DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

FACILITY LAYOUT OPTIMIZATION USING SIMULATION IN AN AUTOMATIVE COMPANY

by
Gizem KAYA

February, 2009
İZMİR

FACILITY LAYOUT OPTIMIZATION USING SIMULATION IN AN AUTOMATIVE COMPANY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"FACILITY LAYOUT OPTIMIZATION USING SIMULATION IN AN AUTOMATIVE COMPANY"** completed by **GİZEM KAYA** under supervision of **PROF. DR. G. MİRAÇ BAYHAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Gizem KAYA

FACILITY LAYOUT OPTIMIZATION USING SIMULATION IN AN AUTOMATIVE COMPANY

ABSTRACT

The aim of this study is to transform an assembly line in an automotive company on which only one type of a car can be operated, into a flexible assembly line on which different types of cars can be operated at the same time.

In this company, two different car models will start being produced on the same assembly line instead of one. Therefore, some changes in the system are needed to be made. In the first stage of this thesis, current production system, facility layout and transportation activities are examined and problems of the system are determined. In the system, there is not an effective material handling and stock control system and parts are being damaged and delays are occurring during the transportation. In order to solve these problems and make production system more flexible, some improvements are proposed. A pull system which controls production between departments and quantity of work in progress is developed. Facility layout for new coming models is also designed and in order to perform transportation operations in more effective way with minimum cost, AGV (automatic guided vehicle) system is suggested instead of forklifts.

In this thesis, also a simulation study was developed to see at what degree the improvements increase the system performance and to find the optimum value of decision variables by using ARENA 10.0.

Keywords: Facility layout, assembly line, simulation, stock control, material handling, automatic guided vehicle.

BİR OTOMOTİV FİRMASINDA YERLEŞİM ALANININ SİMÜLASYON KULLANILARAK OPTİMİZE EDİLMESİ

ÖZ

Bu çalışmanın amacı, bir otomotiv firmasında tek bir modelin işlem görebildiği montaj hattını, aynı anda birden fazla modelin işlem görebileceği esnek bir hat haline getirmektir.

Bu firmada, aynı montaj hattı üzerinde, tek model yerine iki farklı modelde araba üretilmeye başlanacaktır. Bu nedenle; sistemde bir takım değişiklere ihtiyaç duyulmaktadır. Tezin ilk aşamasında, mevcut üretim sistemi, fabrika yerleşimi, taşıma aktiviteleri incelenmiş ve sistemde görülen bir takım problemler tespit edilmiştir. Firmada, etkin bir malzeme aktarma ve stok kontrol sistemi bulunmamakta, taşıma esnasında parçalar zarar görmekte ve gecikmeler yaşanmaktadır. Bu problemleri çözmek, üretim sistemini daha esnek hale getirmek için bazı iyileştirme önerileri yapılmıştır. Bölümler arasındaki üretim ve ara ürün stok miktarını kontrol eden bir çekme sistemi geliştirilmiştir. Ayrıca yeni gelecek modellere ait yerleşim planları tasarlanmış ve taşıma operasyonlarının minimum maliyetle daha etkin bir şekilde yapılabilmesi için çekici arabalar yerine AGV (otomatik kılavuzlu araçların) kullanılması önerilmiştir.

Bu çalışmada, ayrıca, yapılan iyileştirmelerin sistemde ne kadar performans artışı yaratacağını görmek ve karar değişkenlerinin en uygun değerini bulmak için simülasyon çalışması ARENA 10.0 kullanılarak yapılmıştır.

Anahtar sözcükler: Fabrika yerleşimi düzenlemesi, montaj hattı, simülasyon, stok kontrol, malzeme taşıma, otomatik kılavuzlu araç.

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CHAPTER ONE

INTRODUCTION

1.1 Definition of the Problem and Purpose of the Project

The most noticeable characteristics of today's production system are variable demand for quantity, small batch production with variable batch size, being adaptable to variable processing and preparation time, high level of knowledge and competitive pressure. A rapidly changing competitive landscape and dynamic customer expectations require manufacturing firms to seek flexibility in product development. In order to compete and maintain survival in world-class competition, any company also must be able to make some improvements in the layout design, material handling system and machine-equipment and production management.

In an automotive company, L38/B32 models will start being produced instead of L84; therefore, some improvements in the layout design, material handling system and machine-equipment and production management are needed to be made. When the L38/B32 models begin to be produced, the quantity of carriages used in post SC020 will increase and there will not be enough space to place them. Besides, the company wants to know whether using AGV system instead of forklifts will be appropriate or not, what will be the optimum workflow path that minimizes the distance between two departments in the case of using AGV and how to solve the problem of layout beside the middle-floor line in the SC020 post.

In the current situation, preparing department of L84 are in the building P and the main assembly line is in the building D. The assembled parts are transported between preparing and the main assembly line by the carriages. One of the carriages is in the preparing post, another one is near the assembly line and the last one is stocked for safety. Transportation is provided by forklifts that 3 carriages can be attached at once. Capacity of the carriages can vary according to the shapes and size of the parts.

In the current situation, the production system is “push system”. Parts are continuously produced in the preparing department and the needed parts are carried to the assembly line. Capacity of the line is 26.9vehicles/hour.

The assembled parts just produced in the preparing department are listed below:

- L84 left side floor with left-side steering wheel (L84 left Plancher DAG)
- L84 right side floor with left-side steering wheel (L84 right Plancher DAG)
- L84 left side floor with right-side steering wheel (L84 left Plancher DAD)
- L84 right side floor with right-side steering wheel (L84 right Plancher DAD)
- L84 tunnel with right-side steering wheel (L84 Tunnel DAD)
- L84 tunnel with left-side steering wheel (L84 Tunnel DAG)

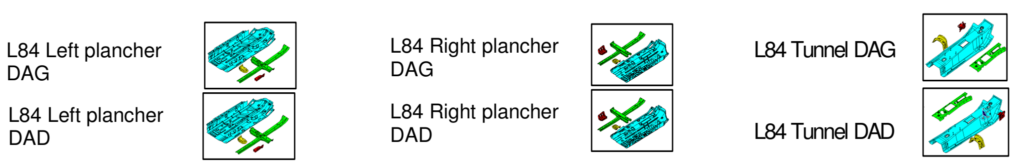


Figure 1.1 Synoptic of model L84 parts

Layout of Middle-floor SC020 post is given in Figure 1.2. There are 8 packages (2 left side floor with left-side steering wheel -One of them is safety stock-, 2 right side floor with left-side steering wheel -One of them is safety stock-, 2 tunnel–One of them is safety stock- , 1 left side floor with right-side steering wheel, and finally 1 right side floor with right-side steering wheel) beside the Middle-floor SC020 post (Storage yard shown in yellow). Number of packages used in this post is 6; if safety stocks are not included.

1.1.1 Definition of the Problem

1. Numbers of packages used in middle floor SC020 will increase to 12 with the newcoming models L38/B32. For newcoming packages, there is not enough space available on existing layout of the SC020 post. Layout of middle-floor SC020 post is given in Figure 1.2.

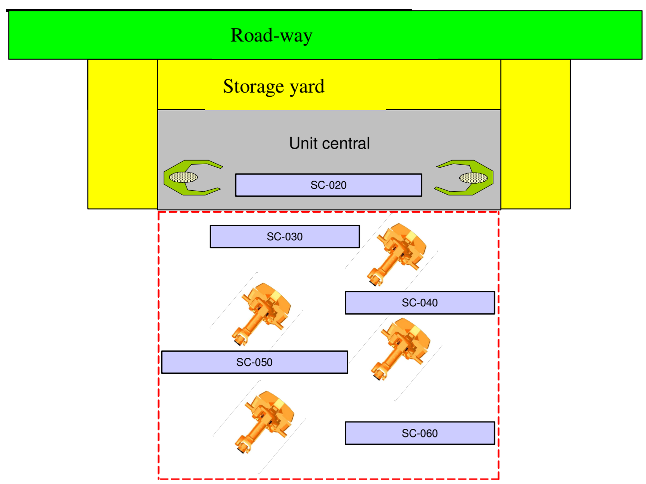


Figure 1.2 Layout of middle-floor SC020 post

The assembled parts are processed in preparing department. Part synoptic of the models B32/L38 are given in Figure 1.3 and listed below.

- B32 left side floor with left-side steering wheel (B32 left Plancher DAG)
- B32 right side floor with left-side steering wheel (B32 right Plancher DAG)
- B32 left side floor with right-side steering wheel (B32 left Plancher DAD)
- B32 right side floor with right-side steering wheel (B32 right Plancher DAD)
- B32 tunnel with right-side steering wheel (B32 Tunnel DAD)
- B32 tunnel with left-side steering wheel (B32 Tunnel DAG)

- L38 left side floor with left-side steering wheel (L38 left Plancher DAG)
- L38 right side floor with left-side steering wheel (L38 right Plancher DAG)
- L38 left side floor with right-side steering wheel (L38 left Plancher DAD)
- L38 right side floor with right-side steering wheel (L38 right Plancher DAD)
- L38 tunnel with right-side steering wheel (L38 Tunnel DAD)
- L38 tunnel with left-side steering wheel (L38 Tunnel DAG)

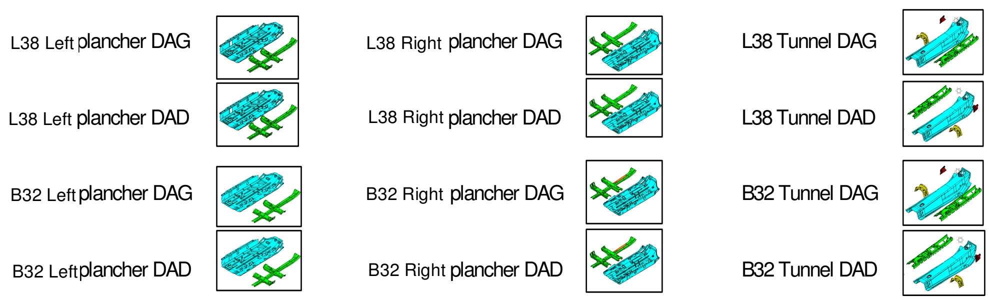


Figure 1.3 Part synoptic of the models B32/L38

2. Preparing department continuously produces to stock (make-to-stock) and There is not an effective stock control system.

