

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

**DETERMINING THE SIZE AND TYPE OF
AUTOMATED GUIDED VEHICLE FLEET WITH
A CASE STUDY**

by
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October 2023

İZMİR

DETERMINING THE SIZE AND TYPE OF AUTOMATED GUIDED VEHICLE FLEET WITH A CASE STUDY

**A Thesis Submitted to the
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by

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İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

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Deniz Esen ERDOĞAN

DETERMINING THE SIZE AND TYPE OF AUTOMATED GUIDED VEHICLE FLEET WITH A CASE STUDY

ABSTRACT

Industry 4.0 has brought with it radical changes in transportation systems. The ability of objects to communicate with each other has made carrying the newly developed direction-finding systems components faster and more independent from humans than ever before. Human-independent transport systems are much safer than conventional systems and simplified the laborious and difficult to control structure used for the transfer of materials within the facility. Automated Guided Vehicles (AGVs) are unmanned transports that use a variety of navigation and control systems to automatically move along predetermined paths. Well-designed AGV systems will prevent damage to the product quality due to transportation, will provide a safe working environment for employees and will provide a long-term profit to the business. The aim of this study is to determine the AGV type and fleet size while ensuring occupational health and safety for the enterprise. To find this out, first, the type of AGV suitable for the needs of the enterprise was determined, and then the existing system and alternative systems were simulated to calculate how many AGVs of this type are needed. The system was tested with the experimental design method under different conditions and the most optimal result was achieved are examined, best alternative selected. the most suitable AGV type for the operation is Fork type AGV and these type of AGVs can carry more than one load at the same time. In order for the system to work optimally, the need for 3 AGVs has been determined, and each AGV must carry 3 pallets of products at a time. The fleet size cannot be increased further because in the feasibility study, the company must pay off itself in a maximum of 2 years to make the investment.

Keywords: material handling systems, automated guided vehicle systems, simulation

BİR VAKA ÇALIŞMASI İLE OTOMATİK GÜDÜMLÜ ARAÇ FİLOSUNUN BÜYÜKLÜK VE ÇEŞİDİNİN BELİRLENMESİ

ÖZ

Endüstri 4.0, ulaşım sistemlerinde köklü değişiklikleri beraberinde getirdi. Nesnelerin birbirleriyle iletişim kurabilme yeteneği, yeni geliştirilen yön bulma sistemleri bileşenlerinin insanlardan her zamankinden daha hızlı ve daha bağımsız taşınmasını sağlamıştır. İnsandan bağımsız taşıma sistemleri, geleneksel sistemlere göre çok daha güvenlidir ve tesis içindeki malzemelerin transferi için kullanılan zahmetli ve kontrolü zor yapıyı basitleştirmiştir. Otomatik Güdümlü Araçlar (agv'ler), önceden belirlenmiş yollarda otomatik olarak hareket etmek için çeşitli navigasyon ve kontrol sistemleri kullanan insansız taşımalarıdır. İyi tasarlanmış AGV sistemleri, nakliye nedeniyle ürün kalitesinin zarar görmesini önleyecek, çalışanlar için güvenli bir çalışma ortamı sağlayacak ve işletmeye uzun vadeli kar sağlayacaktır. Bu çalışmada mevcut sistem ve alternatif sistem analiz edilmiştir. Bunun için öncelikle işletmenin ihtiyaçlarına uygun AGV tipi belirlendi, daha sonra mevcut sistem ve alternatif sistemler simüle edilerek bu tipte kaç adet AGV'ye ihtiyaç duyulduğu hesaplandı. Sistem deneysel tasarım yöntemiyle farklı koşullar altında test edilmiş ve en optimal sonuca ulaşılmış, en iyi alternatif seçilmiştir. Operasyona en uygun AGV tipi Fork tipi AGV olup, bu tip AGV'ler aynı anda birden fazla yükü taşıyabilmektedir. Sistemin optimum şekilde çalışabilmesi için 3 adet AGV'ye ihtiyaç olduğu belirlenmiş olup, her bir AGV'nin aynı anda 3 palet ürün taşınması gerekmektedir. Filo büyüklüğünün daha fazla arttırılması mümkün değil çünkü fizibilite çalışmasında firmanın yatırımı yapabilmesi için maksimum 2 yıl içinde kendini amorti etmesi gerekiyor.

Anahtar kelimeler: malzeme elleçleme sistemi, otomatik güdümlü araçlar, simülasyon

CONTENTS	Page
THESIS EXAMINATION RESULT FORM	ii
ACKNOWLEDMENT.....	iii
ABSTRACT.....	iv
ÖZ	v
CONTENTS.....	vi
LIST OF FIGURES	vii
LIST OF TABLES	vii
CHAPTER ONE-INTRODUCTION	1
CHAPTER TWO-AGV SYSTEMS	3
2.1. What are Automated Guided Vehicles?	3
2.2. AGV Types	4
2.2.1 Towing Type AGV	4
2.2.2 Unit Load AGVs	5
2.2.3 Battery Types	9
2.3. AGV Navigation Systems	7
2.3.1 Magnetic Type	7
2.3.2 Laser Guided Navigation	7
2.3.3 Naturel Navigation	8
2.3.4 Battery Types	9
2.2.5 AGV System Simulation	10
2.2.6 Advantages of AGV Systems	13
2.2.7 Design of Experiment	14
2.4 Literature Review	15
CHAPTER THREE-SYSTEM DESIGN PROCESS.....	18
3.1. System Planning.....	18
3.2. System Analysis.....	18

3.3. Current System Analysis.....	19
3.4. Assumptions of the Current System.....	20
3.5. Current System Simulation	20
3.6. Pros and Cons of Current System	28
3.7. Alternative System Design.....	29
3.8. Verification and Validation.....	34
CHAPTER FOUR-CASE STUDY, RESULTS AND CONCLUSIONS	36
4.1. Case Study.....	36
4.2. Conclusions	39
REFERENCES.....	44

LIST OF FIGURES

Page

Figure 2.1. Tow Truck	4
Figure 2.2. Unit Type AGV	5
Figure 2.3. Fork Type AGV	5
Figure 3.1. Current System Flow Chart	18
Figure 4.1 Utilization According to Number of Forklifts	39
Figure 4.2 Resource Utilization Rates According to the Number of Forklifts and AGVs.....	40
Figure 4.3 Production Quantities According to AGV and the Number of Pallets Transported at One Time	41

LIST OF TABLES

Page

Table 2.1. AGV Types	6
Table 2.2. Navigation Methods	9
Table 3.1. Current System Data	30
Table 4.1. AGV Utilization	38
Table 4.1 Results	37
Table 4.2 Production Quantities According to the Number of Forklifts	38
Table 4.3 Production Quantities According to the Number of Forklifts and AGVs ..	40
Table 4.4 Resource Utilization Rates According to AGV and the Number of Pallets M Transported at One Time	42
Table 4.5 Paired T-Test.....	42

CHAPTER ONE

INTRODUCTION

Material flow control has become one of the critical concerns for system efficiency as industrial systems have expanded in size and complexity, and determining the number of vehicles necessary is a significant issue in the design of AGV (Automatic Guided Vehicle) systems for automated material flow management. AGVs are unmanned electric vehicles that move materials from one point to another (Ryck et al., 2020). They move on fixed routes that require infrastructure and need pre-programmed software for operating instructions. A driverless transport system called an AGV is used to carry items horizontally. The first AGVs appeared in 1955 (Müller, 1983). Since their inception, AGV usage has significantly increased. Both the variety of types and the amount of application areas have grown dramatically. AGVs are applicable to both indoor and outdoor settings, including production, distribution, transshipment, and (external) transportation sectors. A driverless vehicle that follows a path (virtual or guided) and is managed by a computer or microprocessor makes up an advanced material handling system known as an AGV system (Hammond, 1986). An AGV typically consists of the following parts: a frame, batteries, electrical system, driving unit, steering, precision stop unit, onboard controller, communication unit, safety system, and work platform.

The system is unidirectional if the AGVs can only go in one direction. On the other hand, the system is bi-directional if the AGVs are permitted to travel through a lane in two opposed directions. In industrial facilities, AGV systems are generally employed for material transportation from production and storage regions as well as for material distribution in warehouse settings. Making the proper design selections initially, followed by operational choices, is crucial to create an effective AGV system (Rahaman, 2015). The best sort of AGV and navigation system must be chosen, and the fleet size of AGVs must then be determined.

To develop an effective AGV system, one of the most important points to be decided is to determine the number of AGVs. If the number of AGVs is low, it will

cause material delays, and many AGVs will not work effectively (Sinriech et al., 1992). At the same time, it is very important to choose best AGV type, navigation system and route for the system to work effectively. There are many methods for determine AGV fleet size (Valmiki et al., 2018). Some of these methods ensure optimum solution but it is too hard to design system according to real system. Simulation method doesn't ensure optimum solution, but it is much preferable then other methods for design complex systems (Neradilova et al., 2017). Because reel systems aren't perfect, there are many different constraints effecting the system.

The aim of this study is to create an alternative system having less accidents. In the electronic system, forklifts frequently had accidents and the loads they carried were sent to production late. Occupational safety risk in a business is calculated by multiplying the probability of a work accident in that area and the severity of the accident when it occurs. The closer this score is to zero, the more secure the system is. In the current system, probability of having an accident is daily 6 points and severity is 9 daily so risk point is 54 dailies, and in the alternative system, this value is intended to be zero. It was thought that eliminating the human factor would provide the safest result to eliminate the risk of accidents. For this reason, the use of AGVs, which are unmanned transport vehicles, has been deemed suitable for operation. In addition, since the study is carried out in electronic industry, the simulation method will be used to analyze the current situation in the most detailed way.

Simulation is a technique that is used to test and measure the behavior of a specific system under given set of conditions (Banks et al., 2014). To evaluate alternative design and control strategies of AGV systems, it is required to estimate the system behavior under these strategies. Simulation enables the user to create a computer model of the actual AGV system that can be used to measure the effects of design and control related changes to the system.

One advantage of simulation is that a system can be tested without existing in the real world. This may be the case if a company attempts to evaluate the feasibility of

an AGV system before making an investment. Simulation can also be used to test the effects of a layout change in an existing AGV system. Another advantage of simulation is its speed of execution. Long lasting operations can be simulated in a few seconds. This may be important if a dynamic AGV control system or a dynamic shop floor control system is utilized. For many AGV systems, simulation is not an option, but a requirement (Hammond, 1986).

