	5,36
63	30000	0,05	0,25	0,003	6,28	5,95

For cases which have P1PB1V of $1.000, profit margin of 0.05 and penalty rate of 0.003 and 0.001, the improvement rate in the Approach3 Forced Version 2 is worse than the improvement rate of the Approach1 because of the initial investment. Moreover, in some of these cases, impact of the gain obtained from the increase of the production becomes lower than the loses caused from the increase in the amount of WIP inventory and the amount of stockout. Furthermore, when the P1PB1V is equal to $10.000, worse case occurs if the OCR value is 0.2 or 0.25, profit margin 0.05, and penalty rate 0.003. With these parameters, the effects of the WIP inventory and stockouts are maximum. If P1PB1V is equal to $30.000, the worst case occurs if and only if the value of profit margin is 0.05, the value of OCR is 0.25 and the penalty rate is equal to 0.003. The comparison of the Approach3 Forced Version 2 with the Approach1 is given in Figure 56 below.

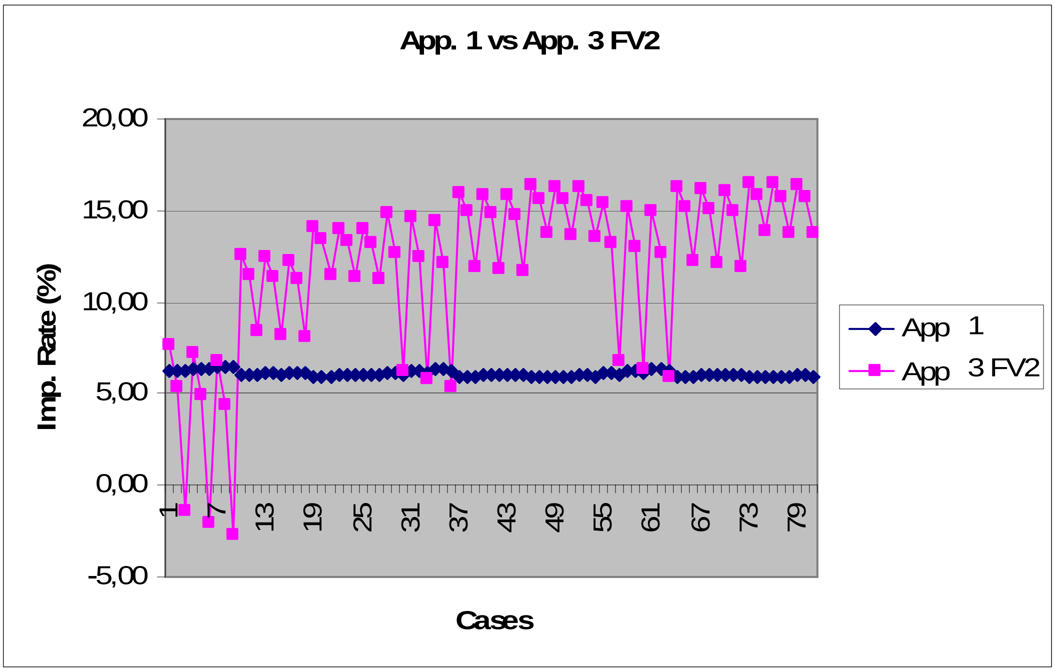

Figure 56. The Comparison of the Approach3 Forced Version 2 with the Approach1

The parameters of the cases in which the Approach3 Forced Version 2 is worse than the Approach2 is given below in Table 68.

Table 68. The Parameters of the Cases in Which the Approach3 Forced Version 2 is Worse than the Approach2

Case	**P1PB1V** ($)	**Profit Margin**	**OCR**	**Penalty Rate**	**Imp. 2** (%)	**Imp. 3 Forced V.2** (%)
3	1000	0,05	0,15	0,003	0,47	-1,39
6	1000	0,05	0,2	0,003	0,51	-2,04
9	1000	0,05	0,25	0,003	0,55	-2,72
30	10000	0,05	0,15	0,003	7,96	6,28
33	10000	0,05	0,2	0,003	8,19	5,83
36	10000	0,05	0,25	0,003	8,42	5,36
57	30000	0,05	0,15	0,003	8,51	6,83
60	30000	0,05	0,2	0,003	8,75	6,40
63	30000	0,05	0,25	0,003	9,00	5,95

For all P1PB1V and OCR, the worse cases of the Approach3 Forced Version 2 occur when the value of profit margin is 0.05 and the penalty rate is 0.003. The reason of this is that the effect of WIP inventory to the improvement rate is not very high for these two approaches with respect to effect of stockout. The change of the OCR does not affect the improvement rate so much but the change of the penalty rate affects the improvement rates. The comparison of the Approach3 Forced Version 2 with the Approach2 is given in Figure 57 below.

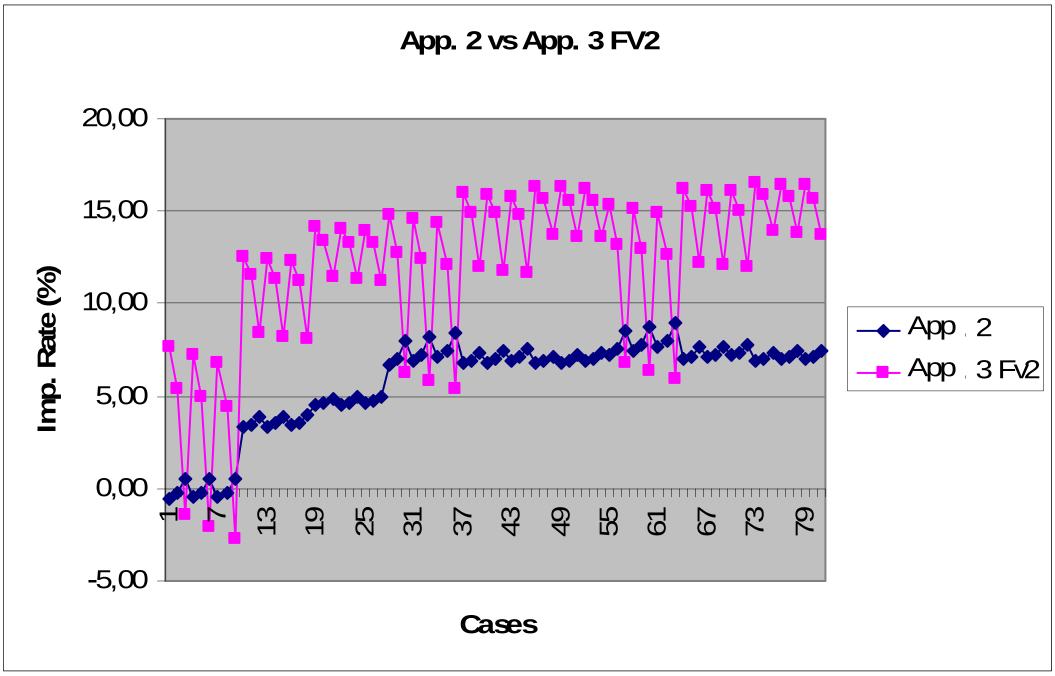

Figure 57. The Comparison of the Approach3 Forced Version 2 with the Approach2

For all cases, the improvement rates of the Approach3 Forced Version 2 is better than the ones of the Approach2 Forced Version. The comparison of the Approach3 Forced Version 2 with the Approach2 Forced Version is given in Figure 58 below.

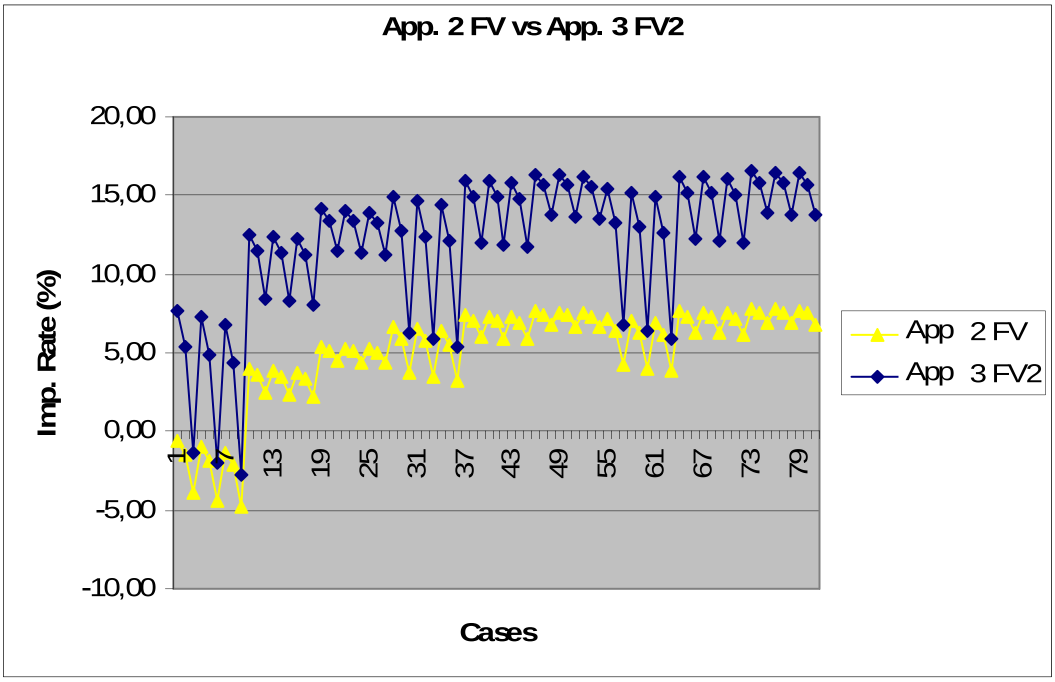

Figure 58. The Comparison of the Approach3 Forced Version 2 with the Approach2 Forced Version

The parameters of the cases in which the Approach3 Forced Version 2 are worse than the Approach3 is given below in Table 69.

Table 69. The Parameters of the Cases in which the Approach3 Forced Version 2 is Worse than the Approach3

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 3 (%)	Imp. 3 Forced V.2 (%)
3	1000	0,05	0,15	0,003	4,17	-1,39
6	1000	0,05	0,2	0,003	4,75	-2,04
9	1000	0,05	0,25	0,003	5,35	-2,72
30	10000	0,05	0,15	0,003	11,40	6,28
33	10000	0,05	0,2	0,003	12,15	5,83
36	10000	0,05	0,25	0,003	12,94	5,36
57	30000	0,05	0,15	0,003	11,93	6,83
60	30000	0,05	0,2	0,003	12,69	6,40
63	30000	0,05	0,25	0,003	13,49	5,95

For all P1PB1V and OCR, the worse cases of the Approach3 Forced Version 2 occur when the value of profit margin is 0.05 and the penalty rate is 0.003. The reason of this is that the effect of WIP to the improvement rate is not very high for these two approaches with respect to effect of stockout. The change of the OCR does not affect the improvement rate so much but the change of the penalty rate affects the improvement rate. The comparison of the Approach3 Forced Version 2 with the Approach3 is given in Figure 59 below.

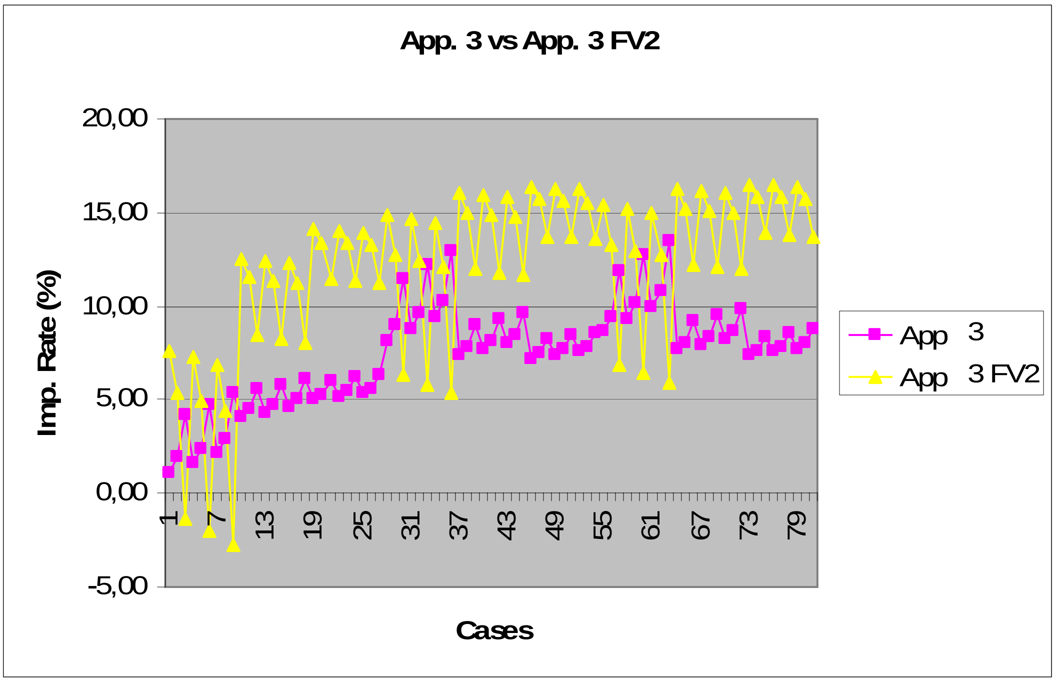

Figure 59. The Comparison of the Approach3 Forced Version 2 with the Approach3

The parameters of the cases in which the Approach3 Forced Version 2 is worse than the Approach3 Forced Version 1 is given below in Table 70.