3. There is not an effective material handling and control system between preparing department and main assembly line. Packages beside the Middle-floor SC020 post are checked visually against running out completely. When emptied, new packages are brought from preparing department in building P.

4. There is a long distance between building P and building D. Transportation is provided by forklifts. Parts can get damaged and delays can occur during the transportation.

1.1.2 Purpose of the Project

The Purpose of the Project is to find the permanent solutions to these problems mentioned above. The Simulation model was designed in order to see how these suggested solutions affect the system performance. The details of the purpose of the Project are listed below:

1. Suggesting permanent solutions for newcoming products and diversities,

2. Providing transportation and control system between the main assembly line and the preparation department,

3. Avoiding unnecessary workmanship,

4. Minimizing the work in progress,

5. Decreasing the transportation(workmanship and energy) costs,

6. Transporting products in a fast and safe way,

7. Setting up an effective stock control system.

1.2 Scope of the Project

The Project is composed of seven titles:

1. Solving the layout problem of beside L38/B32 Middle-floor line at the SC020 post.

2. Deciding whether using a pull system to provide a stock control between the main assembly line and the preparation department will be appropriate or not.

3. Planning the layout of preparation line of the models L38/B32.

4. Deciding whether using AGV to provide transportation and control between the main assembly line and the preparation department will be appropriate or not; and finding the route which will minimize the transporting distance between two department if using AGV is appropriate.

5. Comparing the performances of push and pull systems by simulating them and making a suggestion to the firm about choosing push or pull system considering the results of simulation.

6. Determining the decision variables such as number of parts in a package and re-ordering point considering the data obtained from simulation.

7. Results and Evaluation.

CHAPTER TWO

SOLUTIONS OF THE PROBLEMS

The solutions of the problems and suggestions are presented in this section.

2.1 Solving the Layout Problem beside L38/B32 Middle-floor Line at the SC020 Post

There are 8 packages beside middle-floor SC020 post (7 of them are at the stock area reserved for this post and 1 of them is out of this post). 6 packages are used in this post excluding the packages reserved for stock. The number of packages will increase to 12 with the new coming model L38/B32 that replaces the model L84. (1 left side floor with left-side steering wheel, 1 right side floor with left-side steering wheel , 2 tunnel, 1 left side floor with right-side steering wheel, and finally 1 right side floor with right-side steering wheel, totally 6 packages for model B32 ; 1 left side floor with left-side steering wheel, 1 right side floor with left-side steering wheel, 2 tunnel, 1 left side floor with right-side steering wheel, and finally 1 right side floor with right-side steering wheel, totally 6 packages for model B32, totally 6 packages for model L38, overall 12 packages will be needed). But the capacity of the stock area is 7 and there is not enough space to stock the newcoming packages.

2.1.1 Suggested Solution

Preparing line will product the parts that belong to models B32/L38 according to work orders given by the production planning department. The parts of different models could be processed in the same preparing lines (left side floor, right side floor and tunnel lines). There will be carriages for sorting the completed assembled parts at the end of “left side floor”, “right side floor” and “tunnel” lines (1 carriage for each, totally 3).

The parts must be sorted in the same order that is given in the work order. The operators work in the TSG010 -TSD010- TU010&TU015 posts will process the parts in the given order. The processed parts will be sorted at the carriage keeping the order. For instance, it will be possible to produce the "left side floor" for the model L38 just after producing the "left side floor" for the model B32 in the same producing line. And it will also be possible to sort them in an order at the same carriage. The suggested layout beside the line "L38/B32 Middle floor SC020" is given in Figure 2.1.

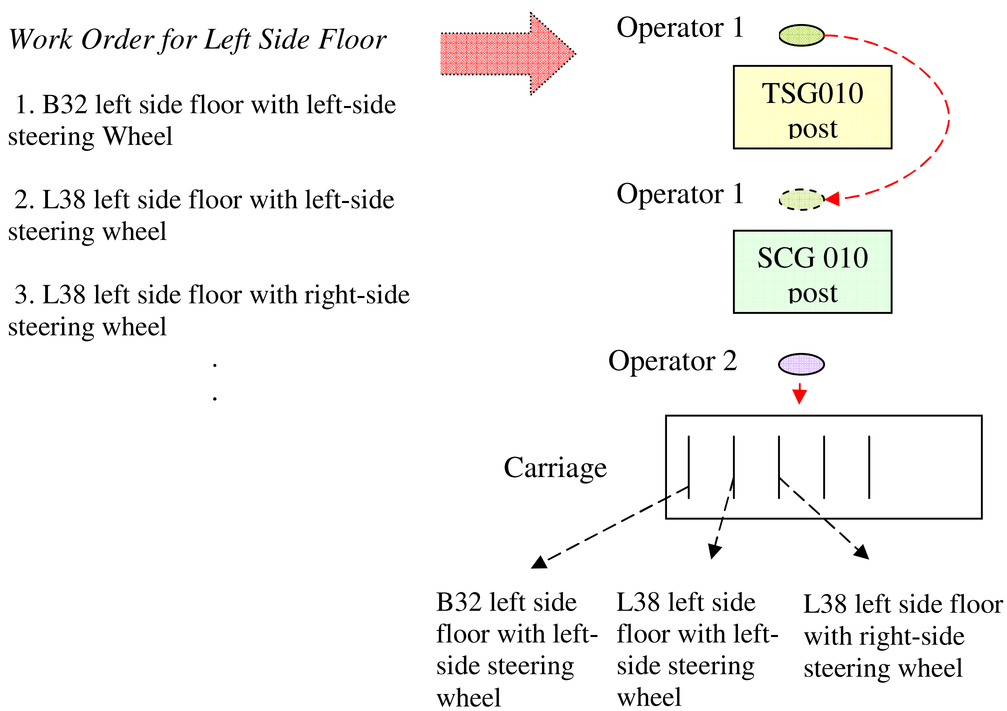


Figure 2.1 Suggested layout beside L38/B32 Middle-floor line at the SC020 post

2.1.2 Advantages of this Suggestion

1. In the case of rising the number of packages up to 12, finding the parts for the models and diversities requested by production planning will cause loss of time. This will increase the risk of disorder. Using 3 packages for the parts of

two different models and diversities, instead of 12 packages for the models B32/L38 will almost prevent the disorder.

2. The operators will be able to work in a more comfortable environment than before with the help of the decreasing number of packages to 3. This will motivate the operators and reduce the risk of the accidents.

3. It will be able to process more than one model and diversity in the same preparing line; so changing the number of models or diversities will not affect the system. The number of packages will be 3 -1 for left side floor, 1 for the right side floor and 1 for the tunnel- for any number of models that will be produced.

2.2 Deciding whether Developing a Pull System between Assembly and Preparing Lines for an Effective Stock Control will be Appropriate or Not

The current production system works as a “push system”. The production is made continuously in the preparing line. The produced parts are carried to the assembly line when needed. So, the preparing line continuously produces and there is not an effective system to control stock. At least 12 packages (for left side floor, right side floor and tunnel assembled parts) are at the empty area beside the preparing line, waiting for being sent to the main assembly line.

2.2.1 Suggested Solution

Level of work in progress must be minimized, because:

1. Producing more than necessary and before needed, means; more workmanship, more needed space and energy. If the amount of stock increases, the cost of workmanship, the equipment, the space and the energy increase too.

2. Stocks are left to be waited without making any process on them. Waiting does not increase the value of the product but it does lower the productivity, besides, increases the costs and lengthens the process time and it is wastage.

3. Another negative side effect of stock is about the “opportunity cost”. The firm can use the money to make profit (by using it for investments or with bank interest) instead of using the money for stocking. The firm will be deprived of this opportunity by making stock.

4. The products can easily be damaged or become a waste while they are stocked. This situation was seen at the factory while observing the production period.

Setting up a pull system between preparing and assembly lines is suggested for an effective stock control system. In this system, if the stock level (quantity of parts in the packages) in the SC020 post decreases under a certain number, a “work order” will be given to the operators work at the TSG010 -TSD010- TU010&TU015 posts. In this situation, operators will start producing the parts according to the work orders which are given by the production planning department. So preparing line will not make a production if the assembly line does not make a request. Re-order point for replenishment of stock occurs when the quantity of stock is decreased to a definite number. The optimum value of the re-order point was found by simulation. The details of simulation are given in chapter 3.

2.2.2 Advantages of this Suggestion

1. With an accurately chosen re-order point, it is possible to minimize the stock. Because the preparing line will make production only when needed.