The simulation method on its own is insufficient to give the optimum result. For this reason, the simulation model is run with different parameters using methods such as experimental design and the best result is selected. A methodical strategy to comprehending how process and product factors influence response variables like processability, physical characteristics, or product performance is known as design of experiments (DOE) (Wagner, 1997). The term "experiment" is used in a very specific sense to describe research in which the system under study is within the investigator's control. In observational research, on the other hand, certain features will be beyond the investigator's control. (Cox, 2000). The experiment may be thought of as a test, or a series of tests, in which suggested variations are made to the input variables of a process or system, and then the effects on the output variables are observed (Montgomery 1999).

In summary, in this study, in the business that is operating in the electronics industry where accidents occur frequently is examined the simulation method. There are deficiencies in the current system in terms of occupational health and safety. Risk assessment studies are carried out regularly to measure occupational health and safety. Two parameters are used for risk assessment, the first of which is the probability of the accident occurring and the other parameter is the severity of the accident. In the current system, the risk score is 54(it calculates with occupation probability multiply with severity). The closer this score is to zero, the more secure the system is. It has been observed that alternative secure systems should be used since the risk score is quite high. It was thought that designing a system independent of human control would be the most appropriate alternative, and it was concluded that the use of AGV would be the most suitable alternative. An alternative system is simulated to determine the

fleet size of AGV. It is observed how the two parameters change under different conditions. The first of these is the utilization of workers and the other is the utilization of vehicles. It should be taken into consideration that, there are no unlimited resources. Due to the limited budget of the business, the system must amortize itself within a maximum of two years. This constitutes the most important constraint for determining the number of AGVs to be used in the alternative system. Even if the utilization of workers and vehicles increases, additional vehicles will not be available due to resource constraints. With the experimental design method, the system is evaluated for different parameters. Considering the money constraint, and the appropriate fleet size is selected. Finally, the designed system is tested in a real factory environment and the results is examined.

The rest of this thesis study is organized as follows. AGV types, navigation methods and the related literature is surveyed in Chapter 2. The new system and its stages are explained in Chapter 3. At the same time, the model of the current system is explained in this section. The current system is simulated. Alternative systems have been designed. Finally, the study is ended with a case study and conclusions in Chapter 4.

CHAPTER TWO

AGV SYSTEMS

In this section, the purpose of the study is explained. Description of AGV systems is given in Section 2.1. AGV types and advantages are examined in Section 2.2 and 2.3. Studies on AGVs in the literature are examined in Section 2.4. The methods used to determine fleet size are examined.

2.1. What are Automated Guided Vehicles?

An autonomous mobile robot (AMR) is a mobile robot that moves independently of human control; an automated guided vehicle (AGV) is a mobile robot that follows predetermined long lines or cables on the ground or navigates using radio waves, cameras with integrated vision, magnets, or lasers (Vancea et al., 2019). To array large goods throughout a massive industrial building, such as a factory or warehouse, they are most typically used in industrial settings. The applications for automatic guided vehicles grew in the second half of the 20th century (Berman et al., 2009).

It should first be established what an AGV is. The term "Automated Guided Vehicle" or "Automatic Guided Vehicle" is abbreviated as "AGV". Different sources have different definitions, yet they all demonstrate the same thing by taking various paths (Wu et al., 2004). Vis (2015) claims that it can be described as the vehicle that doesn't have a driver and is used to deliver items horizontally. Although their primary function is to move objects horizontally, these vehicles can also occasionally move objects vertically. AGVs are unmanned electric vehicles that move materials from one point to another. They move on fixed routes that require infrastructure and need pre-programmed software for operating instructions. Another justification for touching AGV is that it has a battery. AGVs are battery-powered, contactless steering devices that use energy from the battery (Müller, 1983).

The expansion of flexible manufacturing systems, the large-scale use of robots and other computer-controlled machines, is a huge demand for the use of AGVs. Although

AGV systems which have an important place among material handling systems, were first discovered in the United States, they were used as driverless tractors in Europe for the first time after World War II (Taghaboni et al., 1997). The first introduction of automatic vehicle systems was made in 1953 on a line in the warehouse, and since 1959 it has been used extensively in factories and warehouses (Kaspi, 2002). An AGV system is a sophisticated material handling system that consists of a driverless vehicle that follows a path (virtual or guided) and is controlled by a computer or microprocessor (Hammond, 1986). AGV systems are primarily utilized for material distribution in warehouse environments, as well as material moving to and from production areas and storage areas in industrial facilities. Other non-manufacturing uses of AGV systems include, but are not limited to, delivering mail, messages, and goods in offices and meals and laundry in hospitals.

2.2 AGV Types

An AGV system is a sophisticated material handling system that consists of a driverless vehicle that follows a path (virtual or guided) and is controlled by a computer or microprocessor (Hammond, 1986). In the following, the AGV types are explained.

2.2.1 Towing Type AGV

These AGVs, as shown in figure 2.1, can be equipped with a trailer and tow a load behind them to their route (Evans et al.1992). Typically used in a manufacturing process application. The truck will tow its load to predetermined stops in its area.



Figure 2.1 Tow Truck

2.2.2 Unit Load AGVs

The AGV has a loading deck that allows it to load and unload goods as well as move them through its load deck (Schulze, 2006). This type of AGV is appropriate for medium to small loads and frequently utilized in a flexible production line, as illustrated in Figure 2.2.



Figure 2.2 Unit Type AGV

2.2.3 Fork Type AGVs

This type of AGVs is like a human-operated forklift, but with an automated mechanism that lowers/raises and loads/unloads a desired load (see in Figure 2.3). Has the capability of placing loads at higher heights, such as shelf or rack (Ryck et al., 2010) Typically encountered in a warehouse or goods in/out environment. Each system described is specialized and designed to do a certain task. There are also hybrid systems that mix the above-mentioned equipment or competences.



Figure 2.3 Fork Type AGV

For selecting the best type of the AGV, systems need must be analyzed clearly and types of AGVs must be determined for different needs. In this study, AGV types are

investigated under three main types (see Table 2.1.), their advantages and disadvantages are analyzed.

Table 2.1 AGV Types

AGV Type	Movement Area Need	Flexibility	Transportation Capacity	Ancillary Equipment Need
Unit Type	Low	High	Low	High
Towing Type	High	Low	High	High
Fork Type	High	Low	Moderate	Low

Unit type AGVs work in confined spaces and it is possible to easily modify these vehicles. It is not suitable for carrying heavy materials. This type of AGV can't transfer components without carriage. Towing type AGVs transfer many components ones but it is not work in confined spaces. It is hard to change vehicle design. Tow type AGV needs to many carriages for transfer many components. Fork type AGV's are the same as forklift. It needs wide space for turning because of the vehicle size. It is not easy for change vehicle design. It could carry heavy components. It doesn't need to ancillary equipment because it can load the pallet from the ground and unload it to ground.

After the mission has been defined and the proper AGV has been chosen, attention turns to the navigation and sensor technology used. The AGV's navigation and sensors are determined by the environment the AGV works. The type of work, the workspace, the shared space the AGV will occupy with humans and other AGV, the surface they will move on, the environment's layout, and whether the environment is static, or dynamic are all considerations in the navigation and sensor selection process.

2.3 AGV Navigation Systems

AGVs use three different types of navigation. The system selected is impacted by the arrangement of the area as well as the assigned task. Each mechanism is described in detail below.

2.3.1 Magnetic Tape

Autonomous guided vehicles are outfitted with magnetic sensors and travel along a predefined route created by a magnetic tape track. A magnetic tape laid on the floor surface creates the guided route. The magnetic field from the tape is detected by the AGV magnetic sensor, which propels the AGV down the course (Fujimoto et al., 2001). Magnetic tape is simple to apply. The magnetic tracks are laid using a high-bond glue. The tape's standard measurements are 1 mm thick and 5 cm broad, so it's not at all intrusive.

The damage caused by other people walking across magnetic tape can be severe. It might be required to cover it with epoxy glue or specific protective tapes, which would raise the cost of installation (Zeng et al., 2018). Strong and trustworthy navigation that is unaffected by dirt, noise, or dust. The environment around it has no bearing on it. This navigation system makes AGVs less expensive and more productive.

2.3.2 Laser Guided Navigation

Each Laser Guided Vehicle is outfitted with a Navigation Laser (also known as a Navigation Device) located on the top of a pole that interacts with objects in the AGV operating area (Vale et al., 2017).

The Navigation Device broadcasts a 360-degree pattern of revolving laser arrays. Several reflector targets are reached by these arrays. Reflectors are 20-inch (60-cm) high reflecting tapes or cylinders that are placed in facility constructions such as columns, walls, poles, and so on. The reflector center must be at Navigation Device height and at least 100 feet (30 meters) away from any AGV. Reflectors send the laser array signal back to the AGV Laser Navigation Device (Yong et al., 2017). Depending on the AGV manufacturer, LGVs calculate and correct their positioning between 30

and 40 times per second. These devices are incredibly accurate. This type of AGVs installation is easy and quick. It is not suitable for using dusty environment.

2.3.3 Natural Navigation

SLAM Navigation, or Simultaneous Localization and Mapping, is the most significant technology (SLAM). It means that an AGV equipped with SLAM Navigation can map its surroundings and determine its location based on information gathered from them. AGVs may map their surroundings using various AGV sensors such as vision cameras, lidar sensors, or even the same lasers used for safety. All of this information is integrated with an internal inertial measurement unit (IMU) to define and recalculate the actual AGV placement. All these computations are performed by SLAM, a complicated algorithm. As a result, SLAM is more of a notion than a working technique (Zhang et al., 2021). It is easy to install and modify in case of layout changes. Installation is fast and quick. Due to the changeable surroundings, Autonomous Mobile Robots with Natural Navigation may have "orienting" issues in industrial and/or complex regions. In other words, if the environment is too chaotic, the robot will be unable to locate itself (Moshayedi et al., 2019). Vehicles with good and reliable natural navigation are still more expensive if compared to other technologies.

For designing AGV system one of the most important things is selecting best type of navigation method (Zhou et al., 2022). AGV systems are design for different needs some facilities use AGVs because of the cost advantages beside labor cost, some of them use because occupation risk, some of facilities use prevent to damage of product, some of them use because of it is monitor easily. There are 3 main types of navigation methods. Facilities can prefer navigation according to their aim of use AGV. Table 2.2 shows advances and disadvantages of each navigation methods.