Table 70. The Parameters of the Cases in Which the Approach3 Forced Version 2 is Worse than the Approach3 Forced Version 1

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 3 Forced V.1 (%)	Imp. 3 Forced V.2 (%)
3	1000	0,05	0,15	0,003	0,69	-1,39
6	1000	0,05	0,2	0,003	1,02	-2,04
9	1000	0,05	0,25	0,003	1,37	-2,72
30	10000	0,05	0,15	0,003	8,19	6,28
33	10000	0,05	0,2	0,003	8,70	5,83
36	10000	0,05	0,25	0,003	9,24	5,36
57	30000	0,05	0,15	0,003	8,73	6,83
60	30000	0,05	0,2	0,003	9,26	6,40
63	30000	0,05	0,25	0,003	9,81	5,95

For all P1PB1V and OCR, the worse cases of the Approach3 Forced Version 2 occur when the value of profit margin is 0.05 and the penalty rate is 0.003. The reason of this is that the effect of WIP inventory to the improvement rate is not very high for these two approaches with respect to effect of stockout. The change of the OCR does not affect the improvement rate so much but the change of the penalty rate affects the improvement rate so much. The comparison of the Approach3 Forced Version 2 with the Approach3 Forced Version 1 is given in Figure 60 below.

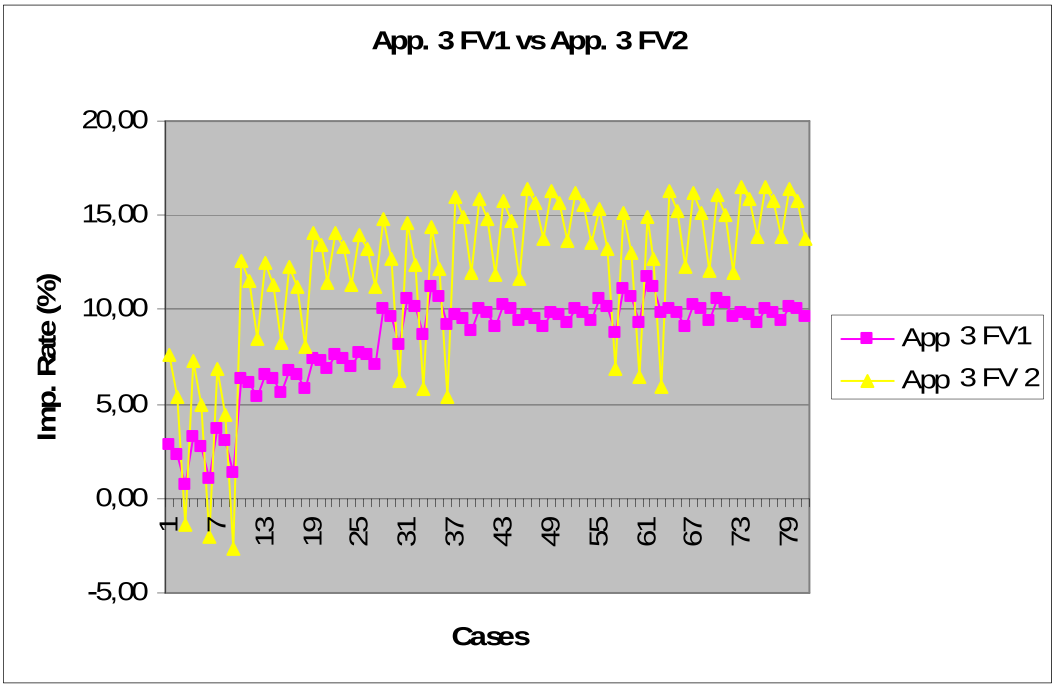

Figure 60. The Comparison of the Approach3 Forced Version 2 with the Approach3 Forced Version 1

To summarize, it can be said that because the amount of the stockouts, amount of transportation, amount of WIP inventory and the amount of production investment made in the Approach3 Forced Version 2 are higher than the initial case, the best improvement rate occurs in the case which has lower penalty rate, lower OCR and higher P1PB1V and profit margin value for this approach.

5.5.3. Approach3 Forced Versions 3

The improvement rates of the Approach3 Forced Version 3 fluctuate according to the cases, because the patterns of the WIP inventory, stockouts, production and transportation are not similar with ones in the initial situation. The changes of Approach3 Forced Version 3's improvement rates according to the cases are given in Figure 61.

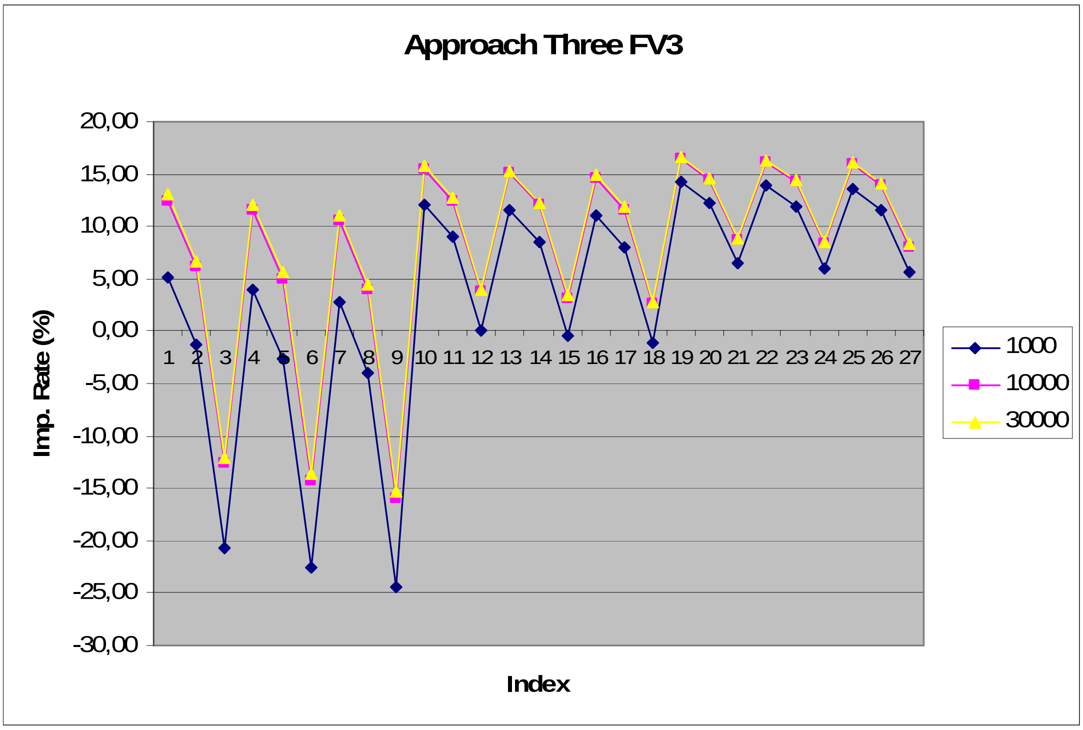

Figure 61. The Changes of the Improvement Rates According to the Cases in Approach3 Forced Version 3

After the examination of the improvement rates' inclination it can be said that with the decrease of the penalty rate and OCR, the improvement rates get better. The reason behind this is that stockouts and WIP inventory of Approach3 Forced Version 3 are worse than the ones of the initial case and with the decrease of penalty rate and OCR, the net profit of the Approach3 Forced Version 3 increases more with respect to the initial case. Furthermore, the amount of transportation made is worse than the transportation made in the initial cases. In high P1PB1V, the improvement rates are better, because the effects of the transportation and initial investment are minimum in high sales values. For Approach3 Forced Version 3, the best improved case is the case 73 with the improvement rate of the 16.61 percent and on the other hand the worst improved case is the case 9 with the improvement rate of -24,47 percent. The case parameters and the value of the costs and sales for these cases are given in Table 71 and Table 72.

Table 71. The Information of the Best Case of the Approach3 Forced Version 3

Case 73			
Improvement Rate (%)	16,61	**Sales** ($)	466.452.000
P1PB1V	$30.000	**WIP inventory Cost** ($)	13.069.260
Profit Margin	0,15	**Stockouts Cost** ($)	3.860.902
OCR	0,15	**Transportation Cost** ($)	112.525
Penalty Rate	0,0003	**Installation Cost** ($)	300.000

Table 72. The Information of the Worst Case of the Approach3 Forced Version 3

Case 9			
Improvement rate (%)	-24,47	**sales** ($)	5.182.800
P1PB1V	$1.000	**WIP inventory cost** ($)	776.070
Profit margin	0,05	**Stockouts cost** ($)	1.286.967
OCR	0,25	**Transportation cost** ($)	112.525
penalty rate	0,003	**Installation Cost** ($)	300.000

The best improvement rate occurs in case 73:

- Penalty rates and OCR take their lowest values to maximize the improvement rate because the stockouts and WIP inventory are much higher than the initial case.
- The profit margin takes its maximum value for minimizing the impact of the increase in the production.
- P1PB1V gets its maximum value for minimizing the effect of the transportation and initial investment cost.

The case parameters of the costs in the case 9 take the opposite values of the case parameters in the case 73, because the improvement rate of case 9 is lowest.

The parameters of the cases in which the Approach3 Forced Version 3 are worse than the Approach1 is given below in Table 73.

Table 73. The Parameters of the Cases in Which the Approach3 Forced Version 3 are Worse than the Approach1

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 1 (%)	Imp. 3 Forced V.3 (%)
1	1000	0,05	0,15	0,0003	6,28	5,17
2	1000	0,05	0,15	0,001	6,27	-1,33
3	1000	0,05	0,15	0,003	6,24	-20,67
4	1000	0,05	0,2	0,0003	6,40	4,03
5	1000	0,05	0,2	0,001	6,39	-2,65
6	1000	0,05	0,2	0,003	6,35	-22,52
7	1000	0,05	0,25	0,0003	6,51	2,82
8	1000	0,05	0,25	0,001	6,50	-4,03
9	1000	0,05	0,25	0,003	6,48	-24,47
12	1000	0,1	0,15	0,003	6,02	0,09
15	1000	0,1	0,2	0,003	6,07	-0,52
18	1000	0,1	0,25	0,003	6,12	-1,15
27	1000	0,15	0,25	0,003	6,01	5,71
30	10000	0,05	0,15	0,003	6,07	-12,61
32	10000	0,05	0,2	0,001	6,22	5,04
33	10000	0,05	0,2	0,003	6,18	-14,23
35	10000	0,05	0,25	0,001	6,33	3,88
36	10000	0,05	0,25	0,003	6,30	-15,93
39	10000	0,1	0,15	0,003	5,94	3,71
42	10000	0,1	0,2	0,003	5,99	3,15
45	10000	0,1	0,25	0,003	6,04	2,57
57	30000	0,05	0,15	0,003	6,06	-12,02
59	30000	0,05	0,2	0,001	6,20	5,60
60	30000	0,05	0,2	0,003	6,17	-13,62
62	30000	0,05	0,25	0,001	6,32	4,45
63	30000	0,05	0,25	0,003	6,28	-15,31
66	30000	0,1	0,15	0,003	5,93	3,98
69	30000	0,1	0,2	0,003	5,98	3,42
72	30000	0,1	0,25	0,003	6,03	2,85

For most of the cases which have profit margin of 0.05 or 0.1, and penalty rate of 0.003 and 0.001, the improvement rates in the Approach3 Forced Version 3 are worse then the improvement rate of the Approach1. The reason of this is that the impact of the gain obtained from the increase of the production becomes lower than the loses caused from the increase in the amount of WIP inventory and amount of stockout and there is a initial investment cost in the Approach3 Forced Version 3. The comparison of the Approach3 Forced Version 3 with the Approach1 is given in Figure 62 below.

Figure 62. The Comparison of the Approach3 Forced Version 3 with the Approach1

The parameters of the cases in which the Approach3 Forced Version 3 are worse than the Approach2 is given below in Table 74.