2. The suggested pull system is an information system, which controls production between preparing and assembly lines and quantity of work in progress.

2.3 Planning the Layout of New Preparing Line of Models L38/B32

In current situation, preparing moulds of L84 are located at the building P and the main assembly line is at the building D. There is a long distance between two buildings. Preparing line of newcoming B32/L38 models (in which, left and right side floor and tunnel assembled parts will be produced) will be moved to building D from building P. The position of the new preparing line will be as shown in Figure 2.2. It will be established at an area of 12.3x13.8 m^2.

There is a flow-shop-type production in preparing line. In this production system, the layout is planned according to the producing processes of the parts. Another point is that enabling the AGV to pass through the corridors that have the least traffic.

2.3.1 Suggested Solution

The new layout of preparing line is given in Figure 2.5. The topics taken into account while planning this layout are listed below:

1- Minimizing the transportation,

2- Locating the carriages which carry the raw materials and works in progress as close as possible to posts,

3- Minimizing the movements of materials, raw materials, works in progress, products and workers,

4- Using this area effectively,

5- Providing comfortable and safe area for operators to work.

Material and work flows (Figure 2.3, Figure 2.4) are also considered while planning the layout.

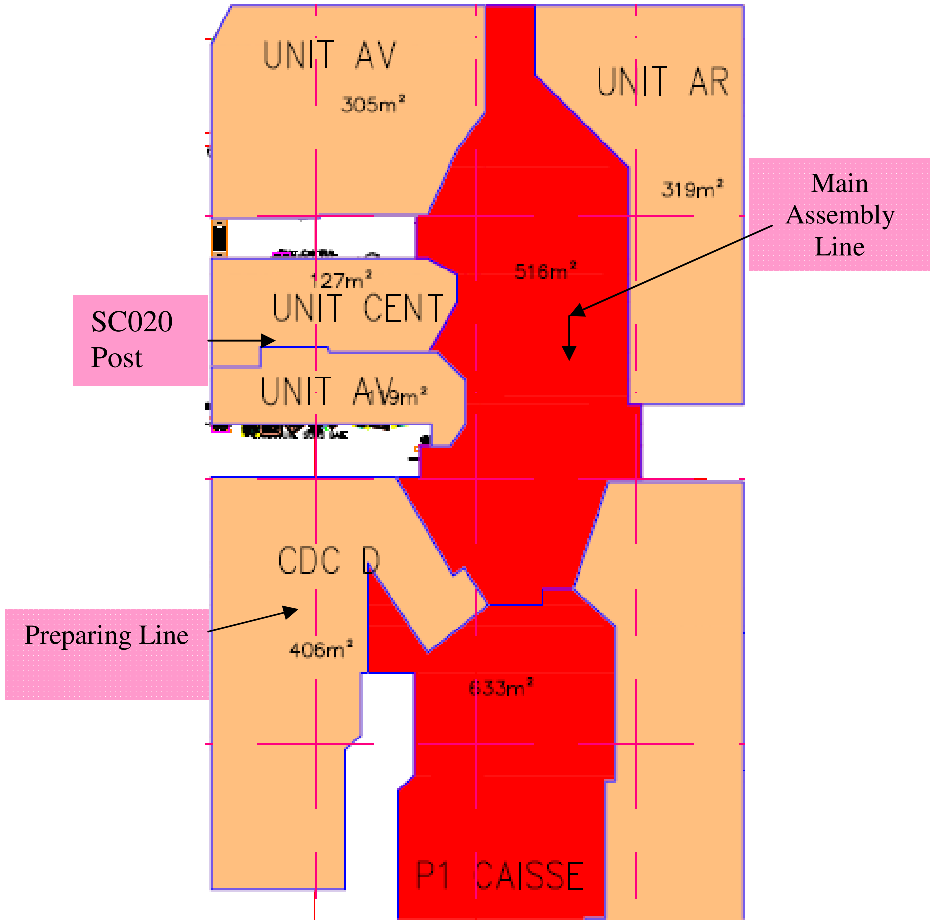


Figure 2.2 Position of new-establishing preparing line

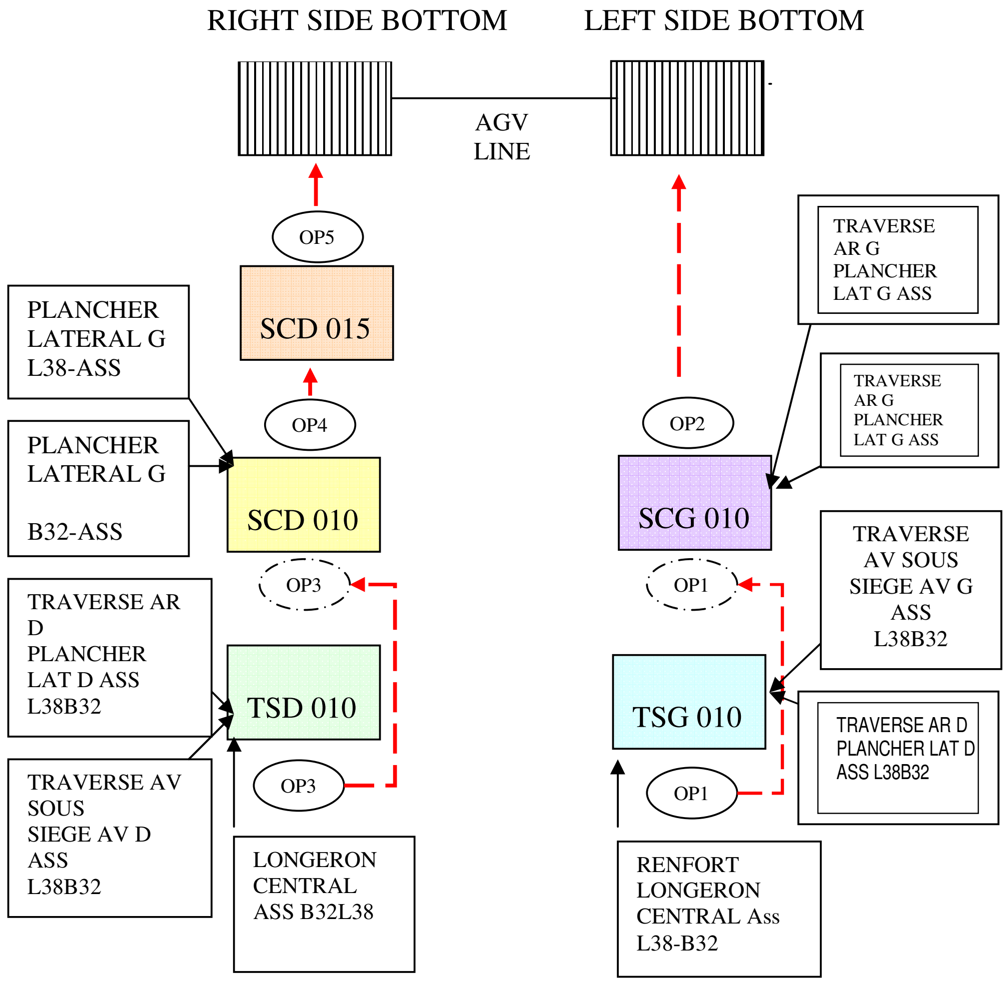


Figure 2.3 Table of the work and material flow for "left side floor" and "right side floor"

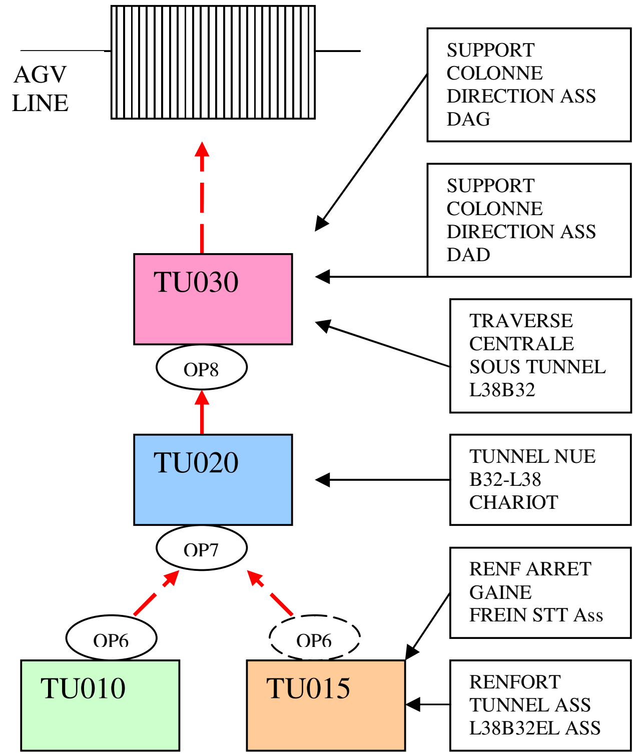


Figure 2.4 Table of the work and material flow for “tunnel”