Table 2.2 Navigation Methods

Navigation Method	Investment Cost	Contraction/ Infrastructures Cost	Maintenance Cost	Sensitivity	Speed	Flexibility
Line Follow	Low	High	High	High	Low	Low
Laser Navigation	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Natural Navigation	High	Low	Low	Low	High	High

Line follows navigation's initial invest cost is very low than others, but magnetic tapes are easily damage and it must regularly change this tape. When layout change it is hard to redesign AGV roads (Wang et al., 2019). Laser navigation's initial cost is much expensive than line follow navigation but it is easier to construct the system. It is not suitable for dusty environment. When layout change in facility it is much easy than change AGV route. Natural navigation's initial invest cost is quietly higher than other navigation methods. It nearly does not have any constriction cost. Doing layout changes is very easy.

2.2.4 Battery Types

AGVs are vehicles that run on batteries. Battery charging is often conducted using either an opportunity charging approach or a full cycle charging technique. The opportunity charging approach charges the batteries while the car is stopped at a station (Abderrahim et al., 2020), The full cycle charging approach necessitates the AGV being pulled out of operation by directing it to a specified charging place. The battery in this technology can be charged manually or automatically on the vehicle (Hammond, 1986). Furthermore, the drained battery may be exchanged with a charged backup battery.

2.2.5 Advantages of AGV Systems

AGV systems significantly reduce labor cost because AGVs are unmanned vehicles, and they are transferring components without human control. This gives opportunity to more flexible movements and it is easy to manage material handling operations. They ensure effective inventory control. It causes flexible manufacturing. AGVs provide traceability, it is quite easy to make changes to AGV systems, they are not affected too much by layout changes. This provides flexibility in the system.. In traditional transportation methods, there is a need for labor to transport materials from place to place. Since the AGV operates unmanned, the lab reduces the cost. Systems pay for themselves in a short time.

2.4 Literature Review

AGV systems are frequently reviewed in the literature in recent years. Handling operations play a significant role and has impacted overall performance, efficiency, and effectiveness of final product cost (Ryan, 1988). Reduction in handling operation costs will have a significant impact on overall costs. With the expansion of flexible manufacturing systems, the large-scale use of robots such as AGVs and other computer-controlled machines has become popular. According to Fazlollahtabar (2015), over 20.000 AGVs are used in all around the world for different purposes. The reasons for being extremely popular these systems, they significantly reduce labor cost, are much safer than forklifts also increase transportation cost.

AGV systems with good designs can save costs, however creating an AGV system is quite difficult since there are so many choices that have a direct impact on how well the system works. Numerous elements need to be taken into account while developing an AGV system. These factors include the quantity of units to be transported, the points in time at which they can or must be transported, the vehicle's capacity and speed, the system's cost, the system's design and guide path, traffic congestion, vehicle

dispatching techniques, and the quantity and location of pick-up and delivery points (Saputra, 2021). In this study, three main AGV system problems are investigated. These are routing, scheduling, and fleet sizing problems. Alternative solution methods have been applied to these problems in the literature. In this section, the studies and methods that are used are examined.

When the literature is reviewed from the routing perspective, the selection of a certain route mainly affects the performance of the system. The longer it takes to transport a job, the fewer the jobs that can be handled within a certain time (Arifin, 2000). Main purpose of the routing problems is to minimize the total travel distance of an AGVs. Xing et al. (2020) used novel tabu search algorithm for improve the efficiencies of picking goods of automated guided vehicles. Soylu (2000) applied neural network approach to find the shortest tour for a single AGV. Bi-Level Path Planning Algorithm is presented for avoiding the AGV path conflicts. Yuan (2020) used a dynamic programming method for supervisory control of multiple automated guided vehicles that are traveling within a layout of a given warehouse. The route planning problem to minimize the total transportation time is formulated by Nishi and Maeno (2005). They proposed the petri net decomposition approach to reduce computational complexity.

When the literature is reviewed from the scheduling perspective, it is necessary to prioritize the intersecting paths in systems where more than one AGV is used. At the same time, prioritization of critical components service is also important for the performance of production systems. Zou (2023) applied iterated greedy algorithm for minimize the total cost of the system. Xue (2018) solved the scheduling problem with reinforcement learning method. Aim of this study was minimize the average job delay and total makespan. Nishi et al. (2016) developed a mixed integer programming model to minimize the total weighted tardiness of the set of jobs related to these tasks. Goli et al. (2021) designed a new cellular manufacturing system which used a set of automated guided vehicles (AGVs) which were responsible for transporting parts between cells. They developed a hybrid genetic algorithm and a whale optimization algorithm. Mousavi et al. (2017) developed a mathematical model and integrated with

evolutionary algorithms (genetic algorithm particle swarm optimization, and hybrid) to optimize the task scheduling of AGVs with the objectives of minimizing makespan and number of AGVs while considering the AGVs' battery charge.

When the literature is reviewed from the fleet sizing perspective, one of the most important factors in implementing an automation is the cost of the system. The main goal of every business is to maximize the profits from the product sold. The less money spent on the production, transportation, and other activities of the product, the greater the profit will be. Accurate calculation of the fleet size is especially important for AGV systems, as the fleet size will directly affect the initial investment cost, maintenance, and repair costs. If more AGVs are purchased than the needed, the cost will increase, if less AGVs are purchased, the need will not be met. In the literature, the studies conducted to determine the fleet size were examined. Pjevcevic et al. (2011) simulated a real system and changing the metrics of the AGVs found the fleet size of AGV system. Rahimikelarijani et al. (2020) developed a non-linear mathematical model for reduce system penalty cost up by using the multiple load AGV instead of single load AGV. Rjeb et al. (2021) concluded the optimal types and number of robots for multiple types by formulating an integer linear model.

According to the literature review, initial studies were only focusing on routing of one AGV where main aim is on to decide on the path and AGV priority of the intersecting paths. Technology has seen great advance in the last years. By these advances, new types of AGVs are used in facilities to meet unique needs. It has become common for businesses to use several types of AGVs on the same route. While initial studies have focused on determining the fleet size of one type of AGV, recent studies have focused on determining the fleet size of multiple types of AGVs. This study will also focus on determining the fleet size of a real manufacturing system by using simulation method. In the literature, simulation method is used complex systems because it is possible to testing in different conditions. That is why we are simulated system with Arena Simulation Software (Rockwell Automation, 2014) and tested for different conditions for finding best solution.

CHAPTER THREE

SYSTEM DESIGN PROCESS

The interconnected, agile, and iterative methods used in system design lead to a confirmed set of requirements and a design answer that lives up to stakeholders' expectations

In this context, eight stages. The first stage, system planning is described in Section 3.1. The second stage, system analysis is explained in Section 3.2, this is followed by the current system analysis in Section 3.3. After, assumptions of current systems are given in Section 3.4 and current systems simulation is explained in Section 3.5. Then, pros and cons of current system are discussed in Section 3.6 and alternative system design is given in Section 3.7. Finally, the chapter is ended by verification and validation of the simulation model in Section 3.8.

3.1 System Planning

It consists of the idea that feeds the purpose of establishing the system. This idea offers innovations for the future of the system. Thus, plans begin to be made to realize this idea (King et al., 1988).

Employees in the current system are generally insufficient in sending products to the lines. There are downtimes due to line product waiting. In addition, the area open to pedestrian traffic and forklift areas are intertwined. This causes a job security risk. The aim of this study is to eliminate inefficiencies during transportation, to make the work area safe and to reduce material-induced line stops to zero.

3.2 System Analysis

Project goals are now translated into the specified operations and functions of the expected application. This includes obtaining and analyzing data, identifying issues, and making system improvement suggestions (Whitten et al., 1986). Analysis of end-

user information requirements and elimination of any contradictions and gaps will help the project achieve its aims.

3.3 Current System Analysis

Simulation is an imitation of a real system, to improve performance (Harrell, 2000). It allows users to predict how the system will behave in risky investments where the system installation cost is high. It is also used to prevent faulty and unnecessary investments, understand system performance based on key metrics such as costs, throughput, cycle times, equipment utilization and resource availability (Bowen et al., 1997). Time study method is used for analyzing the component's arrival time. It is a trial and tested method of work measurement for setting the standard times for carrying out specified work. The aim of time study is to establish a time for a qualified worker to perform specified work under stated conditions and at a defined rate of working.

After the time study, inputs are analyzed, and system is simulated by using a simulation software. Discrete-event simulation (DES) represents a system's functioning as a series of occurrences in time. Each event occurs at a certain point in time and represents a change in the system's state (Robinson, 2005). Because no change in the system is believed to arise between consecutive events, the simulation time can directly leap to the occurrence time of the next event, which is known as next-event time progression (Wedemann et al., 2014).

In this study, Arena Simulation Software (Rockwell Automation, 2014) was used to simulate the system. A small sample of the system planned to be built with this program is animated on the computer. The outputs obtained were observed and the system was run repeatedly by changing certain parameters, the results were examined, and the method that gave the best results was tried to be determined.

In the current system, the products are in a warehouse. Products from these warehouses are transported by a forklift. A production plan is created upon requests

from customers. Based on this plan, the required component requirement is determined.