Table 74. The Parameters of the Cases in Which the Approach3 Forced Version 3 are Worse than the Approach2

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 2 (%)	Imp. 3 Forced V.3 (%)
2	1000	0,05	0,15	0,001	-0,27	-1,33
3	1000	0,05	0,15	0,003	0,47	-20,67
5	1000	0,05	0,2	0,001	-0,25	-2,65
6	1000	0,05	0,2	0,003	0,51	-22,52
8	1000	0,05	0,25	0,001	-0,23	-4,03
9	1000	0,05	0,25	0,003	0,55	-24,47
12	1000	0,1	0,15	0,003	3,85	0,09
15	1000	0,1	0,2	0,003	3,90	-0,52
18	1000	0,1	0,25	0,003	3,96	-1,15
29	10000	0,05	0,15	0,001	7,02	6,16
30	10000	0,05	0,15	0,003	7,96	-12,61
32	10000	0,05	0,2	0,001	7,22	5,04
33	10000	0,05	0,2	0,003	8,19	-14,23
35	10000	0,05	0,25	0,001	7,42	3,88
36	10000	0,05	0,25	0,003	8,42	-15,93
39	10000	0,1	0,15	0,003	7,35	3,71
42	10000	0,1	0,2	0,003	7,45	3,15
45	10000	0,1	0,25	0,003	7,55	2,57
56	30000	0,05	0,15	0,001	7,55	6,70
57	30000	0,05	0,15	0,003	8,51	-12,02
59	30000	0,05	0,2	0,001	7,76	5,60
60	30000	0,05	0,2	0,003	8,75	-13,62
62	30000	0,05	0,25	0,001	7,97	4,45
63	30000	0,05	0,25	0,003	9,00	-15,31
66	30000	0,1	0,15	0,003	7,61	3,98
69	30000	0,1	0,2	0,003	7,71	3,42
72	30000	0,1	0,25	0,003	7,81	2,85

For all value of P1PB1V and OCR, the worse cases of the Approach3 Forced Version 3 occur when the value of profit margin is 0.05 or 0.1 and the penalty rate is 0.003 or 0.001. The reason of this is that the effect of WIP inventory to the improvement rate is not very high for these two approaches with respect to effect of stockout. The change of the OCR does not affect the improvement rate so much but the change of the penalty rate affects the improvement rate. The comparison of the Approach3 Forced Version 3 with the Approach2 is given in Figure 63 below.

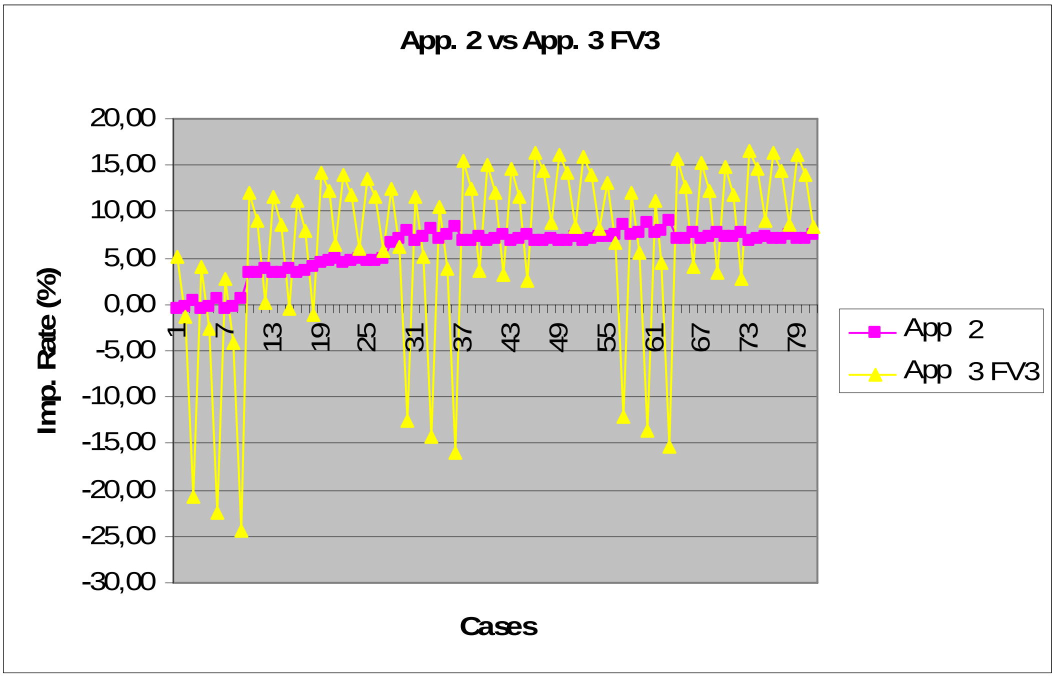

Figure 63. The Comparison of the Approach3 Forced Version 3 with the Approach2

The parameters of the cases in which the Approach3 Forced Version 3 are worse than the Approach2 Forced Version is given below in Table 75.

Table 75. The Parameters of the Cases in Which the Approach3 Forced Version 3 are Worse than the Approach2 Forced Version

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 2 Forced V (%)	Imp. 3 Forced V.3 (%)
3	1000	0,05	0,15	0,003	-3,91	-20,67
5	1000	0,05	0,2	0,001	-1,80	-2,65
6	1000	0,05	0,2	0,003	-4,35	-22,52
8	1000	0,05	0,25	0,001	-2,18	-4,03
9	1000	0,05	0,25	0,003	-4,80	-24,47
12	1000	0,1	0,15	0,003	2,49	0,09
15	1000	0,1	0,2	0,003	2,36	-0,52
18	1000	0,1	0,25	0,003	2,24	-1,15
30	10000	0,05	0,15	0,003	3,70	-12,61
32	10000	0,05	0,2	0,001	5,74	5,04
33	10000	0,05	0,2	0,003	3,47	-14,23
35	10000	0,05	0,25	0,001	5,55	3,88
36	10000	0,05	0,25	0,003	3,22	-15,93
39	10000	0,1	0,15	0,003	6,03	3,71
42	10000	0,1	0,2	0,003	5,95	3,15
45	10000	0,1	0,25	0,003	5,86	2,57
57	30000	0,05	0,15	0,003	4,26	-12,02
59	30000	0,05	0,2	0,001	6,28	5,60
60	30000	0,05	0,2	0,003	4,04	-13,62
62	30000	0,05	0,25	0,001	6,12	4,45
63	30000	0,05	0,25	0,003	3,80	-15,31
66	30000	0,1	0,15	0,003	6,29	3,98
69	30000	0,1	0,2	0,003	6,21	3,42
72	30000	0,1	0,25	0,003	6,13	2,85

For all P1PB1V and OCR, the worse cases of the Approach3 Forced Version 3 occur when the value of profit margin is 0.05 or 0.1 and the penalty rate is 0.003 or 0.001. The reason is that the effect of WIP inventory to the improvement rate is not very high for these two approaches with respect to effect of stockout. The change of the OCR does not affect the improvement rate so much but the change of the penalty rate affects the improvement rate. The comparison of the Approach3 Forced Version 3 with the Approach2 Forced Version is given in Figure 64 below.

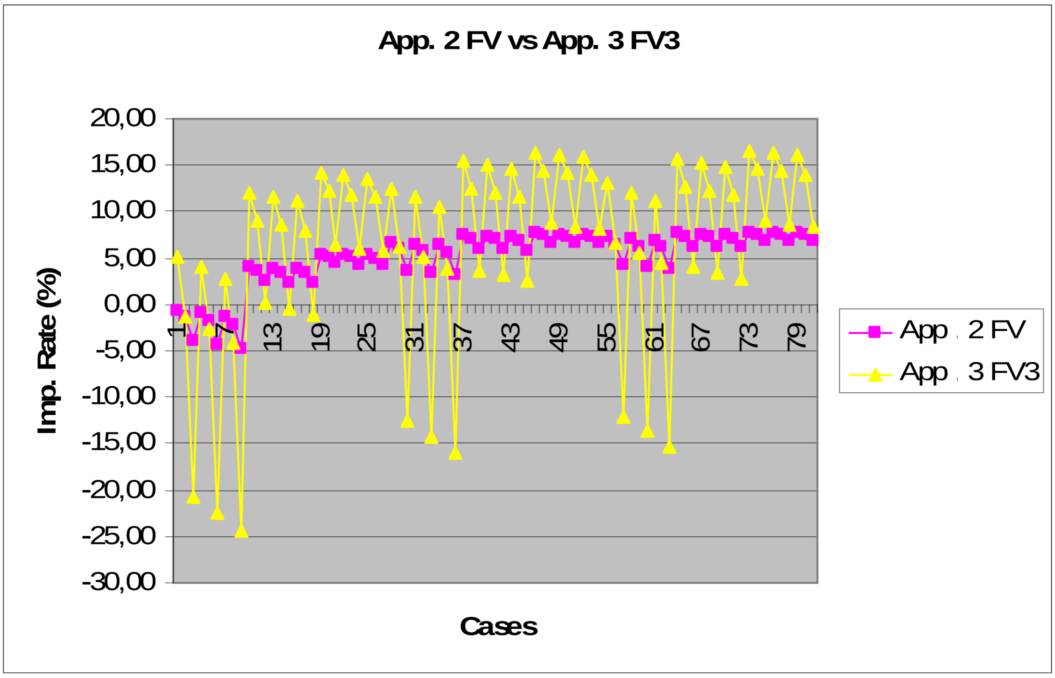

Figure 64. The Comparison of the Approach3 Forced Version 3 with the Approach2 Forced Version

The parameters of the cases in which the Approach3 Forced Version 3 are worse than the Approach3 is given below in Table 76.

Table 76. The Parameters of the Cases in Which the Approach3 Forced Version 3 are Worse than the Approach3

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 3 (%)	Imp. 3 Forced V.3 (%)
2	1000	0,05	0,15	0,001	1,89	-1,33
3	1000	0,05	0,15	0,003	4,17	-20,67
5	1000	0,05	0,2	0,001	2,39	-2,65
6	1000	0,05	0,2	0,003	4,75	-22,52
8	1000	0,05	0,25	0,001	2,92	-4,03
9	1000	0,05	0,25	0,003	5,35	-24,47
12	1000	0,1	0,15	0,003	5,56	0,09
15	1000	0,1	0,2	0,003	5,84	-0,52
18	1000	0,1	0,25	0,003	6,13	-1,15
24	1000	0,15	0,2	0,003	6,17	6,06
27	1000	0,15	0,25	0,003	6,36	5,71
29	10000	0,05	0,15	0,001	8,96	6,16
30	10000	0,05	0,15	0,003	11,40	-12,61
32	10000	0,05	0,2	0,001	9,62	5,04
33	10000	0,05	0,2	0,003	12,15	-14,23
35	10000	0,05	0,25	0,001	10,32	3,88
36	10000	0,05	0,25	0,003	12,94	-15,93
39	10000	0,1	0,15	0,003	8,96	3,71
42	10000	0,1	0,2	0,003	9,28	3,15
45	10000	0,1	0,25	0,003	9,61	2,57
54	10000	0,15	0,25	0,003	8,62	8,09
56	30000	0,05	0,15	0,001	9,47	6,70
57	30000	0,05	0,15	0,003	11,93	-12,02
59	30000	0,05	0,2	0,001	10,15	5,60
60	30000	0,05	0,2	0,003	12,69	-13,62
62	30000	0,05	0,25	0,001	10,86	4,45
63	30000	0,05	0,25	0,003	13,49	-15,31
66	30000	0,1	0,15	0,003	9,21	3,98
69	30000	0,1	0,2	0,003	9,53	3,42
72	30000	0,1	0,25	0,003	9,86	2,85
81	30000	0,15	0,25	0,003	8,78	8,26

Generally in the cases which have penalty rate of 0.003 and 0.001, the improvement rate of the Approach3 Forced Version 3 is worse than the one of the Approach3 Forced Version 2. In high penalty rates, the loses caused from the stockouts compensate the gain gotten from the increase of the production. The comparison of the Approach3 Forced Version 3 with the Approach3 is given in Figure 65 below.