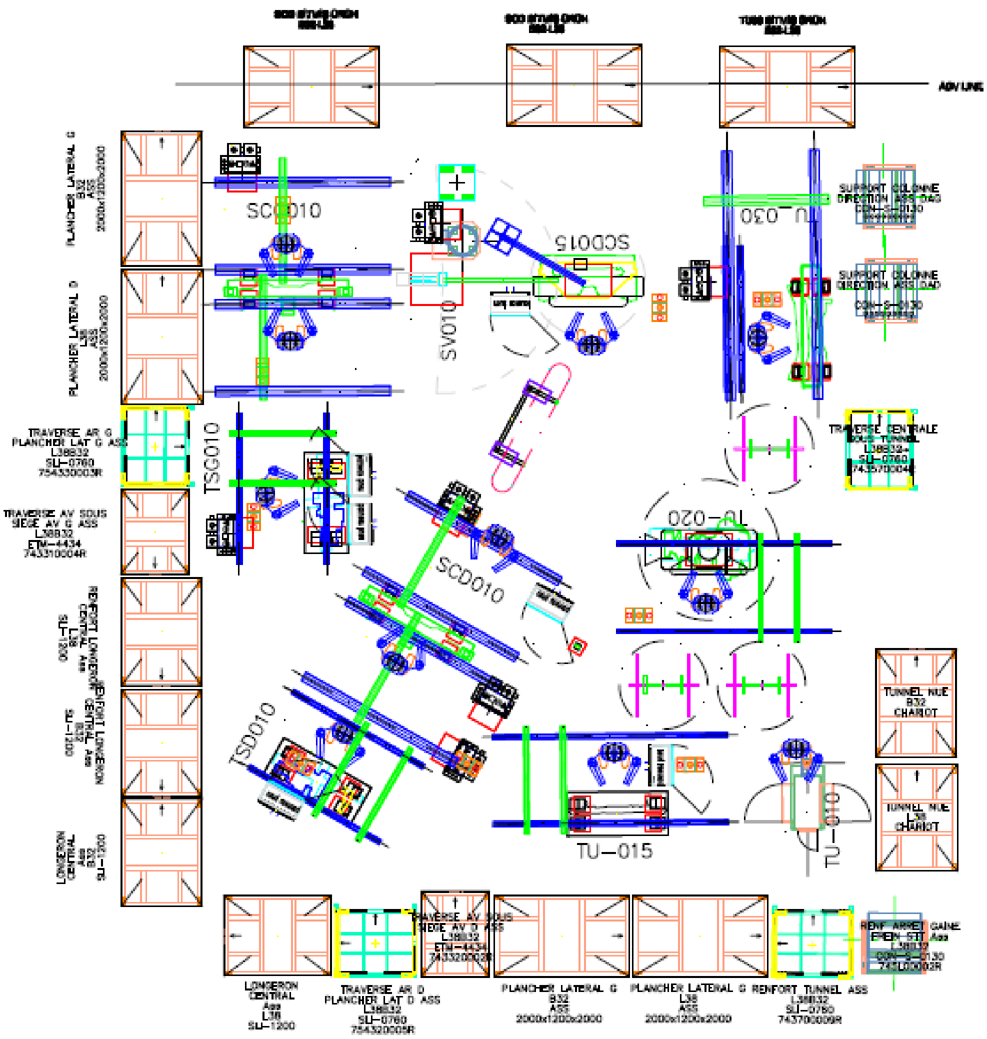


Figure 2.5 The designed layout

2.4 Providing Transportation between the Main Assembly and Preparing Lines by Using AGV instead of Carriages

The transportation of the model L84 is provided by the firm "Euroserve" using forklifts. The maximum number of carriages that can be attached to the vehicle at once is 3.

2.4.1 Suggested Solution

In order to performing transportation operations in more effective way with minimum cost, AGV (Automatic Guided Vehicle) system (that can provide one-direction transportation without an operator) is suggested instead of forklifts which need high workmanship and heavy loads of work in process to work. AGV is a transport vehicle that provides full integration to the computer-controlled production process –especially in the flexible manufacturing systems-. This vehicle is operated by central computer system synchronized with manufacturing. It is an unmanned vehicle and finds its route with the sensors on itself and the sensors on the road. The reasons for choosing this vehicle are; it does not need an operator, it is auto-guided and it is compatible with all the equipment in the factory both mechanically and electronically. The benefits of using AGV are listed below:

1. Saving on workmanship and energy costs,

2. The transportation between assembly and preparing lines will be faster than before,

3. Malfunctions may occur because of the human factor in the usage of forklifts. AGV is controlled by computer system so those malfunctions that are caused by human factor, will be prevented,

4. AGV transports the parts on time. So that AGV reduces the stock, saves money and time.

2.4.1.1 Choosing AGV Type

Two types of AGV's are chosen for the transportation of assembled parts between main assembly line and preparing line. The firm can select the type to use according to the advantages and disadvantages listed below.

2.4.1.1.1 Tugger AGV's .

Tug / Tow Vehicle automated guided vehicles (AGV's) are the most productive form of automated guided vehicle (AGV) for tugging and towing because they haul more loads per trip than other AGV types. These tug vehicle style AGV's are sometimes referred to as "Tuggers", because they are designed to pull wheeled carts (typically 3 at a time) which can be loaded and unloaded with material automatically or manually.

Figure 2.6 Tugger AGV's

Properties:

1. This type of AGV's pull wheeled carriages (generally 3 carriages). Parts can be loaded to these carriages automatically or manually.

2. It is appropriate for transporting big and heavy parts among distances 304.8m and more.

3. The speed of the AGV is 80 meters/minute.

Advantages:

1. It costs less than unit load of AGV's.

Disadvantages:

1. The carriages will be prepared and attached to the AGV by the operators.

Work Logic and Route:

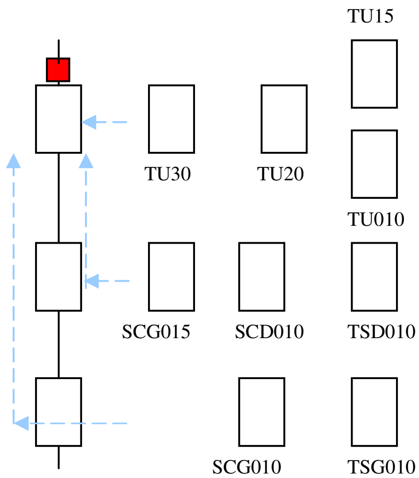
3 carriages belong to “left side floor”, “right side floor” and “tunnel” will be prepared and attached to the AGV by a selected operator. After loading is completed, AGV will carry the parts to the main assembly line. After transportation, operators will detach carriages and leave them to the area that belongs to them. The operators who are assigned to loading and unloading, their duty and the time taken for each operation are explained below.

Table 2.1 Assignments of the operators and time taken during the process

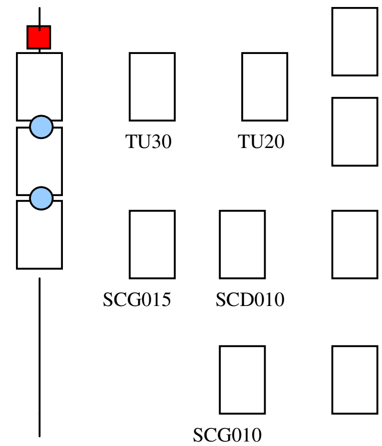
OPERATION	PLACE	PROCESS	OPERATOR	TIME
LOAD	PREPARING DEPARTMENT	carrying full carriages to the AGV	OPERATOR WORKS IN SCD015 POST	71,85 cmin
		attaching carriages to AGV		
UNLOAD	SC020 POST	moving empty carriages to the coridor	2 OPERATORS WORK IN SC020 POST	78,94 cmin
		taking carriages from AGV		
		moving the carriages to their area at the post		
		attaching empty carriages to AGV		

Assignments of the operators are made according to the operator utilization rates which are obtained from the simulation study.

Loading Operation:

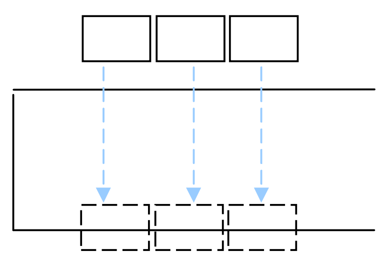


1. Full carriages are moved to the AGV on the route above by the operator.

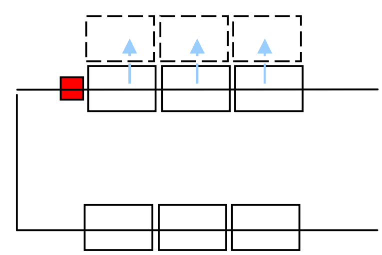


2. Preparing is completed by attaching carriages to AGV.

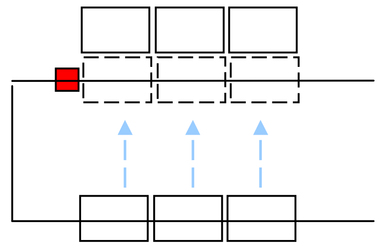
Unloading Operation:



1. The empty carriages standing at the stock area are pushed to the corridor by 2 operators without unlocking the hooks which attach them to each other.



2. The full carriages (transported by AGV) are placed to the stock area of SC020 post without unlocking the hooks which attach them to each other.



3. Unloading is completed by carrying empty carriages to AGV.

The route which will be used for tugger AGV and the distances of this route are given in Figure 2.7 and Figure 2.8.