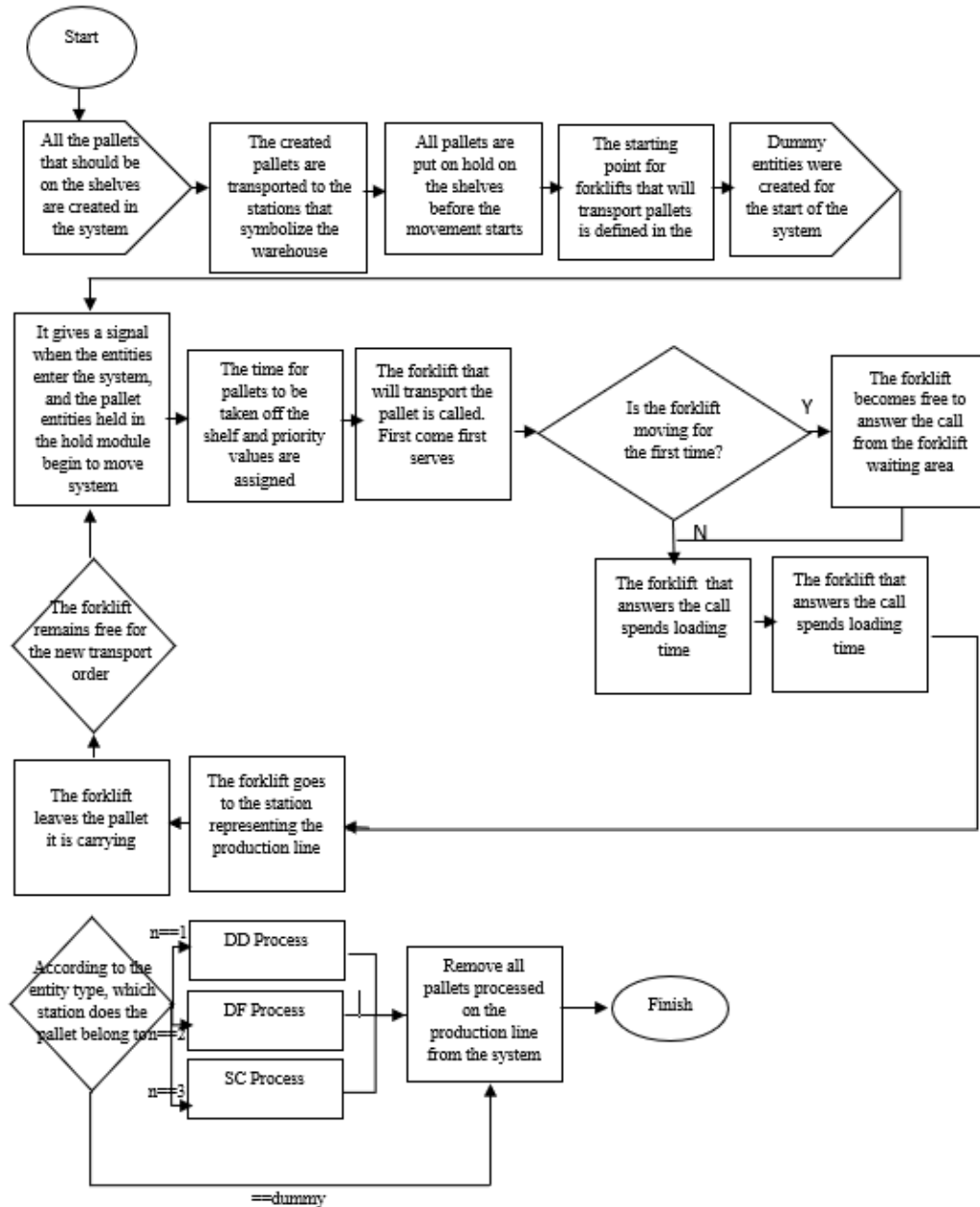


Figure 3.1 The Flowchart Created for The Simulation Model of The Current System

All pallets must be on the shelves. Pallets are shipped to the relevant warehouses. Forklifts take the pallets to defined areas. From here, leaves the products to the line of whichever line he transported the product to. When leaving the products, it takes a certain amount of time for the material to be placed on the ground and placed. The

forklift that drops the pallet becomes free. The next job is assigned to the free forklift and the forklift starts operating.

3.4 Assumptions of Current System

Assumptions for simulating the system are listed below.

- Forklift speed is average 1,8 m/sec. the speed of the vehicle is going at a constant speed, on different surfaces. It is accepted that the speed of the vehicle is always constant.
- The lifting speed of the forklift blade is the same everywhere, regardless of the location.
- The forklift can only carry one pallet at a time.
- There are 14 products in a pallet for model 1, and there are 20 products in each pallet for models 2 and 3. The missing product quantities in the pallets are ignored.
- The system works on the principle of first come first served.
- The model 1 is stored only in the loc 1 rack, the model 2 is stored only in the loc 2 headlight, and the model 3 is stored only in the loc 3 rack.
- It was assumed that the path of the forklift truck is constantly empty while it is carrying the load, there are no obstacles such as pedestrians and materials in front of it.

3.5 Current System Simulation

The system works with a forklift truck. As a result of the scenario analysis, it has been determined that 3 forklifts operate at full capacity and bringing the resources running the line to the highest utilization rates. Details are given in the following sections. From here on, the design of the model is explained:

Create 1-2-3 modules include pallets that are moved into the system. The Entity Types are given as “I_modelPalet”, “II_modelPalet”, “III_modelPalet” respectively according to the palettes. Entities are sent all of them at once because they show the assets to enter. Thus, 100 pallets of each product are considered in this case. Max Arrival refers to the number of times that assets are sent to system. It is limited to 1

for sending them all at once. The other values can be left as in the beginning. Station 2-3-4 modules are the stations that represent warehouses. The main purpose of the Station module is to create a location for the asset to be traded, so that it can be checked where the asset is or may be. As in the model, the entity received into the system is redirected to the corresponding store by connecting directly after the Create module. But since the Station module itself does not serve as a warehouse, it should leave this task to a module that comes after it. This is the Hold module for our case. The main purpose of the Hold 1-2-3 modules is to keep the assets they contain in them until a signal arrives or a certain condition is met. Selecting “Wait for Signal” as the Type in this model is linked to the Signal module in the following sections. Wait for Value indicates which Signal module it is connected to. In other words, for example, if a pallet goes to the DD line to exit the warehouse, the signal number 1 should be given so that the Hold module allows the exit of the corresponding pallet. The limit is an indicator of how many assets leave the Hold module at one time. For the current model, this is one palette at a time. The other values can be left as they were at the beginning.

Assign 1-2-3 modules to assign a set of properties are used to assign to an entity, like attributes, variables, etc. For this model, three attributes are assigned to our assets. The first one is StoreLocX, that is, the horizontal position of the pallet to be transported. It randomly assigns the palette to different locations from 1 to 4 depending on the discrete probability. The second is StoreLocY, that is, the vertical position of our pallet, depending on the blade lowering and lifting speed of the forklift truck, it lengthens and shortens the transportation time by even a second. Thirdly, qEntTime assigns the time when the asset leaves the Hold module as a value using the TNOW function in order to determine priority. It takes priority from a pallet that goes to the SC line that leaves the Hold module per minute because the system works according to FIFO. Request 1-2-3 modules call a transporter to transport the asset it hosts. For our model, this transporter is a forklift truck. Therefore, when the module is opened, the forklift truck in the Transporter Name section is defined. The important point here is that the qEntTime attribute assigned in the previous module is used. When the Priority part is examined in the default state, it is seen that the importance of the value increases as it decreases. But it doesn't necessarily have to be an integer. Accordingly, qEntTime is used, the value is transferred from the system time, and assigned the asset

that made the request in advance as a priority. The other values can be left as they were at the beginning. The purpose of the Delay 1-2-3 modules here is only to stall the forklift when it comes to the system. Therefore, the Delay Time and Units should be given depending on the working time of the forklift. For the current model, the forklift spends 20 seconds of preparation time, while in addition, the knife lifting, and October loading time is also included in this. At this point, the StoreLocY attribute is activated, it determines how the position in the vertical affects the duration. according to the formula $20 + \text{position} * \text{blade time} * 2$ (multiplying by two is due to the consecutive lifting and lowering actions), the time is calculated and included in the Delay Time as an expression. The unit is a second; the Allocation is given as NVA. Transport 1-2-3 modules ensure that when the forklift truck pallet is loaded, it is transported to the corresponding line. The Transporter Name is selected as a forklift, while the Station Name is determined as Station 5 for Transport 1, Station 6 for Transport 2 and Station 7 for Transport 3 according to the model. The station names are detailed in the next stage. The other values of these transport modules that can be left as they were at the beginning.

The following design is obtained after an overview.

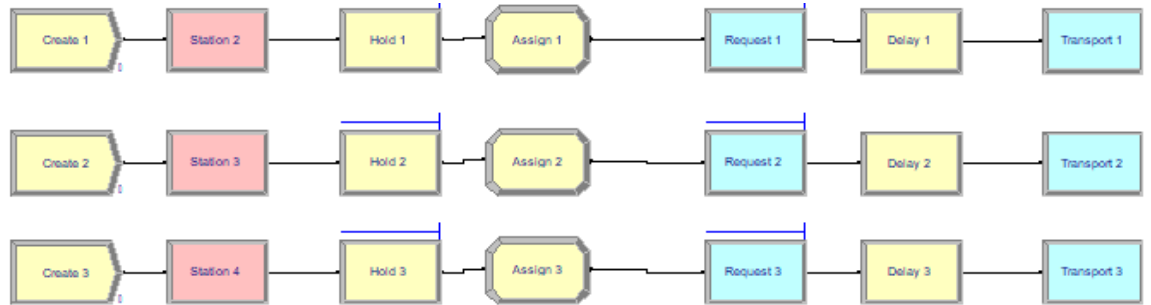


Figure 3.2 Current System Simulation

In turn, assets (i.e. pallets belonging to three different models) enter the system, they are assigned to the stations where their warehouses are located; they are directed to the Hold module for storage, they leave the Hold module with the arrival of the signal to get on the line where they are processed, and their parameters are assigned by Assign, they make a request for the carrier, the carrier spends time loading when the forklift arrives and gets on the right track to the line where it is processed.

Create 4-5-6 is installed to send dummy entities to the system. The purpose of III. that it is used to trigger the Hold module and send the assets inside it out. Because at the beginning, all the assets are stuck in the Hold module and cannot progress through the system. “Dummy” is given as the Entity Type, Entities per Arrival is 1, entity is sent to the system at once; Max Arrivals is 1, because this Create was added to the model for the first trigger operation. For the First Creation Create 4-5-6 modules, respectively, are given such small periods of time that it does not matter, for instance 0.001-0.002-0.003. When it comes to the Signal module the first three of the Station 5-6-7-1 modules are used to define the DD, DF and SC lines, while the last one, Station 1, is used to define the “forklift waiting area”. Delay 4-5-6 modules are the time to leave the pallet carried by the forklift truck on the line. the constant is defined as 12 sec NVA. Free 2-3-4-1 modules allow the forklift truck to release the asset even after moving it. After this point, the forklift comes to, and the asset flow follows. The Transporter Name must be given as a forklift truck.