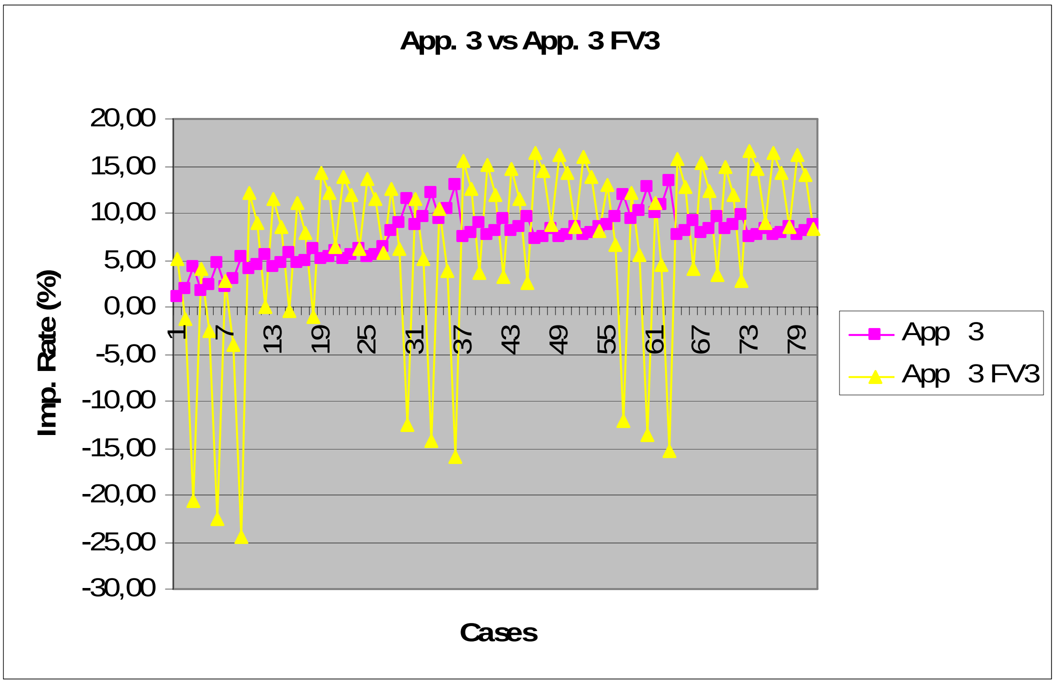

Figure 65. The Comparison of the Approach3 Forced Version 3 with the Approach3

The parameters of the cases in which the Approach3 Forced Version 3 are worse than the Approach3 Forced Version 1 is given below in Table 77.

Table 77. The Parameters of the Cases in which the Approach3 Forced Version 3 are Worse than the Approach3 Forced Version 1

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 3 Forced V.1 (%)	Imp. 3 Forced V.3 (%)
2	1000	0,05	0,15	0,001	2,33	-1,33
3	1000	0,05	0,15	0,003	0,69	-20,67
5	1000	0,05	0,2	0,001	2,69	-2,65
6	1000	0,05	0,2	0,003	1,02	-22,52
7	1000	0,05	0,25	0,0003	3,65	2,82
8	1000	0,05	0,25	0,001	3,07	-4,03
9	1000	0,05	0,25	0,003	1,37	-24,47
12	1000	0,1	0,15	0,003	5,39	0,09
15	1000	0,1	0,2	0,003	5,59	-0,52
18	1000	0,1	0,25	0,003	5,81	-1,15
21	1000	0,15	0,15	0,003	6,82	6,41
24	1000	0,15	0,2	0,003	6,97	6,06
27	1000	0,15	0,25	0,003	7,11	5,71
29	10000	0,05	0,15	0,001	9,59	6,16
30	10000	0,05	0,15	0,003	8,19	-12,61
32	10000	0,05	0,2	0,001	10,12	5,04
33	10000	0,05	0,2	0,003	8,70	-14,23
34	10000	0,05	0,25	0,0003	11,16	10,52
35	10000	0,05	0,25	0,001	10,68	3,88
36	10000	0,05	0,25	0,003	9,24	-15,93
39	10000	0,1	0,15	0,003	8,89	3,71
42	10000	0,1	0,2	0,003	9,13	3,15
45	10000	0,1	0,25	0,003	9,38	2,57
48	10000	0,15	0,15	0,003	9,10	8,75
51	10000	0,15	0,2	0,003	9,26	8,42
54	10000	0,15	0,25	0,003	9,43	8,09
56	30000	0,05	0,15	0,001	10,11	6,70
57	30000	0,05	0,15	0,003	8,73	-12,02
59	30000	0,05	0,2	0,001	10,66	5,60
60	30000	0,05	0,2	0,003	9,26	-13,62
61	30000	0,05	0,25	0,0003	11,70	11,08
62	30000	0,05	0,25	0,001	11,23	4,45
63	30000	0,05	0,25	0,003	9,81	-15,31
66	30000	0,1	0,15	0,003	9,14	3,98
69	30000	0,1	0,2	0,003	9,39	3,42
72	30000	0,1	0,25	0,003	9,65	2,85
75	30000	0,15	0,15	0,003	9,27	8,92
78	30000	0,15	0,2	0,003	9,43	8,59
81	30000	0,15	0,25	0,003	9,60	8,26

In high OCR and penalty rates, the improvement rates of the Approach3 Forced Version 3 are worse than the one of the approach there forced version 1. The comparison of the Approach3 Forced Version 3 with the Approach3 Forced Version 1 is given in Figure 66 below.

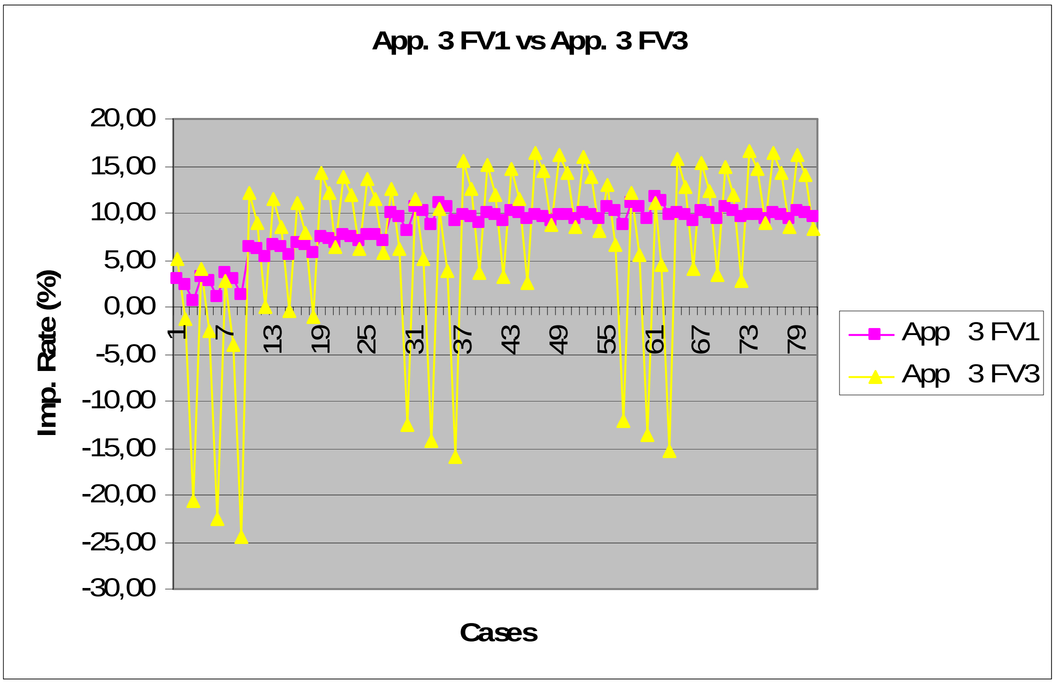

Figure 66. The Comparison of the Approach3 Forced Version 3 with the Approach3 Forced Version 1

The parameters of the cases in which the Approach3 Forced Version 3 are better than the Approach3 Forced Version 2 is given below in Table 78.

Table 78. The Parameters of the Cases in Which the Approach3 Forced Version 3 are Better than the Approach3 Forced Version 2

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Imp. 3 Forced V.2 (%)	Imp. 3 Forced V.3 (%)
19	1000	0,15	0,15	0,0003	14,10	14,17
46	10000	0,15	0,15	0,0003	16,35	16,44
73	30000	0,15	0,15	0,0003	16,52	16,61

The cases in which the Approach3 Forced Version 3 are better than the Approach3 Forced Version 2 are only 19, 46 and 73. In these cases, profit margin has highest values, however OCR and penalty rates have their lowest values. With these values the net gain of Approach3 Forced Version 3 is better than the net gain of the Approach3 Forced Version 2. The comparison of the Approach3 Forced Version 3 with the Approach3 Forced Version 2 is given in Figure 67 below.

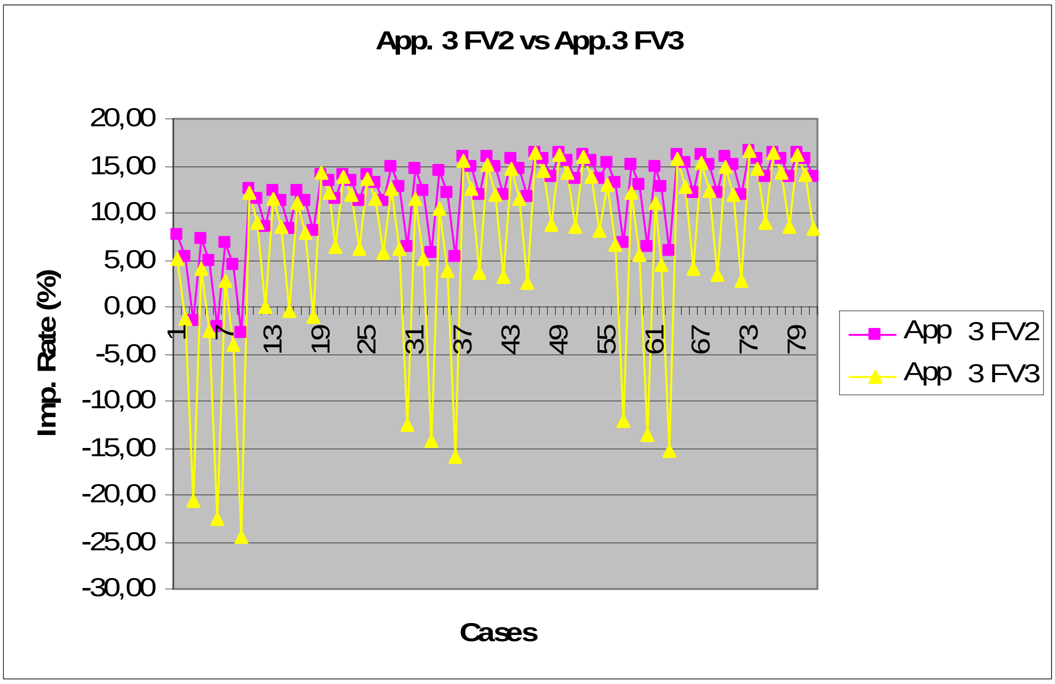

Figure 67. The Comparison of the Approach3 Forced Version 3 with the Approach3 Forced Version 2

To summarize the improvement rates characteristic of Approach3 Forced Version 3, it can be said that because the amount of the stockouts, amount of transportation, amount of WIP inventory and the amount of production made in the Approach3 Forced Version 3 is higher than the initial case, the best improvement rate occurs in the case which has lower penalty rate, OCR and higher P1PB1V, profit margin values for this approach.

5.6. Overall Comparison of All Approaches

Up to now, the approaches are examined according to cases determined with four parameters, P1PB1V, profit margin, OCR, and penalty rate. Best and worst cases of the approaches are investigated and comparison between approaches are made.

Better approach is tried to be determined with the comparison made between improvement rates,. However a general evaluation is not made between approaches. Below in tables Table 79, Table 80, and Table 81, the best approaches are shown in all cases. This table is obtained by determining best improvement rates which are shown as bold in the tables Table 48, Table 49, and Table 50.