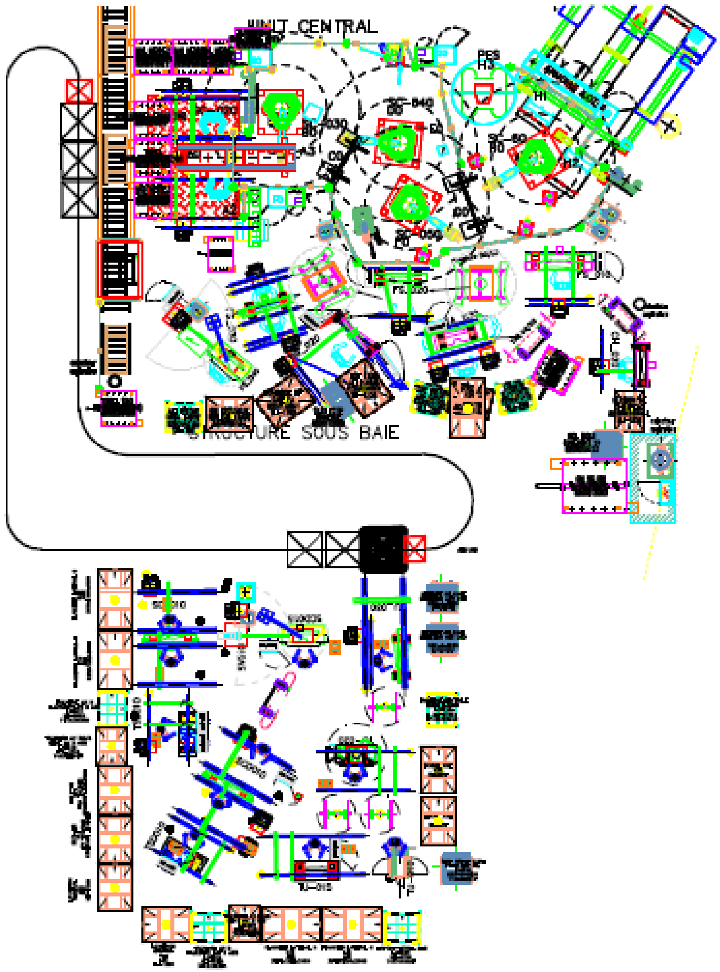


Figure 2.7 The route for tugger AGV

The Properties of the AGV's that will be used:

- AGV will move in one direction.
- Route length is 62.4 metres.
- In the case of using tugger AGV, only one vehicle will use according to the simulation study.

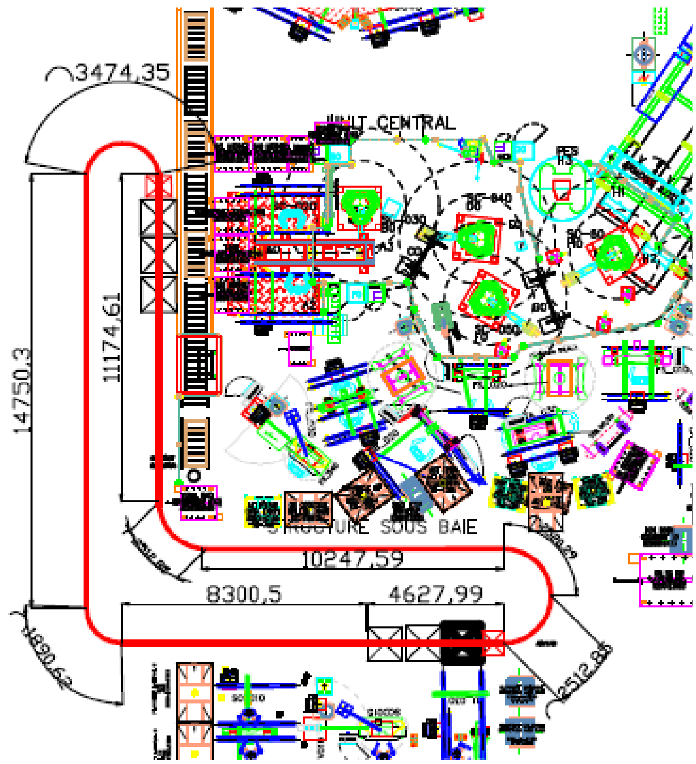


Figure 2.8 Route distances

2.4.1.1.2 Unit Load AGV's.

The Unit load automated guided vehicles (AGV's) are the most traditional type of automated guided vehicle (AGV). The unit load AGV's are sometimes referred to as a "top carrier" because the load rests over the majority of the vehicle. The unit load AGV is available for loads of many sizes and shapes and is sometimes used as an assembly AGV where a product is moved from manufacturing cell to manufacturing cell as it is assembled. The types of loads typically moved by unit load AGV's include the standard pallets (wrapped and unwrapped), drums, carts, racks, rolls, and custom containers.

Figure 2.9 Unit load AGV's

Properties:

1. This type of AGV's carries only one carriage(Figure 2.9)

2. They are appropriate for carrying parts with variable shape and weight in short distances.

3. The average speed of the AGV is 54 meter/minute.

Advantages:

There are tree different unit load AGV's which will be used for each "left side floor", "right side floor" and "tunnel" parts. So this operation will not need preparing operations like attaching and detaching carriages to the AGV.

Disadvantages:

The unit load AGV's cost more than the tugger AGV's.

Work Logic and Route:

Each unit load AGV moves independently. There will not be a waste of time while attaching carriages (as in the tugger AGV's). Even tough these AGV's can move independently, they are still dependent on each other. Because the parts may be carried by different AGV's but still must be processed at the same time (in the assembly line).So the only advantage of using the unit load AGV's is to save the attachment and detachment times that takes totally 150cmin. The route of the unit load AGV is given in Figure 2.10.

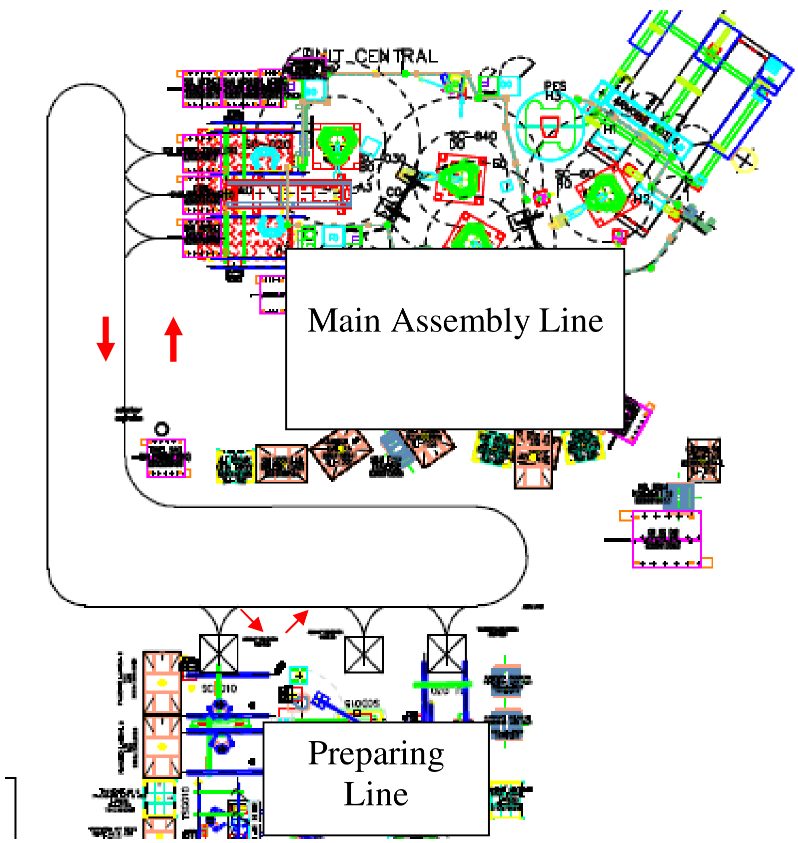


Figure 2.10 Route of unit load AGV

2.5 Comparison of the Performances of Designed Push and Pull Systems

The applicability and the effects of setting up a pull system instead of push system (between assembly and preparing lines) are analyzed and researched in the simulation study. For this, simulation model of current system is developed. And than, pull system is applied to the current system and both pull and push systems are simulated in the ARENA 10.0 software. This simulation is made to see how the suggested pull system works and to find the decision variables. The results of using unmanned and one-direction working AGV's instead of forklifts –which work with the high amount of stock and need heavy workmanship- are also found in the simulation.

Simulation is a period of designing the cause and effect relationship which belongs to a theoretic or a real physical system, observing the conduction of the model under different circumstances and using different strategies, and analyzing and explicating the results. Making experiments on the real systems-especially manufacturing systems- are quite hard because of the high costs of the mechanical equipments and the necessity of stopping the system. Because of this, it provides more advantages to make experiments on the model of the system. Analytical solutions can not detect the coincidental structures. And they are difficult to be used in the systems which include too many elements that have complicated relationship. These are the reasons of using the simulation study instead of the analytic solution. Besides, the manufacturing systems are stochastic, complicated and automated, that makes the use of the simulation inevitable.

2.5.1 Modeling the Suggested Pull System

In the suggested pull system, preparation department will produce B32/L38 requested parts of model and diversity in requested order- according to the work order. The probabilities of how many of each models and diversities will be produced –which are taken from the firm- are given in Table 2.2.