Signal 1-2-3 modules are structures that activate Hold 1-2-3 modules respectively. The first entities that pass over them are the dummy entities. These dummy entities give their first commands to the modules, order them to release the first ones from the pallets accumulated (i.e. stored ones) in the Hold modules. When the pallet assets move within the system at the corresponding Signal module, it activates it again and asks it to send another pallet from the warehouse. In other words, when a pallet arrives on the line, a new one makes a request for the carrier. The Signal Value indicates which Hold module the corresponding Signal module will communicate with. For example, a module with a Signal Value of 3 can trigger a Hold module or all modules with Wait for Value values of 3 in their modules (i.e., more than one module can also trigger a Signal). For this model, Signal 1 has a value of 1 and triggers the Hold 1 module. The same logic works in the other two products (i.e., the values of 1 change to 2 or 3). The Decide module is installed to properly direct the pallets coming to the lines and take the dummy ones directly out of the system. It distributes assets in accordance with the N-way by Condition rule. 3 conditions are entered, and these conditions are Entity Types. I. the Entity Types that we define in the article are written in the Named section. Then it is associated with the processes representing the relevant lines. The process 1-

2-3 modules represent the operation of the DD, DF and SC lines. Seize-Delay-Release is selected as the action, so the line worker can process the products in the incoming pallet. The processing times are defined as fixed, formula-dependent, in minutes and VA. The formula is calculated as $60 / (\text{hourly product capacity} / \text{number of products per pallet})$. It shows how many minutes a pallet can be processed. The Dispose module, on the other hand, removes pallets that have finished work in the Process modules and dummy assets are sent to trigger the Signal modules at the beginning of the simulation from the system. Therefore, assets that come through Process modules and do not return to Process modules in Decide to end up here.

The following design is obtained at the second stage:

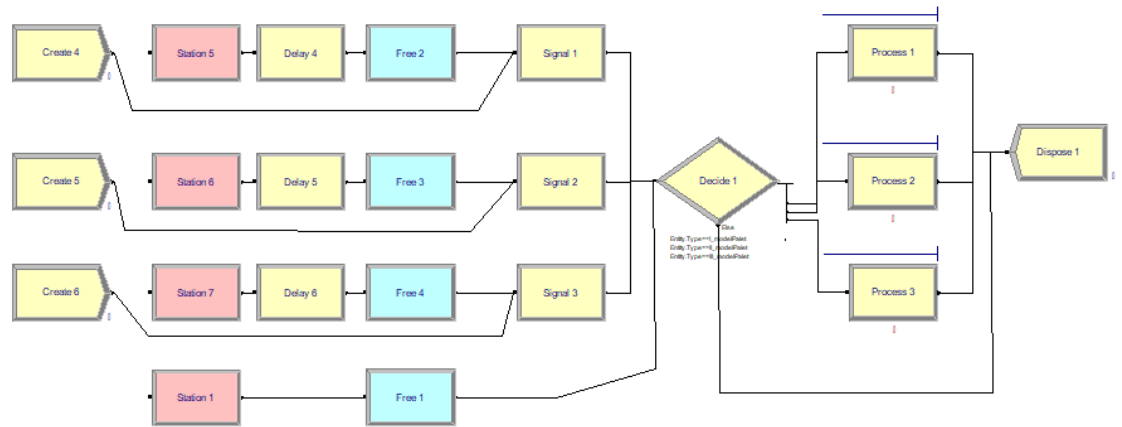


Figure 3.3 Lines Simulation

Dummy assets are sent to the system at the beginning of the simulation to take the first asset out of the warehouse, direct signals are triggered, then they are removed directly from the system by passing through the Decide module. The asset depart from the warehouse arrives at its station on the line. A short time passes for the forklift to drop the pallet. The forklift and pallet are separated (released). A signal is given to send a new pallet to the warehouse; the pallet is directed to the process of the relevant line; it is removed from the system after processing.

Which is output by adding the Trace module via Elements in the .out file, it can be tracked at which stage each entity is at which time. They are used for verification and validation along with animation.

On the Advanced Transfer tab, go to the Transporter table. Since forklifts in the request and transport modules are defined, the forklift row appears automatically in the table, but the data placed. The Number of Unit represents the number of forklifts moving in the system. Therefore, while conducting our scenario analysis, it is checked the value changes by playing only this number. The Velocity and Units are re-entered value by converting the unit to hours because the forklift truck speed is requested to be 1.8 m/s; this makes 6480 units/hour. The Initial Position Status will be used to define the position of the forklift truck at the beginning of the simulation. This is a small table in the attribute; when “Station” is selected as the Initial Position, it will make us select one of the Stations we have defined in the Station. Station 1 is also selected, which represents the waiting area, here and initial status is given value as Active because the forklift is running. Other values can remain as they are.

Again, go to the Distance table under the same tab. The forklift is automatically installed because the forklift is added. The distance attribute has been created, but the data has not yet been placed. “0 rows” located in the Station column and on the same row are selected, and another new, small table is opened. Starting Station and Ending Stations are selected. The distances between other stations are also calculated by assumption and placed in this table.

To calculate how many times we need to replicate the system, the system is first run for 10 replications. The simulation is run 10 times, the Replication Length is given as 960 minutes and the working time of 16 hours (i.e., 1 day) is given for the facility working 2 shifts of 8 hours. The error value presented by the model is desired to be 80%.

Validation parameters will be “Total Output Pallet”. The average obtained from the observations is 120 pallets per day for the real system. T-test will be performed. The H_0 hypothesis is that the average "Total Out Pallet" value It is obtained from the simulation is equal to 120, and the H_1 hypothesis is that it is not equal to 120.

$$t_0 = \left| \frac{\text{mean of model} - \text{mean of current system}}{\frac{\text{standard deviation of model}}{\sqrt{\text{replication quantity}}}} \right|$$

$$t_0 = \left| \frac{120,3 - 120}{\frac{0,4830}{\sqrt{10}}} \right| = 1,9640$$

$$t_{crit} = t_{0,025,9} = 2,262$$

The t_0 value is obtained with the help of the formula given, and the t_{crit} value is obtained by looking at the table. If $t_0 > t_{crit}$, the H_0 hypothesis is rejected, the simulation mean is not equal to the real mean and cannot be validated. If $t_0 < t_{crit}$, the H_0 hypothesis is accepted, the simulation mean is equal to the real mean and is validated.

The key indicators of the system, in which 3 forklifts operated with 10 replications carry out all the transportation, are listed below. The simulation is run by setting the number of replications to 10 to start. Even if the error value of the "AGV Utilization" parameter (that is, the half width value we see in the model output) is low, a lower error value can be achieved by increasing the number of replications.

$$Replication\ Quantity = \left(t_{0,025,9} * \frac{Standard\ Deviation}{Error\ (Half\ Width)} \right)^2$$

$$\left(2,262 * \frac{0,00013}{0,000091 * 0,8} \right)^2 = 15,66 \sim 16$$

In other words, if the number of replications is increased from 10 to 16, the theoretical half width of the error value will be reduced to 80%.

When the system is simulated, it seems that 3 forklifts are needed in the scenario that works in the most optimal way. There should be 3 forklifts. Forklift on models operated for 1-2-3 forklifts. While the utilization value is very close to 1, when higher numbers are reached, it converges to ratios such as 0.75, 0.60, 0.50, respectively, and does not contribute to the Utilization values of DD_isci, DF_isci and SC_isci resources.

3.6 Pros and Cons of Current System

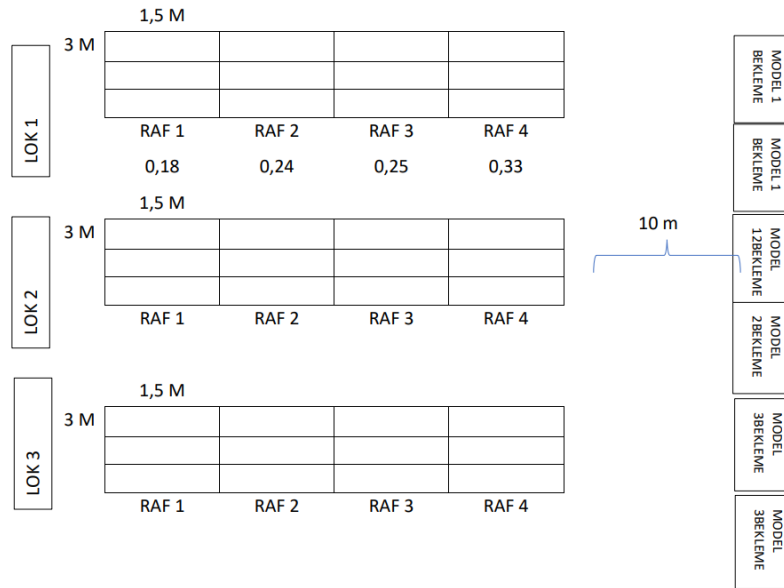
Manually operated systems have advantages such as decision making and taking initiative. Automatic systems cannot go beyond the fictional scenario. Manual management of the transport system in the enterprise provides it with agility. This agility ensures the continuity of production in unexpected situations. It enables to take quick action in cases such as changes in the production plan and the arrival of urgent orders.

In the current system, the waiting times are too long. In cases where the product is not taken from inside the elevator, the elevator cannot be used. It is not possible to measure or monitor the performance, speed, and agility of the transport system. Due to the human factor, fatigue and breaks are experienced. This causes inefficiency. The late arrival of the components to the lines causes line stoppage.

In the current system, the risk of occupational accidents is 54. It could be maximum 100 and it is 54 it means it has quietly high risk for accident. Work accident caused by forklift is frequently experienced. Since the workers do many different jobs besides sending the material, there are delays in sending the materials. In addition, problems such as dropping materials from forklifts are observed.

3.7 Alternative System Design

In the current system there are 3 types of components is in 3 different locations and 3 different components feeding 3 different production lines. In the alternative system AGV can transfer more than one pallet because it has no EHS limitations. Also, AGV can use pedestrian ways and it is an advantage because distance between drop point and load point decreases.



Since AGVs can also use the pedestrian path, the distance that the vehicle needs to take with the line has been reduced. This the distances are as follows:

Table 3.1 Current System Data

MODEL	Line	Production Rate (pc/h)	Material Quantity on A Pallet	Distance between Loading point and DP
MODEL 1	DD	140	14	780 m
MODEL 2	DF	220	20	690 m
MODEL 3	SC	270	20	2100 m

The same model can be used because the single pallet transportation condition of the AGV does not require major changes to the forklift truck model; only the Distance and speed parameters have changed and the AGV has been written instead of the forklift. Results are available in the zip file; it will not be transferred to this part of the document. It can be said with certainty that the AGV works better than the forklift due to the shortening of distances and the faster movement of the AGV.