Table 79. The Best Approaches in All Cases When P1PB1V is $1.000

Case	**P1PB1V** ($)	**Profit Margin**	**OCR**	**Penalty Rate**	**Best Imp. Rate**
1	1000	0,05	0,15	0,0003	APPROACH3 FORCED VERSION 2
2	1000	0,05	0,15	0,001	APPROACH1
3	1000	0,05	0,15	0,003	APPROACH1
4	1000	0,05	0,2	0,0003	APPROACH3 FORCED VERSION 2
5	1000	0,05	0,2	0,001	APPROACH1
6	1000	0,05	0,2	0,003	APPROACH1
7	1000	0,05	0,25	0,0003	APPROACH3 FORCED VERSION 2
8	1000	0,05	0,25	0,001	APPROACH1
9	1000	0,05	0,25	0,003	APPROACH1
10	1000	0,1	0,15	0,0003	APPROACH3 FORCED VERSION 2
11	1000	0,1	0,15	0,001	APPROACH3 FORCED VERSION 2
12	1000	0,1	0,15	0,003	APPROACH3 FORCED VERSION 2
13	1000	0,1	0,2	0,0003	APPROACH3 FORCED VERSION 2
14	1000	0,1	0,2	0,001	APPROACH3 FORCED VERSION 2
15	1000	0,1	0,2	0,003	APPROACH3 FORCED VERSION 2
16	1000	0,1	0,25	0,0003	APPROACH3 FORCED VERSION 2
17	1000	0,1	0,25	0,001	APPROACH3 FORCED VERSION 2
18	1000	0,1	0,25	0,003	APPROACH3 FORCED VERSION 2
19	1000	0,15	0,15	0,0003	APPROACH3 FORCED VERSION 2
20	1000	0,15	0,15	0,001	APPROACH3 FORCED VERSION 2
21	1000	0,15	0,15	0,003	APPROACH3 FORCED VERSION 2
22	1000	0,15	0,2	0,0003	APPROACH3 FORCED VERSION 2
23	1000	0,15	0,2	0,001	APPROACH3 FORCED VERSION 2
24	1000	0,15	0,2	0,003	APPROACH3 FORCED VERSION 2
25	1000	0,15	0,25	0,0003	APPROACH3 FORCED VERSION 2
26	1000	0,15	0,25	0,001	APPROACH3 FORCED VERSION 2
27	1000	0,15	0,25	0,003	APPROACH3 FORCED VERSION 2

Table 80. The Best Approaches in All Cases When P1PB1V is $10.000

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Best Imp. Rate
28	10000	0,05	0,15	0,0003	APPROACH3 FORCED VERSION 2
29	10000	0,05	0,15	0,001	APPROACH3 FORCED VERSION 2
30	10000	0,05	0,15	0,003	APPROACH3
31	10000	0,05	0,2	0,0003	APPROACH3 FORCED VERSION 2
32	10000	0,05	0,2	0,001	APPROACH3 FORCED VERSION 2
33	10000	0,05	0,2	0,003	APPROACH3
34	10000	0,05	0,25	0,0003	APPROACH3 FORCED VERSION 2
35	10000	0,05	0,25	0,001	APPROACH3 FORCED VERSION 2
36	10000	0,05	0,25	0,003	APPROACH3
37	10000	0,1	0,15	0,0003	APPROACH3 FORCED VERSION 2
38	10000	0,1	0,15	0,001	APPROACH3 FORCED VERSION 2
39	10000	0,1	0,15	0,003	APPROACH3 FORCED VERSION 2
40	10000	0,1	0,2	0,0003	APPROACH3 FORCED VERSION 2
41	10000	0,1	0,2	0,001	APPROACH3 FORCED VERSION 2
42	10000	0,1	0,2	0,003	APPROACH3 FORCED VERSION 2
43	10000	0,1	0,25	0,0003	APPROACH3 FORCED VERSION 2
44	10000	0,1	0,25	0,001	APPROACH3 FORCED VERSION 2
45	10000	0,1	0,25	0,003	APPROACH3 FORCED VERSION 2
46	10000	0,15	0,15	0,0003	APPROACH3 FORCED VERSION 2
47	10000	0,15	0,15	0,001	APPROACH3 FORCED VERSION 2
48	10000	0,15	0,15	0,003	APPROACH3 FORCED VERSION 2
49	10000	0,15	0,2	0,0003	APPROACH3 FORCED VERSION 2
50	10000	0,15	0,2	0,001	APPROACH3 FORCED VERSION 2
51	10000	0,15	0,2	0,003	APPROACH3 FORCED VERSION 2
52	10000	0,15	0,25	0,0003	APPROACH3 FORCED VERSION 2
53	10000	0,15	0,25	0,001	APPROACH3 FORCED VERSION 2
54	10000	0,15	0,25	0,003	APPROACH3 FORCED VERSION 2

Table 81. The Best Approaches in All Cases When P1PB1V is $30.000

Case	P1PB1V ($)	Profit Margin	OCR	Penalty Rate	Best Imp. Rate
55	30000	0,05	0,15	0,0003	APPROACH3 FORCED VERSION 2
56	30000	0,05	0,15	0,001	APPROACH3 FORCED VERSION 2
57	30000	0,05	0,15	0,003	APPROACH3
58	30000	0,05	0,2	0,0003	APPROACH3 FORCED VERSION 2
59	30000	0,05	0,2	0,001	APPROACH3 FORCED VERSION 2
60	30000	0,05	0,2	0,003	APPROACH3
61	30000	0,05	0,25	0,0003	APPROACH3 FORCED VERSION 2
62	30000	0,05	0,25	0,001	APPROACH3 FORCED VERSION 2
63	30000	0,05	0,25	0,003	APPROACH3
64	30000	0,1	0,15	0,0003	APPROACH3 FORCED VERSION 2
65	30000	0,1	0,15	0,001	APPROACH3 FORCED VERSION 2
66	30000	0,1	0,15	0,003	APPROACH3 FORCED VERSION 2
67	30000	0,1	0,2	0,0003	APPROACH3 FORCED VERSION 2
68	30000	0,1	0,2	0,001	APPROACH3 FORCED VERSION 2
69	30000	0,1	0,2	0,003	APPROACH3 FORCED VERSION 2
70	30000	0,1	0,25	0,0003	APPROACH3 FORCED VERSION 2
71	30000	0,1	0,25	0,001	APPROACH3 FORCED VERSION 2
72	30000	0,1	0,25	0,003	APPROACH3 FORCED VERSION 2
73	30000	0,15	0,15	0,0003	APPROACH3 FORCED VERSION 2
74	30000	0,15	0,15	0,001	APPROACH3 FORCED VERSION 2
75	30000	0,15	0,15	0,003	APPROACH3 FORCED VERSION 2
76	30000	0,15	0,2	0,0003	APPROACH3 FORCED VERSION 2
77	30000	0,15	0,2	0,001	APPROACH3 FORCED VERSION 2
78	30000	0,15	0,2	0,003	APPROACH3 FORCED VERSION 2
79	30000	0,15	0,25	0,0003	APPROACH3 FORCED VERSION 2
80	30000	0,15	0,25	0,001	APPROACH3 FORCED VERSION 2
81	30000	0,15	0,25	0,003	APPROACH3 FORCED VERSION 2

In Table 79, the P1PB1V is $1.000 and when the profit margin is bigger than 5% best improvement rate occurs in the Approach3 Forced Version 2 although WIP inventory, stock outs, and transportation is not the best of the all approaches. The reason is that the production of this approach is higher than the other ones and the high production compensates the other cost caused from WIP inventory, stock outs, and transportation. However with the lowest profit margin and high penalty rate total gain obtained gets below the total gains of the Approach1.

In Table 80 above, when the profit margin is bigger than 5% best improvement rate is Approach3 Forced Version 2 although WIP inventory, stock outs, and transportation is not the best of the all approaches. The reason is also high production. However with the lowest profit margin and the highest penalty rate best approach is the Approach3 because the stockouts, WIP inventory and transportation of this approach is better than Approach3 Forced Version 3. Therefore, the total gain provided from the approach there is highest.

Table 81 above is same with the second table because of the same reasons mentioned above. When the profit margin is bigger than 5%, best improvement rate is Approach3 Forced Version 2. On the other hand with the lowest profit margin and the highest penalty rate best approach is the Approach3.

With this examination, it can be deducted that except the cases 2, 3, 5, 6, 8, and 9 which have lowest P1PB1V, lower profit margin, and higher penalty rate, usage of RFID technologies are the best way. Moreover, if the profit margin are not lowest, and penalty rate is not highest, the best approach is the usage of RFID technologies with a reordering policy and forcing the system with the rate of 95 percent.

5.7. Summary of the Analysis

In this analysis part, the approaches are examined according to particular cases. The analysis made in this study is summarized below:

- First approach, Approach1 tries to improve the production system of the factory by changing the lot sizes of the printed boards shipped from the subcontractors to the company. By the help of this easy change about 6 percent improvement is provided.
- Improvement of Approach1 is not fluctuated according to the cases so much. Generally with the increase of the profit margin, the improvement rate of this approach increases.
- Second approach, Approach2 tries to integrate RFID technologies to the production system of the company and by using these technologies, the extra delays in the production system are eliminated.
- Because of the initial investment, the improvement rates of Approach2 are lower in the cases which have lowest value of P1PB1V.
- When P1PB1V is $1.000 (the value of the product is lower), the improvement rates of the Aproach2 are lower than the ones of the Approach1. In this

P1PB1V, with the increase of the profit margin, the improvement rates increase however they are still below the improvement rates of the Approach1.

- The actual effect of this approach is seen in the higher P1PB1V. When P1PB1V is higher than $1.000 (the value of the product is higher), the improvement rates of Approach2 are higher than the ones of the Approach1 because in the high-value product the effect of the initial investment is decreases and the improvement caused from the application of RFID technologies becomes more visible.
- In Approach3, RFID technologies are used with the reordering policies. By the help of this approach, the improvement rates get better. The improvement rates of the Approach3 are better than the ones of the Approach2 for all cases.
- Although the improvements rates of Approach3 in the cases which have P1PB1V of $1.000 are still lower than the improvement rates of Approach1, they are better with respect to the Approach2.
- The effect of Approach3 is more visible when P1PB1V is higher than $1.000.
- The forced versions of Approach2 and Approach3 provide more improvement in the high-value products when the penalty rate is lower. These approaches are more sensitive to the penalty rates because their stockouts are high especially the forced version 2 and 3 of Approach3. When the penalty rates are high these approaches has lower improvements rates, in some cases which have highest penalty rates, they have the worst improvement rates.

CHAPTER 6

CONCLUSION

The main purpose of this study is investigating the application of RFID technologies in a company which makes low-volume high-value production. In the study, the production system of a company which makes low-volume production is examined, possible gain and loss cdue to the application of RFID technologies are investigated. To the best of our knowledge this study is one of the primary studies which examines the effect of RFID technologies in low-volume high-value production with detailed discrete event simulation made for a real case.

In this study, the production system of a company which makes low-volume high-value production is selected. First of all the production of this real case is investigated and possible problems and their causes are determined. Mainly the problem of production is the long flowtime (lifetime) of the product. Long lifetime causes high WIP inventory, high stockouts and low production. The simulation model of the initial case is constructed and this simulation is modified with the possible improvement to lower the lifetime in the following approaches. The construction of the simulation models is the first phase of the study and the second phase of the study is the analysis of the results of these approaches. Different scenarios are formed with the help of four parameters, namely the value of first product's first printed board, profit margin, opportunity cost rate and penalty rate. By changing these parameters, scenarios are constructed and for each scenario gain and loss analysis of the approaches are made.

First approach, Approach1, is changing the lot size of the printed boards which shipped from the subcontractors to the company. This approach does not contain any application of RFID technologies and it is developed to show any improvement which can be made without any RFID application. With Approach1, an increase in the relative production and about 6 percent improvement rate are obtained. The improvement rates of Approach1 are not fluctuating much.

Then, Approach2 which is the application of RFID system to the company is implemented in the simulation of the initial case. In Approach2 only extra delays caused from the weak communication is considered. In Approach2, WIP inventory and stockouts decrease and the amount of production increases. The improvement obtained from this approach is low for the low value of the product and profit margin. With increase of the profit margin the improvement rates are increased when the values of the products are low however the actual effect of the Approach2 is seen in high values of products.

The Approach3 is applied to the simulation after the Approach2. Approach3 is composed of reordering of the queues and early shipment of the printed boards from the subcontractor. With the application of the Approach3, considerable decreases in lifetime, WIP inventory and stockouts are obtained. With the Approach3, better improvement rates are achieved in the system. The improvement rates of the Approach3 is better than the improvement rates of Approach2 for all cases however they are still lower when the values of the products are low.

Lastly, the forced versions of Approach2 and Approach3 are constructed by increasing the frequency of the work orders and the results are examined. In the forced versions, the amount of production increases however the amount of WIP inventory and stockouts also increase.

At the end of the analysis, the most important conclusion is that when the values of the products in the company examined in this study are low, the improvements obtained from the application of RFID technologies is lower than the improvements obtained by application of the easy changes over the production system like changing the lot sizes. The reason of that is the initial investment cost. In this study, the application of RFID technologies are not favorable when the weighted average value of the products is $35.600. When the weighted average value of the products is $356.000 and 1.070.000, the usage of RFID technologies is favorable. At this point it can said that with the increase of products' values, the improvements obtained from the application of RFID technologies increase.

Another conclusion obtained from this study is that the improvements due to the application of RFID technology become more visible when combined with the utilization of some policies. In this thesis reordering and early shipment of the inventories policies are used. The reordering policy is reordering of the some queues of the production system, on the other hand the early shipment is the shipment of the printed boards from subcontractors to the company without waiting any certain lot sizes and both policies can be applied easily with the help of RFID technologies.

Finally, if the amount of the production is important for the company, the value of the products are high and the value of the penalty rate which determines the penalty cost is low, using RFID technologies and increasing the frequency of the production orders give better improvements.

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APPENDICES

A. Block Diagrams of the Simulation models

A.1. Informative Explanations about the Blocks

In this study, as a simulation tool ARENA is used. Basic construction items in the arena are blocks. In the ARENA some kind of blocks are available and with the help of this blocks, the simulation models are constructed. Below some concepts and blocks are explained briefly and after that the block diagrams of the simulations to correspond to production stages of the company are given.