Table 2.2 Production rates of the parts due to model and diversity

PRODUCTION RATES			
VEHICLE TYPE		STEERING TYPE	
L38	0.65	left-side steering	0.90
B32	0.35	right-side steering	0.10

Preparing line will wait the “work order” from the SC020 post at the main preparing line to begin the production. When quantity of parts in the packages at the SC020 post decreases under the determined number, a work order will be given to the preparing line. Re-order point –the minimum quantity of stock, for which, work order will be given- is an important decision variable and its optimum value will be determined in chapter 3. Due to the information given by the firm, one car is pulled for each 196cmin from the BR070 post.

Workflow charts and process times is given in the appendix-A.

2.5.2 Determining of Process and Transport Times

Process times which are necessary to set up the simulation model are obtained by using the continuous and accumulative quantification technique. It is determined that process times conform to optimum normal distribution and transportation times conform to (α=0.05) uniform distribution (by using “data analysis module” of Arena 10.0).

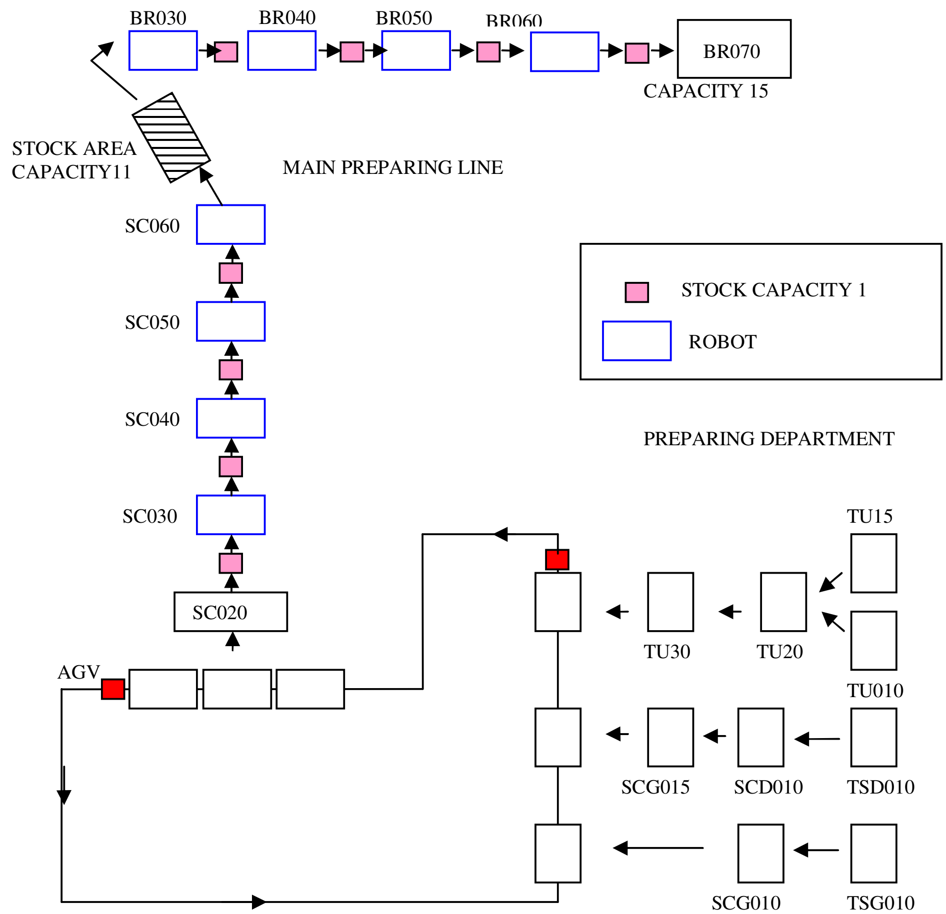


Figure 2.11 Work and material flow of the whole system

2.5.3 Distributions of Operation Times (until Stop Working) and Stoppage Times for each Robot

The optimum probability distributions of operation times (until stop working) and stoppage times for each robot are computed by using "data analysis module" of Arena 10.0 entering the data taken from the firm for 3 months period.

Table 2.3 Distributions of robot stoppages

ROBOTS	TIME PASSED BETWEEN STOPAGES	STOPAGES
SC030	1.9e+004 + WEIB(2.52e+005, 0.537)	99 + WEIB(414, 0.817)
SC040	4.5e+003 + WEIB(2.13e+005, 0.544)	23 + EXPO(690)
SC050	500 + WEIB(1.56e+005, 0.582)	175 + WEIB(893, 0.73)
SC060	1.2e+004 + GAMM(1.2e+006, 0.33)	68 + WEIB(785, 0.635)
BR030	500 + EXPO(3.07e+005)	20 + EXPO(623)
BR040	2.4e+004 + EXPO(9.74e+005)	111 + WEIB(680, 0.694)
BR050	500 + EXPO(2.16e+005)	35 + WEIB(583, 0.866)
BR060	700 + GAMM(1.99e+006, 0.258)	37 + 4.62e+003 * BETA(0.345, 0.793)

2.5.4 Alternative System Designs

2.5.4.1 Push System

Based on the assumption that the preparing line will make the production continuously.

2.5.4.2 Pull System

The preparing line will start producing with the “work order” given by the SC020 post. The preparing line will produce when assembly line needs so.

It will be decided which of these systems is the most appropriate one to use, only after answering the questions below:

- Does the system work properly, on purpose?
- What is the level of mechanical equipment and workmanship to make the system work without a bottleneck?
- Which of the alternative systems conform the criteria of performance such as quantity of production, cycle time, capacity usage ratio and work in process.

2.5.5 Modeling the System

2.5.5.1 Assets Defined in the Model

- Vehicle type(B32/L38),
- Steering type (left-wheeled/right-wheeled),
- Part type (Left side floor, right side floor, tunnel).

2.5.5.2 Sources Defined in the Model

- The operators that process and transport assets,
- The machines and robots that process assets, and AGV.

2.5.5.3 Variables Defined in the Model

Group Volume: Number of parts on each carriage that will be transported to the main assembly line by AGV.

Re-order Point: Work order is sent to the preparing line if the quantity of stock at SC020 post decreases under a definite number. For example, if the work order is sent when the number of parts on each carriage decreases under 3, than the re-order point is 3.

"First come, first served" rule is used for the assets which will be processed in the system and transported by the AGV's.

2.5.5.4 Process Times Defined in the Model

Transporting times are calculated by defining the transporting distances on the ultimate layout (assuming each operator step is 0.75m and takes 1cmin). And then calculation is completed by making comparison with the process times taken from the firm. Process times of each post are given in Figure 2.12.

2.5.5.5 Robot Stoppages Defined in the Model

The optimum distributions of stoppage times and times between stoppages for each robot were determined in chapter 2.5.4. These distributions are used as an input data in the simulation. Special case about robot stoppages is also defined in the model. There are 5 zones, they are; SC050 (the robots SC030-SC040-SC050), SC060, BR030, BR060 (the robots BR030-BR040-BR050) and BR070. When a robot brakes down, every robot in the zone stops at the same time too. Other robots are not allowed to finish their work.

2.5.5.6 Queues defined in the Model

AGV Queue: The queue where 3 packages (left side floor, right side floor and tunnel) are grouped and waited to be loaded to the AGV. Other queues are shown in Figure 2.13.