From here on, the model to be described is of a slightly different structure than the previous one. The purpose of this different model is to simulate the transportation of multiple pallets, and a process was added before which the pallets were transported to

the waiting areas one by one. As a further difference from the first model, this model will be expressed in three stages:

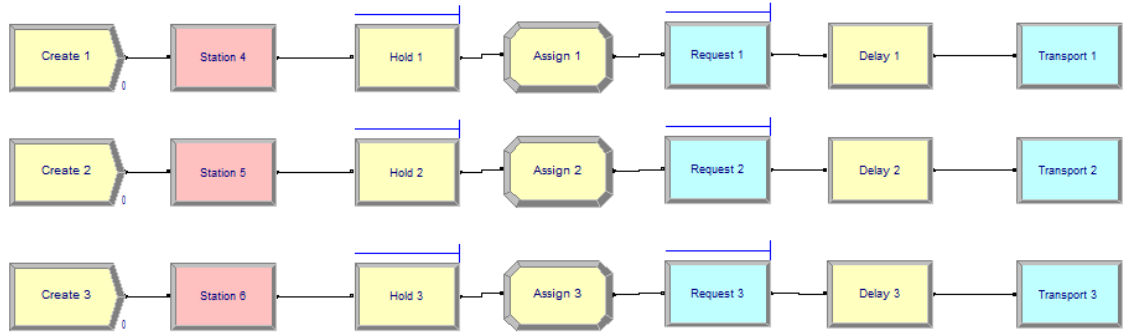


Figure 3.4 Alternative System Simulation

The structure above is similar to the first stage of the first model, but there are some basic differences:

- Considering the increase in efficiency in Create modules, 250 entities will be included in the system at once, not 100 anymore,
- 3 different waiting areas for 3 different products are added to the system by removing the forklift truck waiting area; they will represent Station 1-2-3 waiting areas, Station 4-5-6 warehouses and Station 7-8-9 production lines (there are warehouses as in the first model above)
- The Limit in the Hold module is now connected to an attribute named multiPalet instead of a fixed number 1 (this attribute will also appear frequently in the future and will form one of the columns of this model)
- There are no changes to the Assign, Request and Delay modules, they are the same as the previous model,
- Transport 1-2-3 then directs assets to waiting areas instead of production lines (i.e. Station 1-2-3).

The following path is now followed for the pallets transferred from the warehouse to the waiting areas:

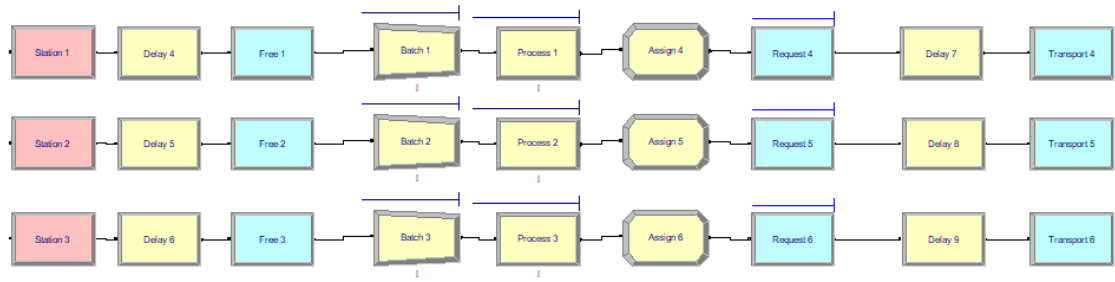


Figure 3.5 AGV System Simulation

The following path is now followed for the pallets transferred from the warehouse to the waiting areas:

- The pallet coming with Station 1-2-3 modules enters the waiting area,
- Delay 4-5-6 modules are for AGV to spend time while leaving the pallet in the waiting area,
- Free 1-2-3 modules free the AGVs to perform other transport tasks,

Batch 1-2-3 modules Deconstruct multiple entities into a new entity by combining them into one. For example, when 20 canned goods are packed in a canned food production facility, they start moving together, the unit price changes, then the processes they will see change, etc. At this point, we no longer start talking about cans, but parcels; the entity has changed its unit and qualities. In our model, this will be the case because we will carry more than one pallet at a time. The type must be set to "Temporary" so that this new entity can be dispersed and returned to its old form later in the simulation. Batch Size is defined as a "multiPalet" attribute, which will make our job easier for 2/3 pallet transitions for simulation. To define the multiPalet attribute, we must first go to the Elements tab, where we also get the Trace module. From there we need to embed the Attributes module into our model (it does not need to relate to any module because it is an element). After placing the module, we must write a multiPalet to the Name as a new attribute, give its Number 1, and enter in the Initial Values section the pallet constraint that we will work only for this model.

- Assign 4-5-6 modules make the qEntTime assignment for FIFO to the new entity,

- Request 4-5-6 modules for the new asset (i.e. pallet stacks) AGV calls,
- Delay 7-8-9 modules pass the loading time of the AGV,
- The Transport 4-5-6 modules direct the AGVs to the relevant production lines (i.e. Station 7-8-9).x 2 if it can carry 2 pallets, 3 if it can carry 3 pallets)

At the third and final stage, the incoming pallet stacks now enter the production lines by becoming normal pallets again, and then leave the system. The processes can be modeled as follows:

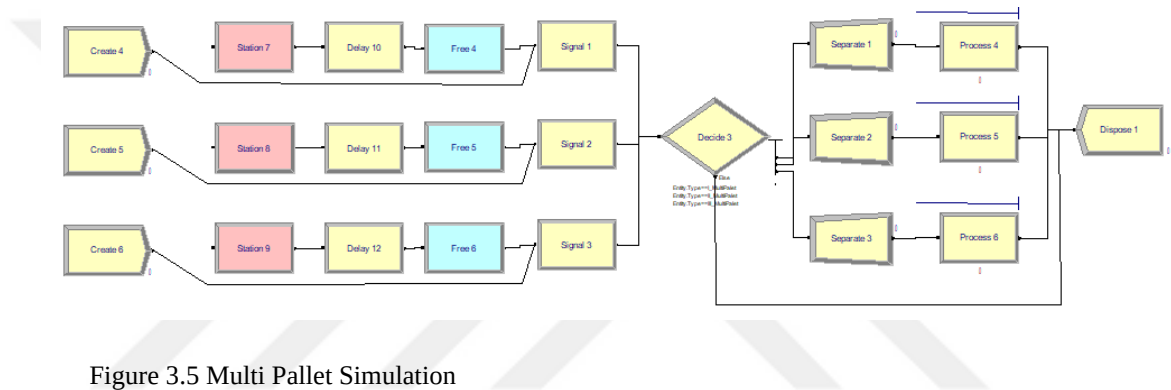


Figure 3.5 Multi Pallet Simulation

- Create 4-5-6 modules again perform the same task as in the previous model, introducing dummy assets into the system and ensuring the beginning of the flow,
- Our pallet stacks are starting to enter the production lines via Station 7-8-9 modules,
- With the Delay 10-11-12 modules, the time AGVs spend leaving pallets is simulated and increases in direct proportion to 12 times the number of pallets per second for the model (we use the multiPalet*12 formula in the definition of time),
- Free 4-5-6 modules release AGVs to return to the warehouse or waiting area,
- Signal 1-2-3 modules are again associated with the Hold modules in the same function as the previous model and signal the pallet exit from the warehouse,

- The Decide module directs pallet stacks to the relevant production lines while removing incoming dummy assets directly from the system,

The Separate 1-2-3 modules Decouple the assets (i.e. the pallets themselves) that are put together with the Batch modules in the second stage. The type is set to "Split Existing Batch", Process 4-5-6 modules are the same as Process 1-2-3 in the previous model. All assets exit the system from the Dispose module, which is the last stage.

Even if the Transporter and Distance elements are defined, they are still empty inside. a movement of 2 m/s means an hourly speed of 7200 m/h, and the Velocity value of the AGV is equal to this; the Initial Position can also be set as Station 1. AGV. The distance table reaches 33 rows this time because it will have more routes (the distance values are included in the model file) (8m between waiting areas, 10m between warehouses, 13m between a product's waiting area and its warehouse were taken). Dec. the distance table will have more routes this time (distance values are included in the model file).

3.8 Verification and Validation

The list of steps followed to check Verification and response actions are listed below:

- Create the simulation in the form of subprograms: The stages in our models are designed with this logic. If a new product is added to the system or a product is removed, the flow of another product will not be disrupted.
- The stages in our models are designed with this logic. If a new product is added to the system or a product is removed, the flow of another product will not be disrupted: For example, when designing the flow initially, the pallet restriction was entered into each module manually. Later, the entire simulation output was changed by changing a single value by connecting to an attribute.
- When preparing the simulation model, opinions should be obtained from more than one person: This project designed with the company. There was a project

group for building and controlling model, this group has been attended all stages for analyzing the need.

- Use the trace module: There is a Trace module in each model. .in the out file, the movement of each entity can be tracked instantly.
- Check its logic: Each stage has been described in the finest detail in this document and made easily controllable by others. It was confirmed that alternative scenarios also did not create errors in the model.
- Use animation: Model analysis has been made easier with animation. When AGV movements were examined, no overlooked or missing movements were detected.

Validation checks the accuracy of the model's representation of the real system. Model validation is defined to mean "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". It was observed whether the model worked in accordance with the current system. The model works in accordance with the parameters of the system. For validation, the system was tested at 95% confidence interval.

The following sequence will be followed to validate the simulation model according to the real system:

a. Which data obtained in the current situation will be considered as validation parameters?

The answer to this question will be "Total Output Pallet". The average obtained from the observations is 120 pallets per day for the real system.

b. Which method will be used?

T-test will be performed. The H_0 hypothesis is that the average "Total Out Pallet" value It is obtained from the simulation is equal to 120, and the H_1 hypothesis is that it is not equal to 120.

The t_0 value is obtained as 1.96640 with the help of the formula given (Banks et al., 2014) and the t_{crit} value is obtained by looking at the table. If $t_0 > t_{crit}$, the H_0 hypothesis is rejected, the simulation mean is not equal to the real mean and cannot be

validated. If $t_0 < t_{crit}$, the H_0 hypothesis is accepted, the simulation mean is equal to the real mean and is validated.