Entity: Entities are used for the representation of the particles which are moves in the model. They generally represent the products, orders, and vehicles. They can have some attributes which assigned by the user and in simulation the values of these attributes can be changed.

Run: Run is the working of the simulation.

Replication: Replication is the process which begins with start of the simulation and finishes at the end of the simulation.

Attribute: An attribute is a particular property of an entity. It can be type, price or color of an entity. It can be changed in a simulation run.

Variables: Variables are the global items which used keeping some data. This data is not property of an entity. Their values can be changed by the entities.

Resource: A resource is used in simulation for the modeling of workers, machines or vehicles. A resource has a status attribute which can be busy or idle.

Sub-model: A sub-model is an isolated small model in main simulation model.

Create: Create is a block and a block can be thought as a smallest construction element in the simulation. Create blocks are used for creating entities. They need three inputs which are first creation time, batch size and creating frequency.

Assign: Assign is a block used for the changing the value of an attribute of an entity or a variable. An entity enters the assign block then in this block assigning process is performed over an attribute of this entity or a variable.

Duplicate: Duplicate is a block used for duplication of the entities.

Count: Count is a block used for counting processes. It is generally used to count number of entities.

Queue: Queue is a block for keep the entities in a places and used for the simulation of the real queues. Queues act according to their ranking creation and this ranking creation is determined by the user and can be first in first out, last in first out, lowest value first, or highest value first.

QPick: If there are more than one queue block and it is required that entity form one of these queues are picked, the QPick is used for this job.

Branch: Branch block is the most important block in the simulation because logical processes are constructed with the help of this block. An entity enters this block and according to logical expressions in branch block, the entities can be sent to different destinations.

Signal: Signal is block used for warning purposes with wait blocks. When a signal block is stimulated by a entity, it exposes a code. Stimulation process is performed by verifying the logical expression in the signal block. For example if there is an expression like if(EntityType==1) in the signal block, when an entity whose entity type is equal to one enters to signal block the signal block exposes the a certain code to the appropriate wait block.

Wait: Wait block is used with signal block and generally used for keeping the entities and it waits for certain code. If this certain code is exposed by a signal block, entities are dismissed.

Delay: Delay block is used to wait the entities for a certain time.

Group: This block groups the entities. Batching processes are performed with the help of this block.

Split: This block splits the grouped block

Size: This block makes a recourse busy. Allocation of the resources a certain job is performed by this block

Release: This block makes a recourse idle.

Tally: This block collects statistics.

A.2. Block Diagrams of the Simulations

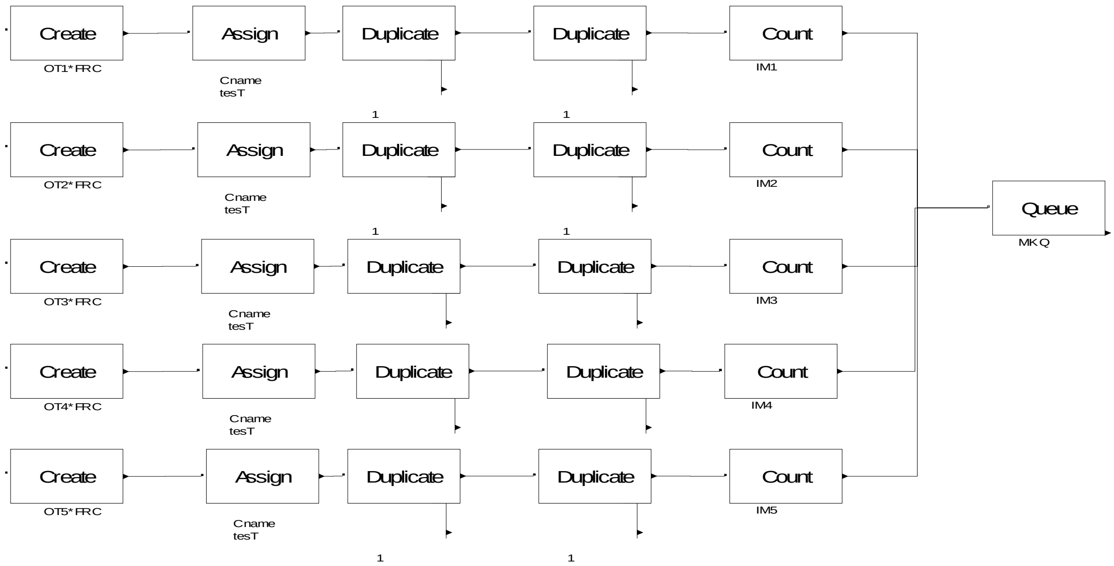

Figure 68. Simulation of the Work Order Section

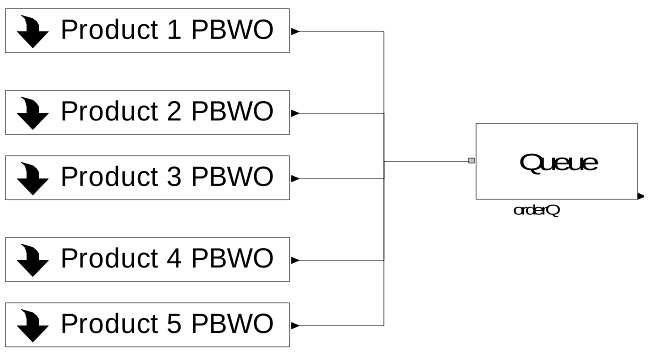

Figure 69. Main Printed Board Work Order Model

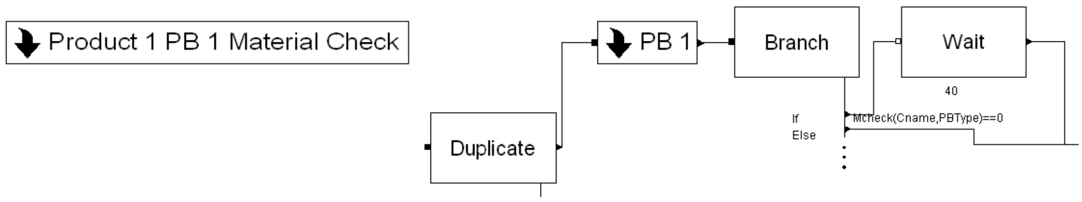

Figure 70. Detail of the Product 1 Printed Board Work Order for Printed Board 1 Sub-model