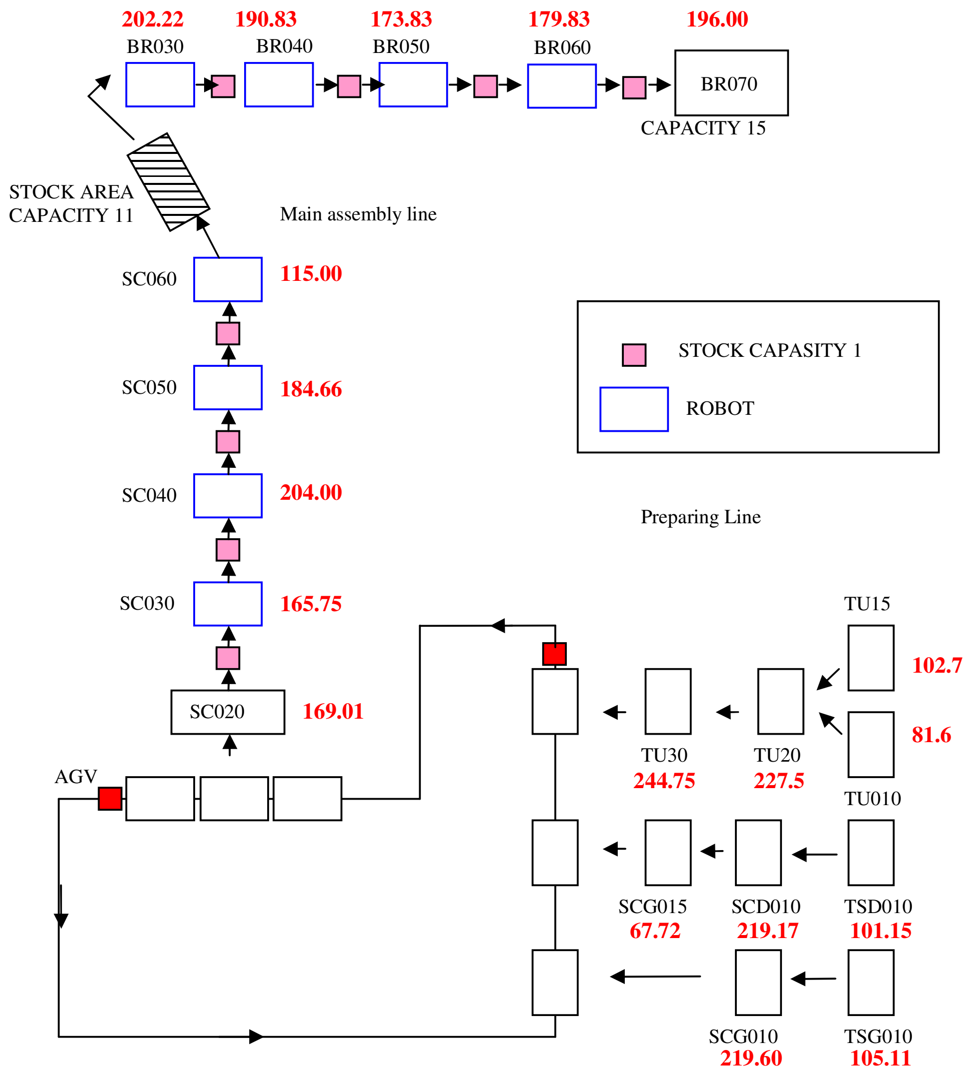


Figure 2.12 Process times taken in the posts

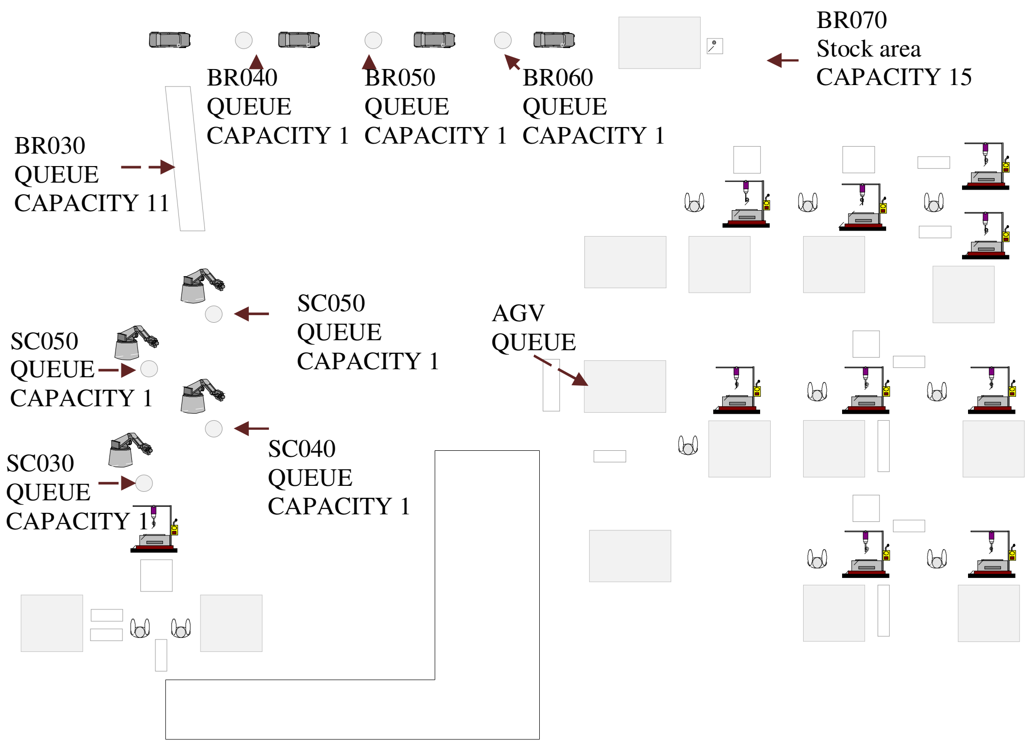


Figure 2.13 Queues and capacities of queues defined in the model

CHAPTER THREE
SIMULATION STUDY

3.1 Push System

The performance criteria which are obtained from the simulation study -assuming the suggested system will work as a push system-, are give in the table 3.1. Simulation is ran for 10 replication 50 days long, assuming group volume (quantity of parts in a package), which is one of the decision variables is 12, and 1 vehicle is pulled from BR070 post per 196cmin. At the end, the results below are acquired. The performance criteria shown in the table are the average of 10 replications.

Table 3.1 Cycle times and numbers of observation

	CYCLE TIME			NUMBER OF OBSERVATION			
	Avarage	Minimum	Maximum	min	max	avarage	
				vehicle/50 days			vehicle/hou
Left side bottom	345.45	345.42	345.50				
Right side bottom	414.34	414.27	414.42				
Tunnel	722.98	722.87	723.08				
Loading, carrying, unloading the AGV	389.49	196.40	1215.1				
Total	2820.6	2792.3	2885.4	**26499**	**26510**	**26504**	**24,315596**

Table 3.2 Operator utilization rate

Operator utilization rate	
Operator	**Avarage**
op01	0,91
op02	0,99
op03	0,91
op04	0,99
op05	0,34
op06	0,75
op07	0,92
op08	1,00
op09	0,73
op10	0,73

Table 3.3 Quantity of work in progress

QUANTITY OF WORK IN PROGRESS	STOCK QUANTITY
stock area	**avarage**
Package number of finished left side bottom assembled parts	183,61
Package number of finished right side bottom assembled parts	199,97
Package number of finished tunnel assembled parts	0,00

Table 3.4 Quantity of production of vehicle types

VEHICLE TYPE	MİKTAR
L38 left-side steering wheel	15523
L38 right-side steering wheel	1721,6
B32 left-side steering wheel	8325,4
B32 right-side steering wheel	934,3
Total	26504

Table 3.5 Time between two parts finished in the line

TIME TAKEN BETWEEN TWO PARTS PROCESSED IN THE POST	
Post	Time (cmin)
Left side bottom SCG010	216.93
Right side bottom SCD015	215.02
Tunnel TU020	227.73
Tunnel TU030	246.74

Due to the results shown in table 3.1-3.5, which are acquired for 10 replications, the maximum number of vehicles that can be produced per hour will be 24.32. But the capacity of this line is 26.9 vehicles/ hour. According to operator utilization rate (Table 3.2) and the time taken between 2 vehicles processed at each post (Table 3.5), there are bottlenecks at the posts TU020 and TU030. The improvements suggested to get rid of these bottlenecks are listed below:

Suggestion 1. Several number of spot welding operation –taking 13cmin of time-, which are made in the TU020 post, should be operated by robots (average 5 spot welding operations).

Suggestion 2. The operator, who works in the post TU030 (operator08) is working at full capacity while the operator who is responsible for preparing the AGV (operator 05) is working at a utilization rate of 0.34. If operator05 helps the spot welding operation in the TU030 post, process time will decrease to 217cmin.

Adding another machine to the TU030 post for the operator05 to work in this post, might lower the process time considerably. But this suggestion is rejected. Because of the high cost and the risk of disorder in the line of parts in progress.

The operator utilization rate, quantity of work in progress and the quantity of production of the vehicle types in the case of applying the suggested improvements above are given in the Tables 3.6-3.7. The performances after applying the improvements will be as in the tables below:

Table 3.6 Cycle times and numbers of observation

	CYCLE TIME			NUMBER OF OBSERVATION			
	Avarage	Minimum	Maximum	min	max	Avarage	
						vehicle/	vehicle/
Left side floor	345.45	345.42	345.50			**50 days**	**hour**
right side floor	414.24	414.20	414.28				
Tunnel	635.10	634.97	635.21				
Loading-carrying-unloading the AGV	526.73	298.45	1306.0				
Total	3238.1	3177.5	3311.9	**29855**	**30033**	**29980**	27,50

According to the Table 3.6, average of 27.50 vehicles will be produced in this line after the improvements. In current situation (before the improvements), the capacity is 26.9vehicles/hour.

Table 3.7 Operator utilization rate

OPERATOR UTILIZATION RATE	
Operator	**Avarage**
op01	0,91
op02	0,99
op03	0,90
op04	0,99
op05	0,73
op06	0,84
op07	0,98
op08	1,00
op09	0,84
op10	0,84

Table 3.8 Quantity of work in progress

Quantity of work in progress	Quantity of the stock
Stock Area	**Avarage**
Numbers of packages of Left side floor completed assembled parts	5,91
Numbers of packages of right side floor completed assembled parts	14,88
Numbers of packages of tunnel completed assembled parts	0,00

After running simulation model for 50 days, the number of packages which carry the assembled parts, is 383.58 (for the parts "left side floor") before the improvements. This number decreases to 5.91 (for left side floor) and 14.88 (for right side floor) after the improvements.

Table 3.9 Quantity of production of the vehicles types

VEHICLE TYPE	QUANTITY
L38 left-side steering wheel	17556
L38 right-side steering wheel	1941
B32 left-side steering wheel	9417,9
B32 right-side steering wheel	1064,9
Total	29980

3.1.1 Defining the Optimum Package Volume for the Push System

Simulation study is made for six packages with different volume and the performance values given in the Table 3.10 are obtained. And then, the most appropriate volume is chosen according to these values. 5 replications are taken for each package. The model is run for 50 days.