Table 3.2 Results

Replication	Forklift Utilization
Replication 1	0,988159722
Replication 10	0,988263889
Replication 2	0,988263889
Replication 3	0,988229167
Replication 4	0,988489583
Replication 5	0,988090278
Replication 6	0,988142361
Replication 7	0,988402778
Replication 8	0,98828125
Replication 9	0,988402778
Mean	0,9883
Error	9,10E-05
95% Confidence Interval	0,98818 < mean < 0,98836

The key indicators of the system, in which 3 forklifts operated with 10 replications carry out all the transportation, are listed below. The simulation is run by setting the number of replications to 10 to start. Even if the error value of the "AGV Utilization" parameter (that is, the half width value we see in the model output) is low, a lower error value can be achieved by increasing the number of replications.

CHAPTER FOUR

CASE STUDY AND CONCLUSIONS

AGVs are frequently used to transport materials. AGV ensures the traceability of the transport system, reduces the risk of occupational accidents, and increases efficiency. A properly designed AGV system reduces labor costs and prevents products from being damaged. To provide all these advantages, it is important to design the AGV system correctly. It is necessary to select the AGV type specific to the project and to calculate the fleet size correctly.

4.1 Case Study

This study was conducted in an electronic company operating in Turkey. The company produces approximately 500 thousand units of refrigerants annually. It is a business in a leading position in the domestic market. There are 4 different production lines in the company. In addition, the company has 4 different facilities in the world. The products produced in the facilities here are distributed to Europe, Asia, and America. The company attaches importance to lean production and its goals are to reduce all possible wastes as much as possible and to continue continuous improvement activities.

There are separate shelves for each production line in the production system at the facility. From this shelf, workers pick up the products by forklift and take them to the production line according to the work order. The length of the shelves is three meters, and a worker arranges the products into the compartments of the shelves. This worker places the product on the first shelf with an 18% probability, on the second shelf with a 24% probability, on the third shelf with a 25% probability and on the shelves with a 33% probability of the materials coming by truck. There is a fixed distance of 4 meters Decoupled between each shelf. There is a waiting area 8 meters away from the shelves. The products are sent to the related production line from here. the speed of the forklift is 1.8 meters/second per hour. The blade lifting speed of the forklift is 0.41 meters/second per hour. There are always 14 items in the pallet to be sent to DD, there

are always 20 items in the pallet to be sent to DF line and there are always 20 items in the pallet to be sent to SC line. The forklift truck always moves at a constant speed in turns and on different surfaces.

Material supply is carried out with forklifts here. Forklifts are the vehicles that have caused the most workplace accidents in recent years. The use of unmanned vehicles in this company, especially for occupational safety, will provide digitalization for the company, facilitate data tracking, and improve product quality. In this study, we have focused on three production lines: DD, DF and SC lines. There are different amounts of products in the boxes of the products. simulation method was used to examine the constraints of the system and to analyze how it can work in different scenarios. Material movements were analyzed by simulation. The current situation was compared with the proposed situation, a feasibility study was conducted.

4.2 Output Analysis

The simulation results in this section, the results obtained with 16 replications, are not recorded, in each scenario analysis and replication analysis, it is not considered unimportant as it can be seen from the validation results and the confidence intervals have very small results. The first model was operated by increasing the number of forklifts sequentially and the results in the table below were achieved.

Table 4.1 Results

Forklift Count	Forklift Utilization	I_model Palet Out	II_model Palet Out	III_model Palet Out	DD_isci Resource Utilization	DF_isci Resource Utilization	SC_isci Resource Utilization
1	99,99%	12	11	11	5,36%	6,25%	5,09%
2	99,99%	23	23	22	10,27%	13,07%	10,19%
3	99,99%	46	51	21	20,91%	28,98%	9,72%
4	74,99%	40	38	29	17,86%	22,05%	13,43%
5	59,99%	41	39	29	18,30%	22,16%	13,43%
6	49,99%	40	41	29	17,86%	23,30%	13,43%

Although it is seen that the production quantities increase in direct proportion to the number of forklifts in the beginning, 4. and the extra forklifts added later could not

contribute to production because more than one forklift truck could not move on a single route. This movement restriction is caused by the Arena program itself.

Table 4.2 Production Quantities According to the Number of Forklifts

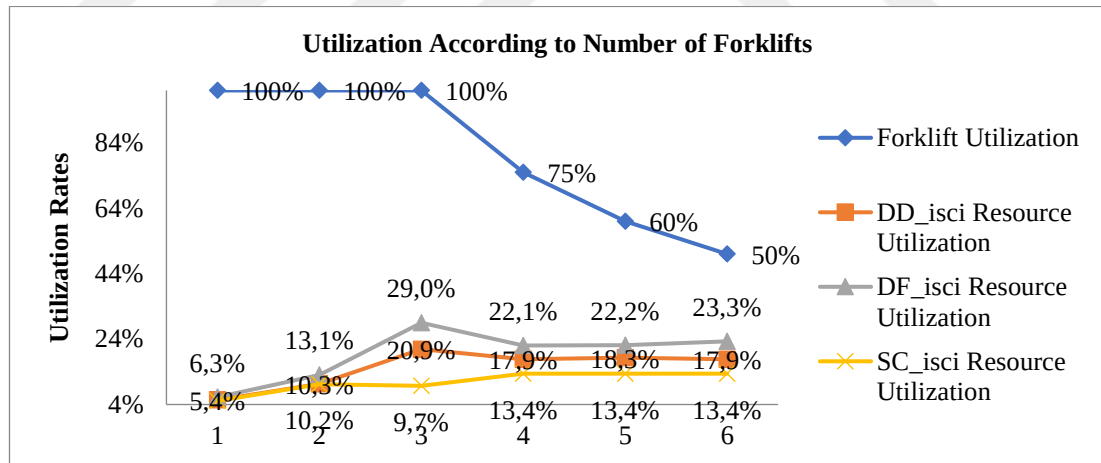
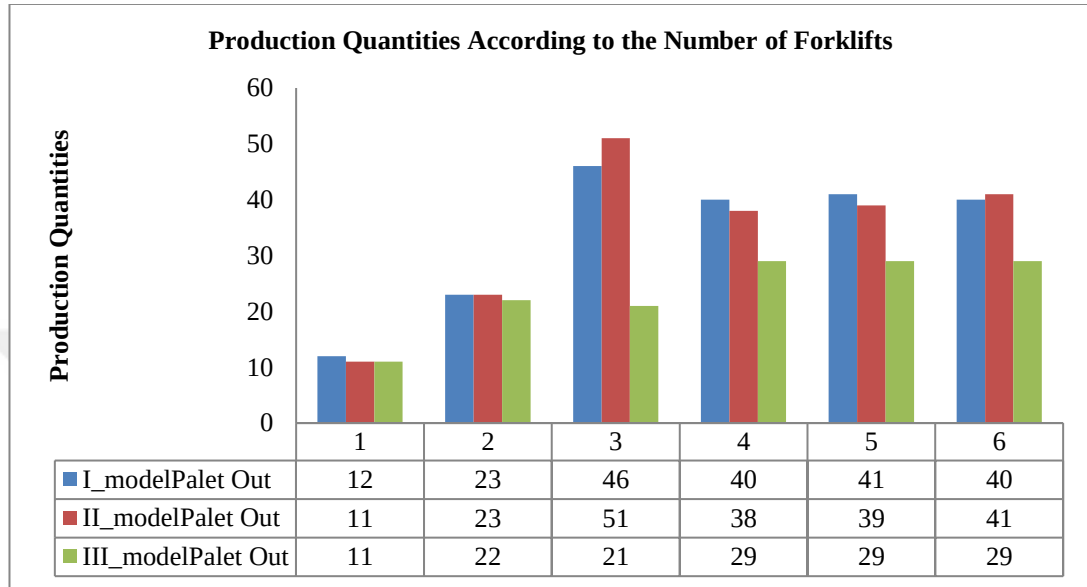


Figure 4.1 Utilization According to Number of Forklifts

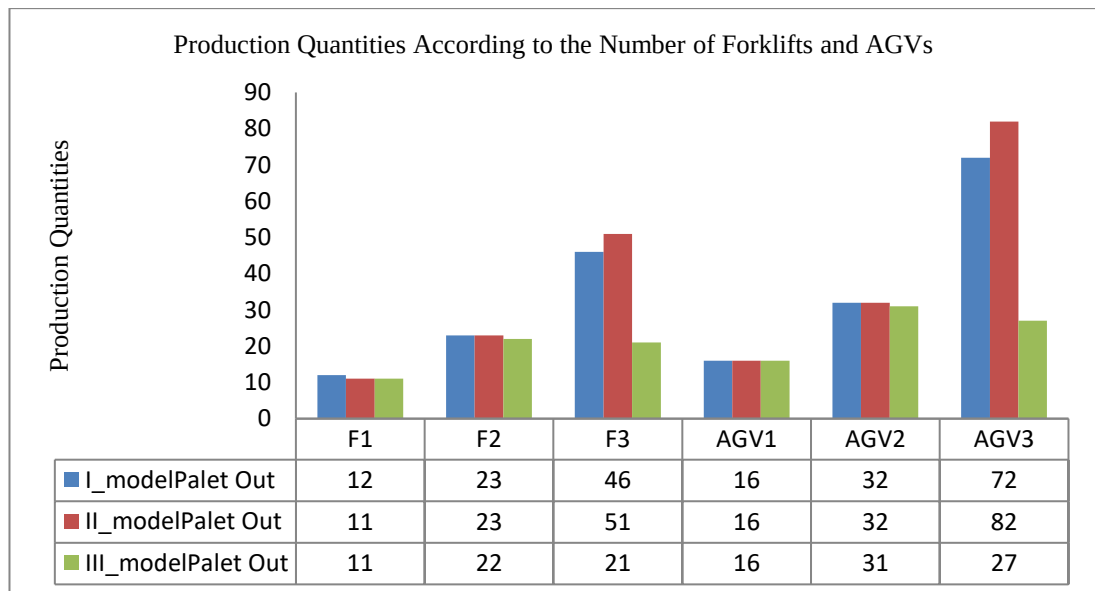
Accordingly, the forklift utilization rate has gradually decreased in the number of 4+ forklifts. the reason why 1, 2 and 3 forklifts can work at full capacity in the system is because production processes occur more slowly than transportation processes. As can be seen from the tables and graphs, the highest labor utilization rates and

production quantities are observed in 3 forklift truck scenarios. Since the transport system is inefficient, there were no queues during production, so their values were not transferred to the tables.

Later, AGV was started to be used instead of forklift. At this point, AGVs are faster than the forklift truck system and the distances between loading and drop points are shorter since they can also use the pedestrian path. This means that if the same number of AGVs and forklifts are used, the utilization of the AGV system will be higher.