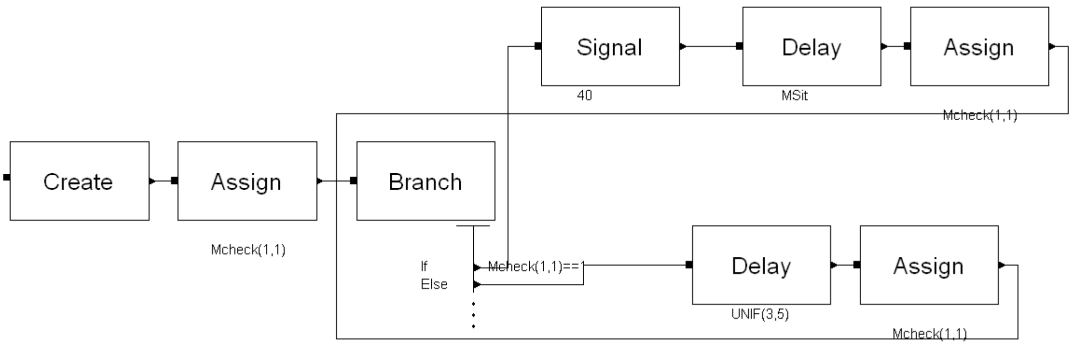

Figure 71. Detail of the Product 1 Printed Board 1 Material Check Sub-model

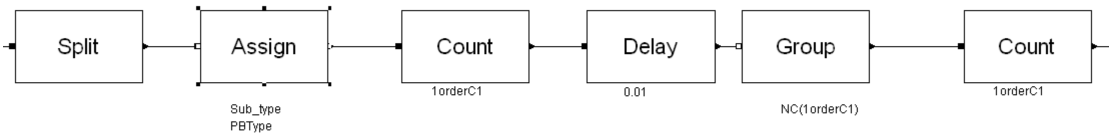

Figure 72. Detail of Printed Board 1 Sub-model

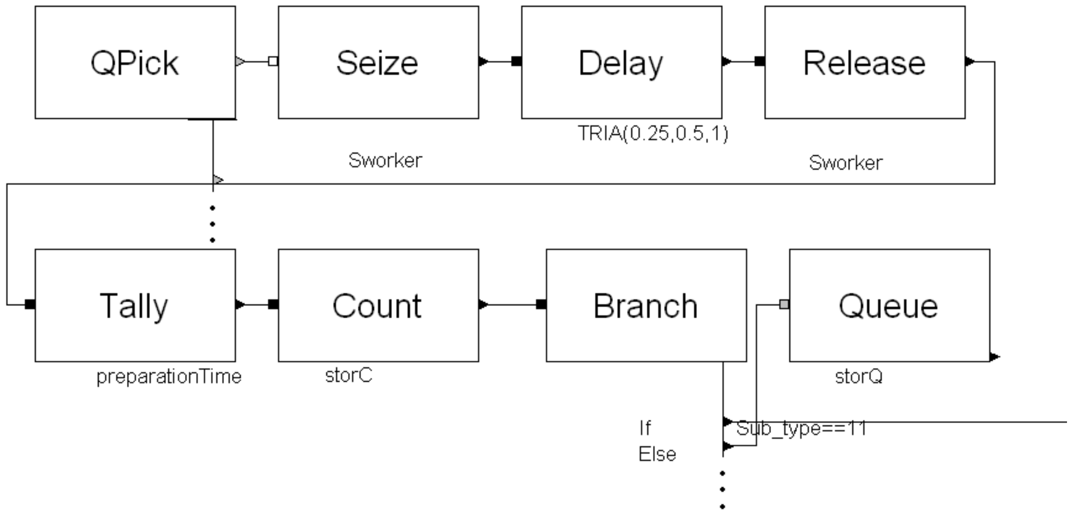

Figure 73. Material Preparation Section

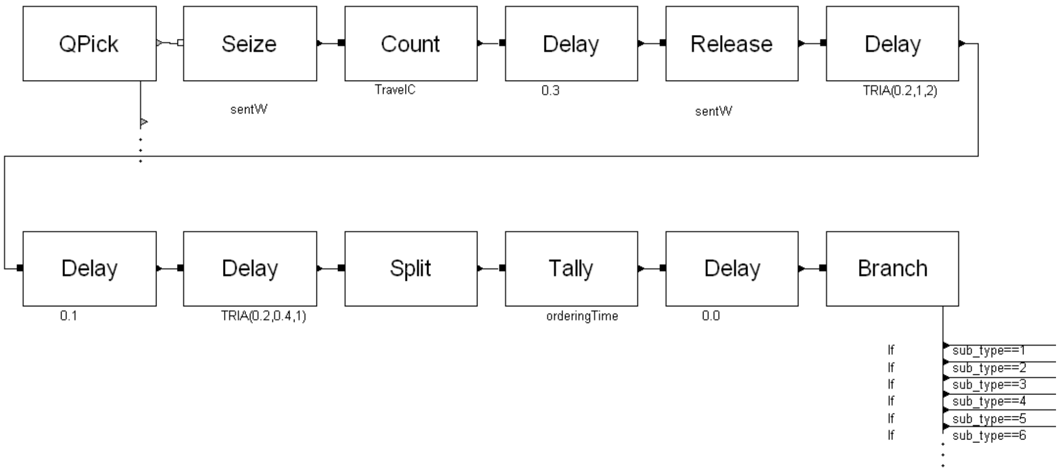

Figure 74. Sending Stage

Figure 75. Internal Printed Board Production

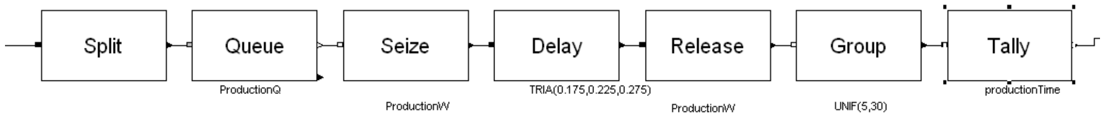

Figure 76. Detail of the Printed Board Processes

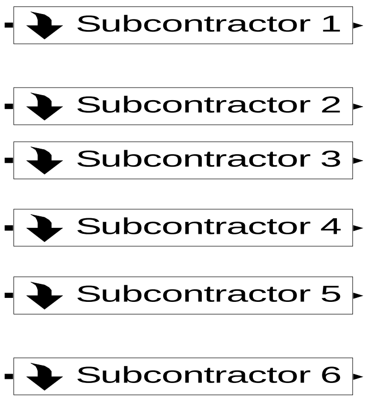

Figure 77. The Sub-model of the Subcontractors

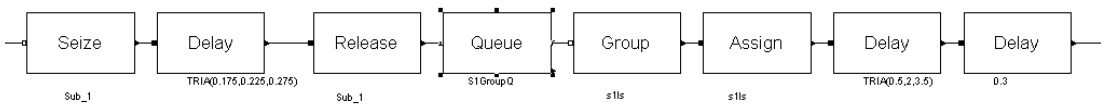

Figure 78. The Detail of the Subcontractors

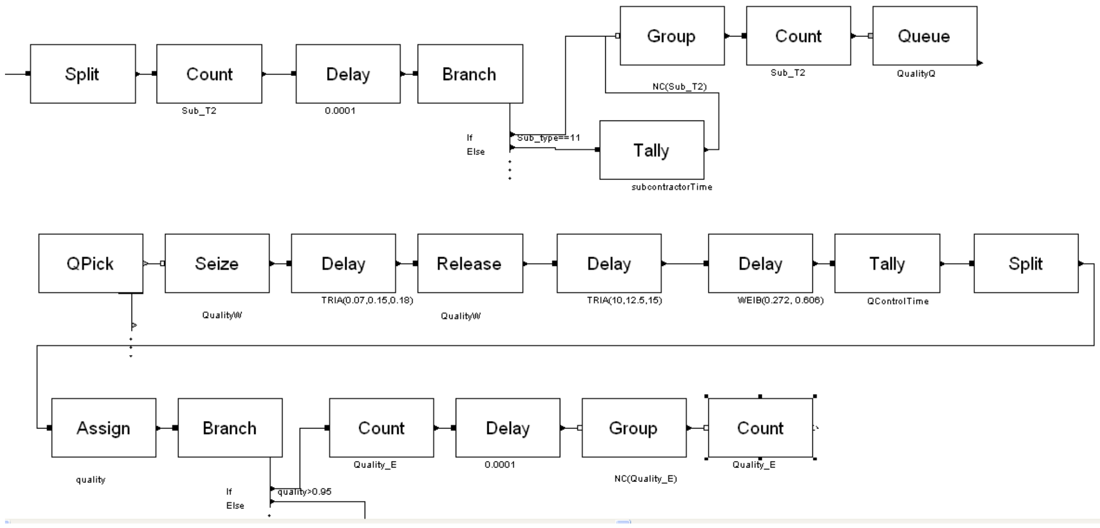

Figure 79. Quality Control Section

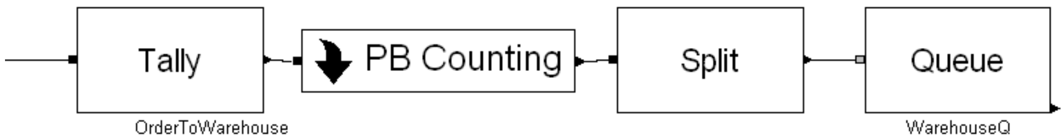

Figure 80. Warehouse Sub-model

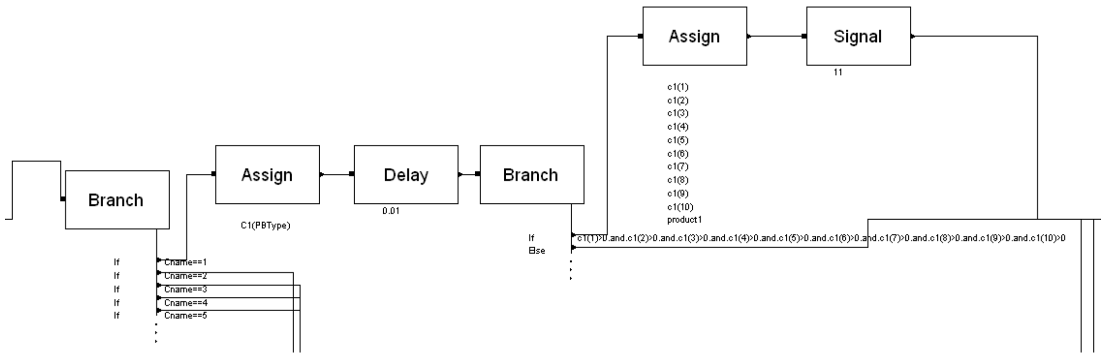

Figure 81. The Detail of the PB Counting Sub-model for Product 1

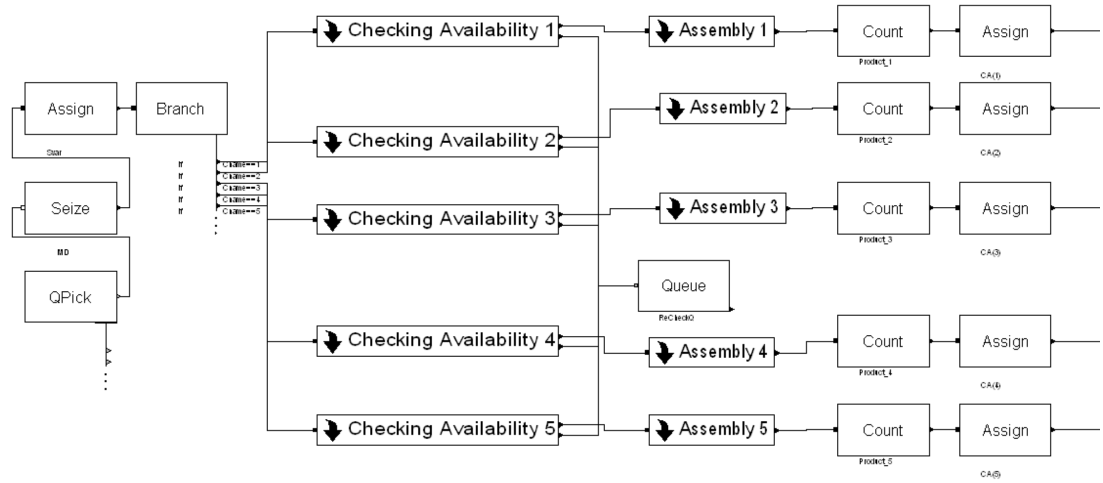

Figure 82. The General Outlook of the Simulation Model of the Assembly Stage

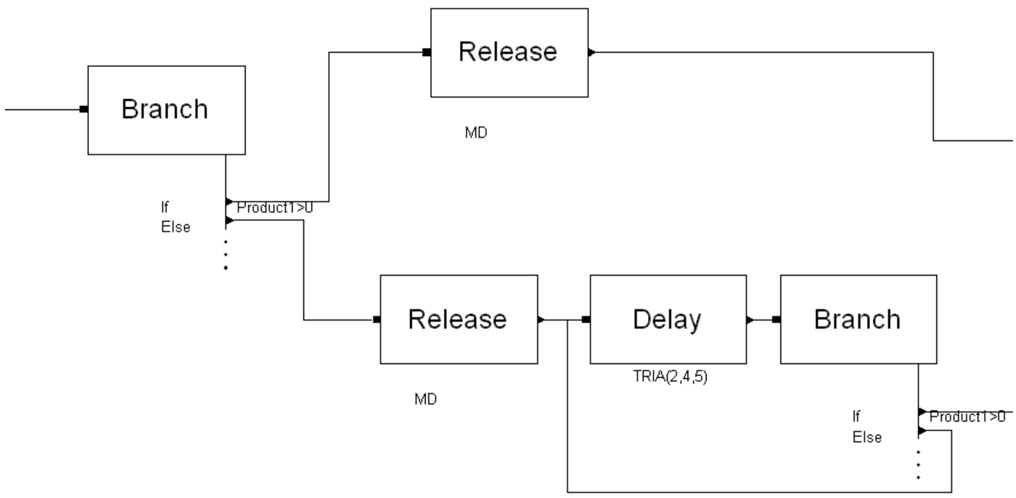

Figure 83. The Detail of the Checking Availability Sub-model

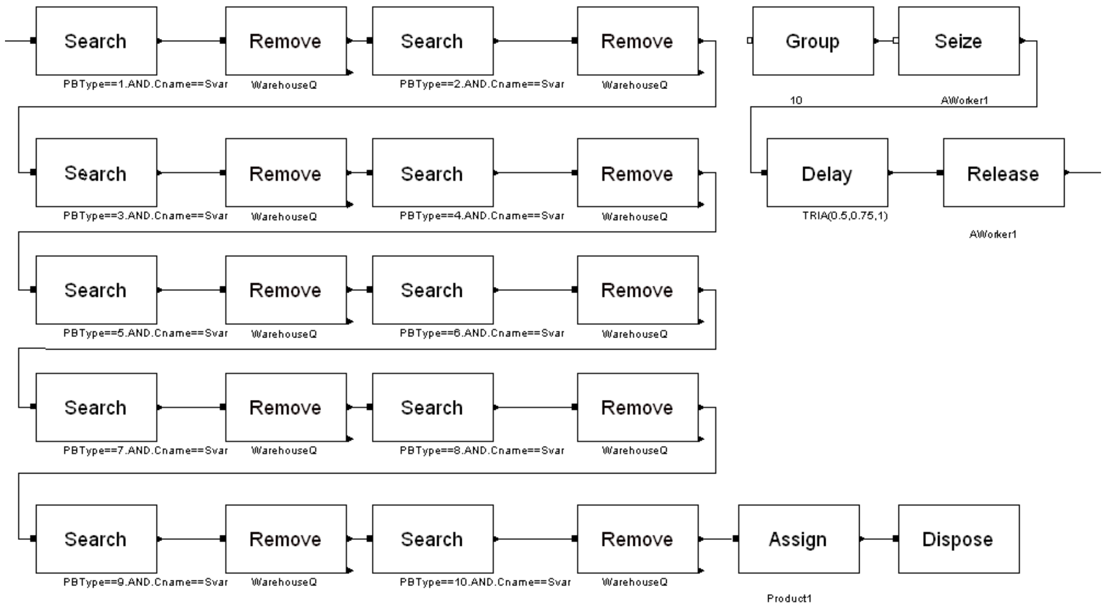

Figure 84. Product Assembly Sub-model

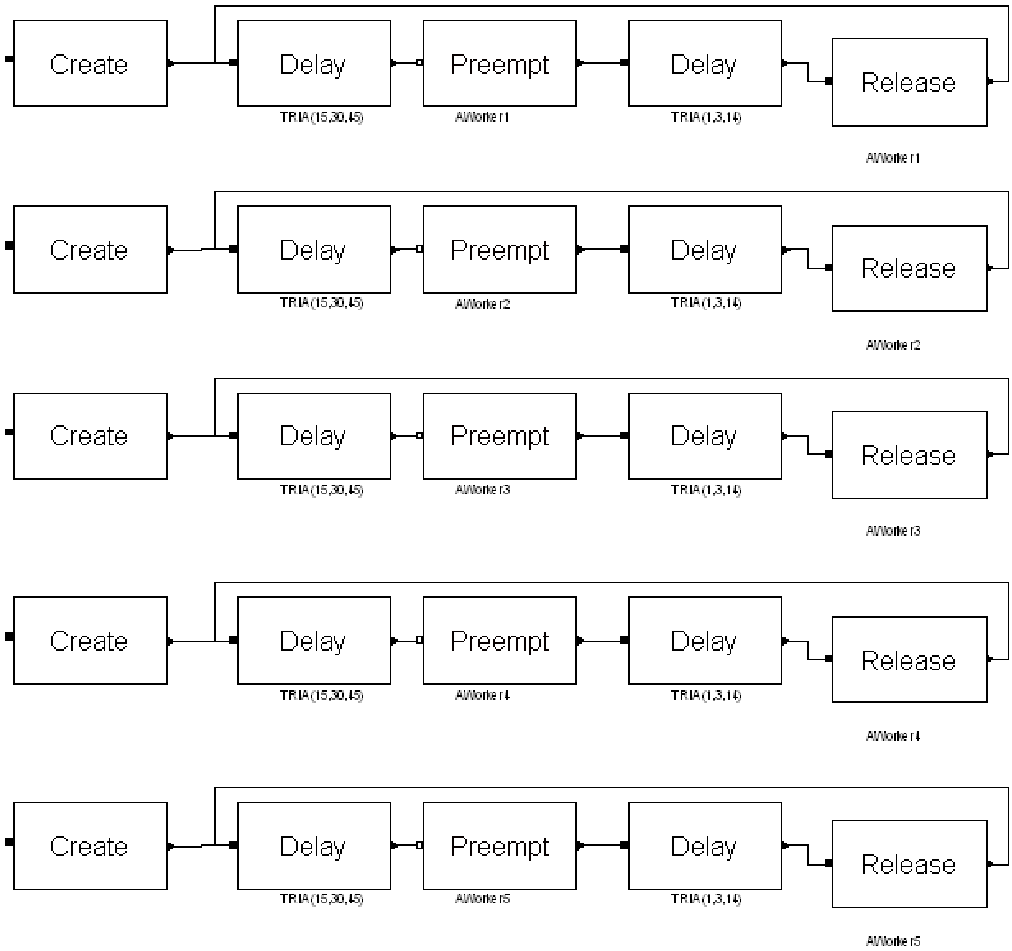

Figure 85. Machine Breakdowns Part

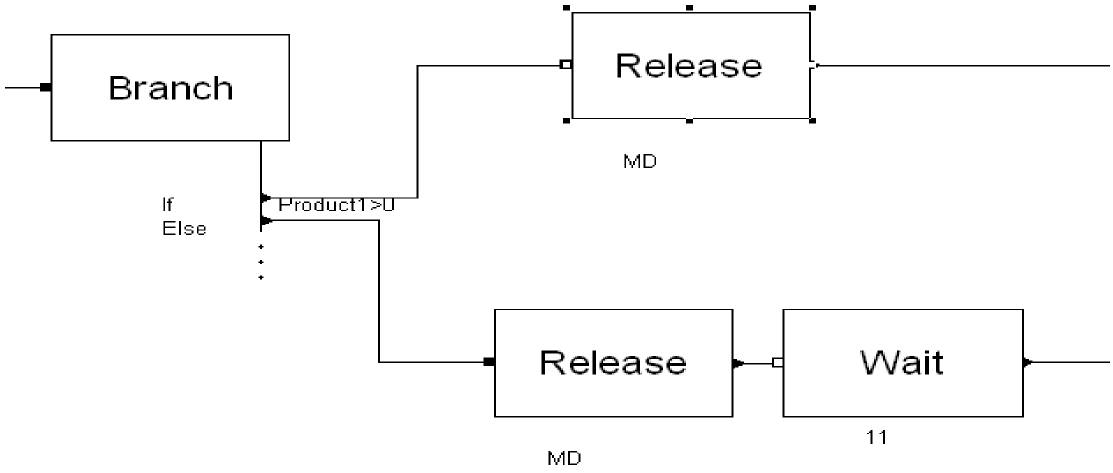

Figure 86. The Modification Made in the Checking Availability Sub-model of Assembly stage in Approach2

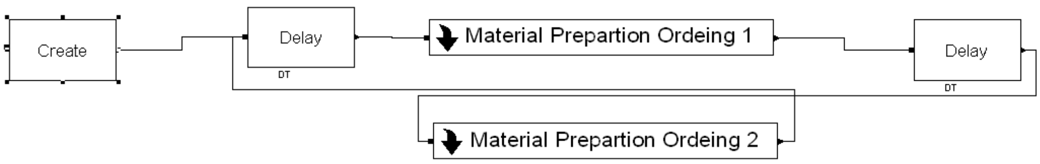

Figure 87. The Overall Picture of This Enhancement Material Preparation in Approach3

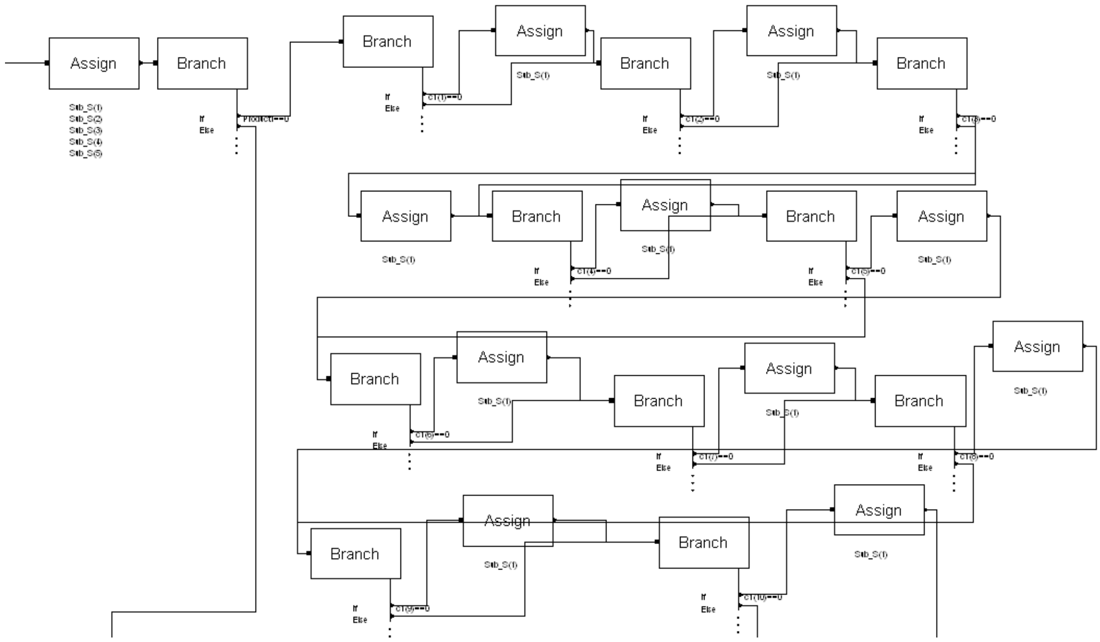

Figure 88. The Some of the Structure for Checking Printed Boards in the Warehouse of Printed Boards in Material Preparation Ordering 1 Sub-model

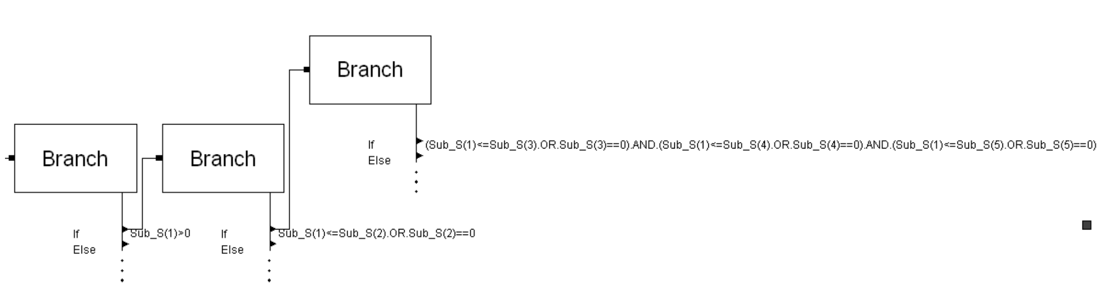

Figure 89. The Some of the Structure for Determining the Reorder Sequence of Printed Boards in Material Preparation Ordering 1 Sub-model

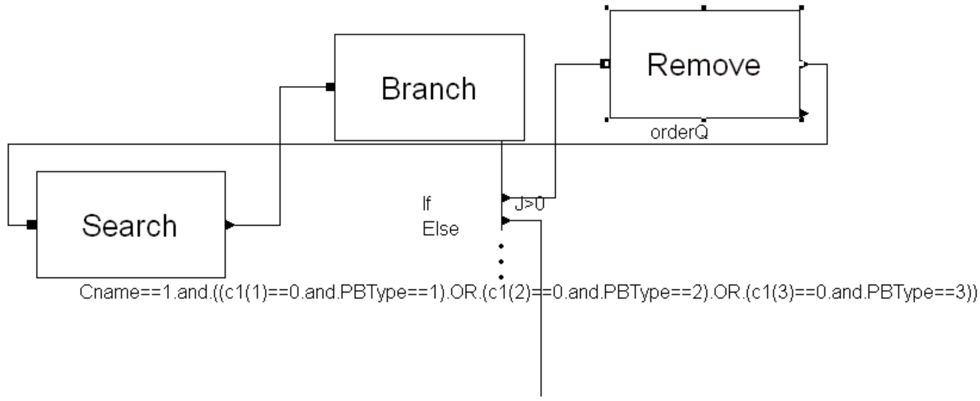

Figure 90. The Some of the Structure for Reordering Processes of Printed Boards in Material Preparation Ordering 1 Sub-model

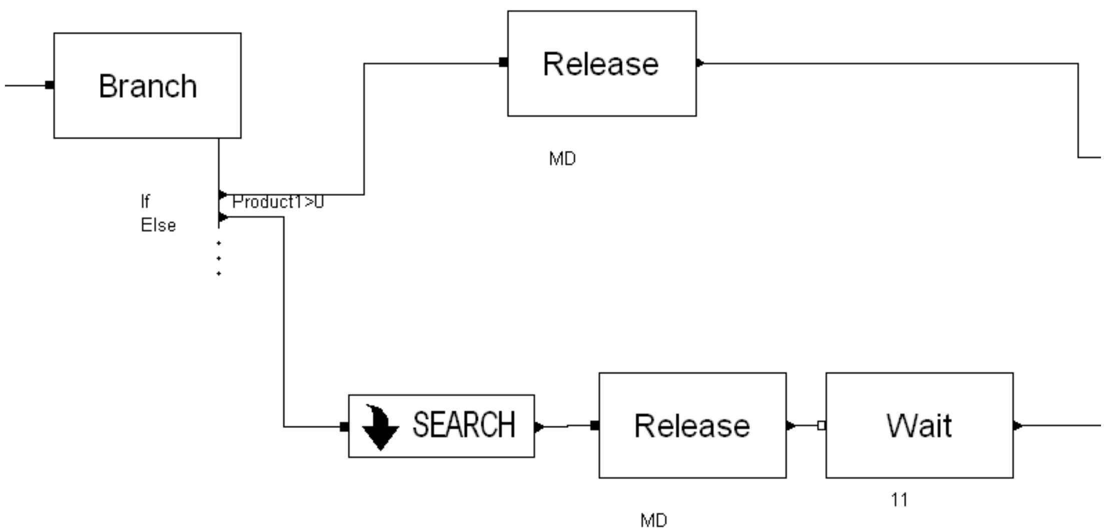

Figure 91. Detail of Modification in the Checking Availability Sub-model of Assembly Stage in Approach3

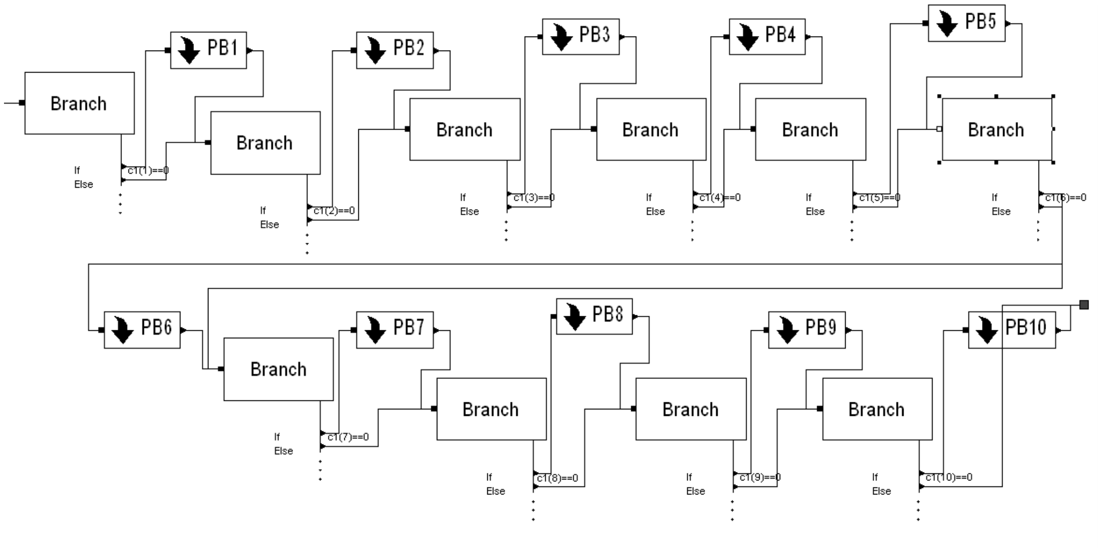

Figure 92. The Detail of Search Sub-model

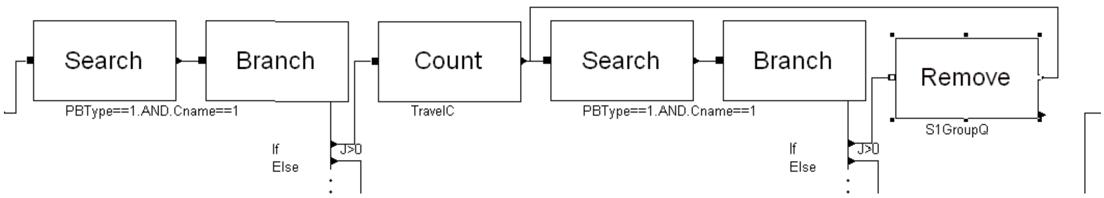

Figure 93. The Detail of PB1 Sub-model