A feasibility study was carried out with the available data. The average purchase and installation cost of an AGV is € 45,000. The average rental price of a forklift truck is € 10,000 and the annual cost of a worker to the factory is € 12,000. Currently, 3 forklifts are working in the system. This means that € 66,000 is spent annually on the forklift truck system. If we use AGV instead (since investments that pay for themselves in a maximum of 2 years are allowed according to company policy), we should use a maximum of 3 AGVs so that it can pay for itself in 2 years.

Table 4.3 Production Quantities According to the Number of Forklifts and AGVs



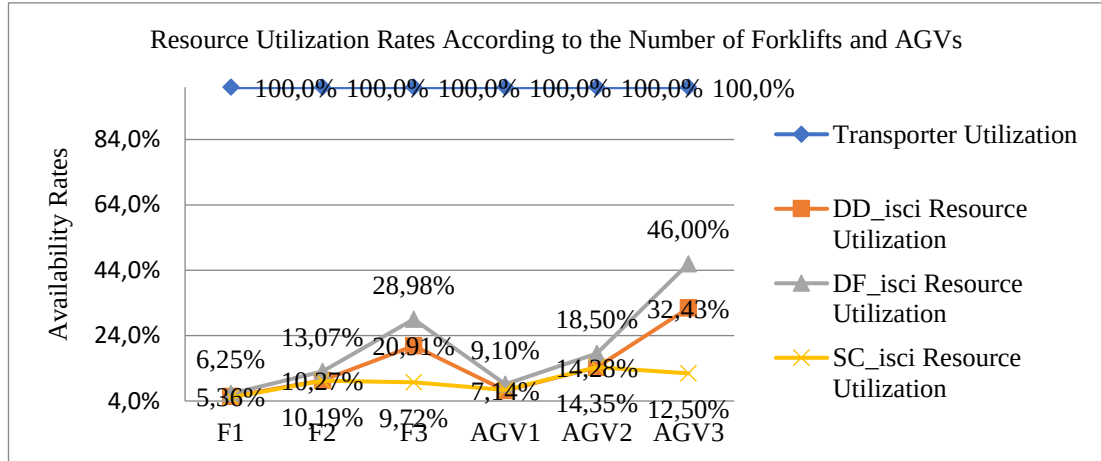


Figure 4.2 Resource Utilization Rates According to the Number of Forklifts and AGVs

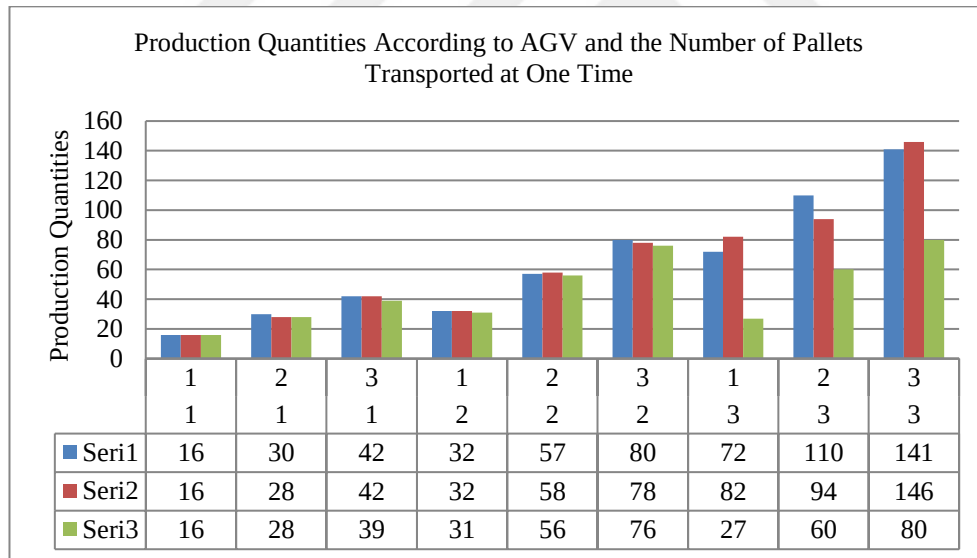
When we look at the production numbers, it is clearly seen that 3 forklift trucks up to 2 AGVs do not reflect the performance. But 3. There is a dramatic increase with the inclusion of AGV in the system. Production and availability values are noticeably increasing. 3 carriers (regardless of forklift or AGV) is the number of carriers that our system will work with full efficiency. More is experienced for AGV, as it is experienced in the case of forklift trucks, and although it does not contribute to production, it also reduces the availability rate of the transporter. In other words, our carriers remain empty. As can be seen from the tables and graphs, the highest worker utilization rates and production quantities are observed in the 3 AGV scenario. There were no queues during production, as the transport system is still not fully efficient (do not Queue this. We can tell by looking at the waiting Time values). If we want to compare the effect of AGV number increase with forklift truck number increase, Paired T-Test application makes.

Table 4.4 Paired T-Test Results

Results of the paired-t test indicated that there is a significant large difference between Before (M = 24.3 ,SD = 14.6) and After (M = 36 ,SD = 24.4), t(8) = 3.6, p = .007.		Results of the paired-t test indicated that there is a significant large difference between Before (M = 0.1 ,SD = 0.08) and After (M = 0.2 ,SD = 0.1), t(8) = 3.4, p = .010.

Finally, since AGV systems are safer, they can transport more than one pallet of products at a time. The carrying capacity of the selected type of AGVs is at a maximum of 300 kg. The average weight of a pallet is 100 kg. According to this, AGVs can carry a maximum of 3 pallets at the same time. Accordingly, the number of pallets that the AGV can carry has been increased and the results have been observed. A feasibility study was carried out with the available data. Again the average purchase and installation cost of an AGV is € 45,000. The average rental price of a forklift truck is € 10,000 and the annual cost of a worker to the factory is € 12,000. Currently, 3 forklifts are working in the system. This means that € 66,000 is spent annually on the forklift truck system. If we use AGV instead (since investments that pay for themselves in a maximum of 2 years are allowed according to company policy), we should use a maximum of 3 AGVs so that it can pay for itself in 2 years.

Table 4.5 Production Quantities According to AGV and the Number of Pallets Transported at One Time



When we look at the production numbers, we clearly see the scenario in which 3 AGVs carry 3 pallets at once with the highest score. Again, the highest worker utilization rates also appear in the scenario where 3 AGVs carry 3 pallets at one time. In the second table, AGV availability rates are starting to decrease with the increase of the beneficial utilization rates of the workers according to the scenarios. This is

because the shipping times are now shorter than the production times. Based on the information given in the second article, waiting times have started to appear in production queues now. in scenarios where 2 and 3 pallets are moved at the same time, the queue waiting values have changed from 0 to positive numbers (can be seen in the table).

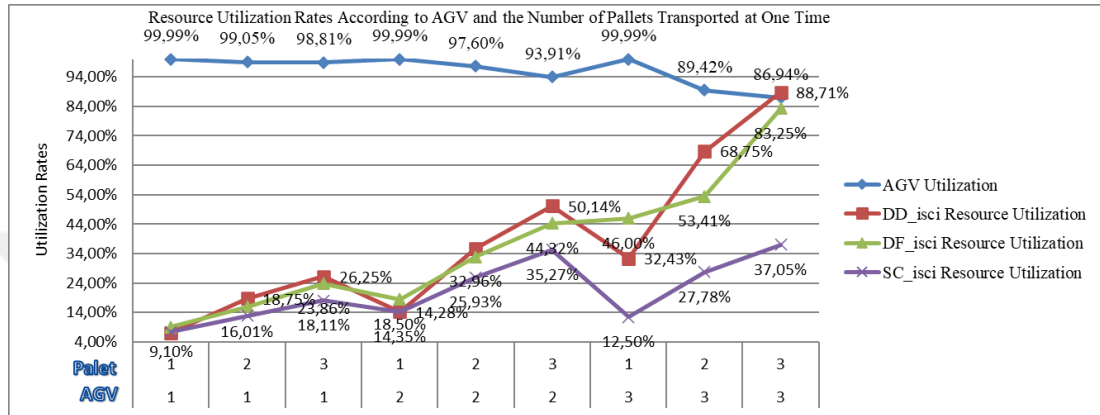


Figure 4.3 Resource Utilization Rates According to AGV and the Number of Pallets Transported at One Time

We also perform a Paired T-Test application to measure the effect of the pallet that the AGV can carry on production. The data used in the test are listed below.

Table 4.6 Paired T-Test

Production Line	One Pallet	Three Pallets
1_DD	16	42
1_DF	16	42
1_SC	16	39
2_DD	32	80
2_DF	32	78
2_SC	31	76
3_DD	72	141
3_DF	82	146
3_SC	27	80

If we interpret the results, since the p value (0.0000431) that appeared in the test is less than 0.05, according to the number of carriers and lines, returning from

transporting 1 pallet at one time to transporting 3 pallets is to create a significantly large change in production quantities. Thus, it has been statistically proven that it is better to carry 3 pallets at once instead of 1 when using the AGV system.

The model results were found through a replication. Terminating Simulation: These are simulation models that start in a defined situation or at a specified time and end when they reach another specified situation or time. In the prepared model, the factory produces within a certain period. Production is completed when working hours end. For this reason, the established model is a terminating model. The results obtained were found by running a replication of the model by taking the simulation length long enough.

4.3 Conclusions

AGVs are frequently used to transport materials. AGV ensures the traceability of the transport system, reduces the risk of accidents, and increases efficiency. A properly designed AGV system reduces labor costs and prevents products from being damaged. To provide all these advantages, it is important to design the AGV system correctly. It is necessary to select the AGV type specific to the project and to calculate the fleet size correctly.

The literature was examined in detail before the study was conducted. Limited examples have been found in the literature that examine both the vehicle type and the fleet size at the same time. The study conducted from this point of view constitutes a source for subsequent studies. There are several studies in literature focusing on the fleet size of AGV. It has been seen that most of these studies only dealt with the fleet size problem. In this study, it was investigated how AGV, which is one of the safest vehicles that can be used in the company, can be integrated into a real system. For this purpose, a simulation model was developed for calculating the fleet size. This model was applied to solve a real-world case study. With the help of the model, how many AGV should be used was calculated. Thus, the most efficient system was designed with optimum cost. This study can serve as a resource for calculating the best solution in different conditions to be made in the future.

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