Table 3.10 Performance chart according to the package volume in the push system

	GROUP VOLUME 16		GROUP VOLUME 15	
	Avarage time	Number of parts	Average	Observations
Time between two parts, "left side"	217,38		217,53	
Time between two parts, "right side"	216,74		217,00	
Time between two parts, "tunnel"	218,12		218,17	
Avarage time for loading, carrying and unloading	542,60		527,30	
Minimum time for loading, carrying and unloading	435,02		414,29	
The whole system		29980,00		29974,00
Avarage number of completed vehicles per day		599,60		599,48
Avarage per hour(working hour: 21.8 hours/day)		**27,50**		**27,50**
Number of packages of left side floor at the end of the prep. line		5,69		5,91
Number of packages of right side floor at the end of the prep. line		14,13		14,88
Number of packages of tunnel at the end of the prep. line		0,00		0,00
Operator 09 utilization rate		0,84		0,84
Operator 10 utilization rate		0,84		0,84

Table 3.10 Continue- Performance chart according to the package volume in the push system

	GROUP VOLUME 14		GROUP VOLUME 13	
	Avarage time	Number of parts	Average	Observations
Time between two parts,"left side"	217,61		217,70	
Time between two parts,"right side"	217,20		217,36	
Time between two parts,"tunnel"	218,18		218,24	
Avarage time for loading, carrying and unloading	528,39		507,21	
Minimum time for loading, carrying and unloading	414,13		412,87	
The whole system		29972,00		29965,00
Avarage number of vehicles per day		599,44		599,30
Avarage per hous(working hours:21.8 hours/day)		**27,50**		**27,49**
Number of packages of left side floor at the end of the prep. line		6,31		6,77
Number of packages of right side floor at the end of the prep. line		15,87		17,01
Number of packages of tunnel at the end of the prep. line		0,00		0,00
Operator 10 utilization rate		0,84		0,83

	GROUP VOLUME 12		GROUP VOLUME 11	
	Average	Observations	Average	Observations
Time between two parts, "left side"	217,82		217,90	
Time between two parts, "right side"	217,49		217,57	
Time between two parts, "tunnel"	218,26		218,28	
Avarage time for loading, carrying and unloading	502,55		496,22	
Minimum time for loading, carrying and unloading	412,62		415,31	
The whole system		29963,00		29960,00
Avarge number of vehicles per day		599,26		599,20
Avarage per hour(working hours:21.8 hours/day)		**27,49**		**27,49**
Number of packages of left side floor at the end of the prep. line		7,30		7,89
Number of packages of right side floor at the end of the prep. line		18,36		19,85
Number of packages of tunnel at the end of the prep. line		0,00		0,00
Operator 09 utilization rate		0,83		0,83
Operator 10 utilization rate		0,83		0,83

The optimum group volume (number of parts in a package) is determined by the performance criteria such as; loading-carrying-unloading times, completed parts per hour, efficiency of operators working in the SC020 post and quantity of stock at the end of the preparing line. As it seems in Table 3.10, when group volume increases, the operator efficiency and the number of completed parts per hour will increase while the quantity of stock at the end of preparing line decreases. It might seem the best to take group volume as large as possible considering these facts; but doing this will increase the time taken for AGV for loading, carrying and unloading. This occasion causes more difficult decision to make. The best values considering operator efficiency and number of parts per hour are, 16, 15 and 14. AGV preparation periods take more time for 15 and 16, than 14. Quantities of stock at the end of the preparing line is close for group volumes 15 and 16, but this value is higher (which means worse for this criterion) in group volume 14. So the optimum decision variable is group volume 15. And group volume 13 is the best alternative in the case of not being able to increase the volume to 15.

3.2 Pull System

The same improvements in the chapter 3.1 to remove the bottlenecks in the push system will be used in the pull system as well. It is acquired from the simulation study that, the average fullness ratio of the stock area in front of BR030 (which has a capacity of 11) is 0.01 for 50 days and fullness ratio of BR070 post is 0.008 by pulling 1 part from BR070 is every 196cmin in the push system which is given in detail the in chapter 3.1. To make the system run properly, the assumption “parts will be pulled from BR070 as many as the capacity of the line” is used. So it will be possible to get more realistic results from the system. With the improvements made, the capacity of the line is increased to 27.3vehicles/hour (chapter3.1). In this case, One vehicle will be pulled from BR070 per 219cmin ((100cmin*60min)/27.3= 219cmin).

3.2.1 The Optimum Package Volume and Re-Order Point for Pull System

Simulation study is made for 6 different package volumes (package volume 16-15-14-13-12-11) and the performance values in the Table 3.11 are obtained. The optimum volume is determined by comparing these values. 5 replications are taken for each package volume. Each replication ran for 50 days with the warm-up-period of 10 days.

The performance criteria to determine the optimum group volume and re-order point are the average number of completed vehicles per hour and total time spent for loading-carrying-unloading. Doubtless, completed parts per hour should be as many as possible while the time for loading-carrying-unloading should be minimized. The time for loading-carrying-unloading rises proportionally with re-order point for each group volume. For example, in Table 3.11, for the group volume 15; loading-carrying-unloading time is 210 for re-order point "0" and it increases to 1419 for re-order point "14". Capacity also increases proportionally with re-order point. Considering the simulation results in Table 3.11, the optimum values for pull system is determined: group volume will be **12** and re-order point will be **2**.

Table 3.11 Performance values due to the package volume

	GROUP VOLUME 16				
	YSN 0	**YSN1**	**YSN 2**	**YSN 3**	**YSN 14**
	Time Observation	Time Observation	Time Observation	Time Observation	Time Observation
Avarage time for loading, carrying and unloading	203,26	205,08	225,19	259,52	1606,5
Minimum time for loading, carrying and unloading	197,1	198,62	206,16	232,49	1379
Number of completed parts per day	29717	29744	29762	29769	29797
Avarage per hour(working hours: 18 hours/day)	**27,263**	**27,288**	**27,3**	**27,31**	**27,337**
Number of packages of parts left side floor at the end of the prep line	0,1617	0,1931	0,223	0,244	0,3514
Number of packages of parts right side floor at the end of the prep line	0,1525	0,1951	0,236	0,266	0,4533
Number of packages of parts tunnel at the end of the prep line	0	0	0	0	0

	GROUP VOLUME 15				
	YSN 0	**YSN1**	**YSN 2**	**YSN 3**	**YSN 14**
	Time Observation	Time Observation	Time Observation	Time Observation	Time Observation
Avarage time for loading, carrying and unloading	200,38	207,37	222,98	266,14	1418,9
Minimum time for loading, carrying and unloading	194,94	197,43	202,95	239,91	1166,7
Number of completed parts per day	29717	29744	29760	29770	29796
Avarage for hour(working hours:18 hours/day)	**27,263**	**27,288**	**27,3**	**27,31**	**27,336**
Number of packages of left side floor at the eng of the prep. line	0,1617	0,1997	0,23	0,25	0,3735
Number of packages of right side floor at the eng of the prep. line	0,1525	0,2006	0,238	0,268	0,471
Number of packages of tunnel at the eng of the prep. line	0	0	0	0	0

	GROUP VOLUME 14				
	YSN 0	**YSN1**	**YSN 2**	**YSN 3**	**YSN 13**
	Time Observation	Time Observation	Time Observation	Time Observation	Time Observation
Avarage time for loading, carrying and unloading	198,97	206,69	238,11	262,31	1253,8
Minimum time for loading, carrying and unloading	193,31	198,08	223,44	240,07	1015,7
Number of completed parts per day	29717	29742	29757	29769	29795
Avarage for hour(working hours:18 hours/day)	**27,263**	**27,286**	**27,3**	**27,31**	**27,335**
Number of packages of left side floor at the eng of the prep. line	0,1657	0,2041	0,232	0,261	0,3931
Number of packages of right side floor at the eng of the prep. line	0,1558	0,2	0,238	0,279	0,4853
Number of packages of tunnel at the eng of the prep. line	0	0	0	0	0

	GROUP VOLUME 13				
	YSN 0	**YSN1**	**YSN 2**	**YSN 3**	**YSN 12**
	Time Observation	Time Observation	Time Observation	Time Observation	Time Observation
Avarage time for loading, carrying and unloading	202,53	223,37	230,98	246,37	1099,5
Minimum time for loading, carrying and unloading	196,76	217,31	210,96	220,3	893,68
Number of completed parts per day	29715	29739	29757	29769	29794
Avarage for hour(working hours:18 hours/day)	**27,261**	**27,283**	**27,3**	**27,31**	**27,334**
Number of packages of left side floor at the eng of the prep. line	0,1494	0,2008	0,2	0,279	0,4133
Number of packages of right side floor at the eng of the prep. line	0,1389	0,1972	0,21	0,286	0,5025
Number of packages of tunnel at the eng of the prep. line	0	0	0	0	0

Table 3.11 Continue- Performance values due to the package volume

	GROUP VOLUME 12				
	YSN 0	YSN1	YSN 2	YSN 3	YSN 11
	time observation	time observation	time observation	time observation	time observation
Avarage time for loading, carrying and unloading	218,31	209,33	212,48	244	943,99
Minimum time for loading, carrying and unloading	212,46	203,22	196,16	212,92	251,26
Number of completed parts per day	29709	29741	29757	29768	29793
Avarage per hour(working hours:18 hours/day)	**27,256**	**27,285**	**27,3**	**27,31**	**27,333**
Number of packages of left side floor at the end of the prep. line	0,1532	0,2077	0,257	0,293	0,4395
Number of packages of right side floor at the end of the prep. line	0,1425	0,2043	0,251	0,296	0,5251
Number of packages of tunnel at the end of the prep. line	0	0	0		0

	GROUP VOLUME 11				
	YSN 0	YSN1	YSN 2	YSN 3	YSN 10
	time observation	time observation	time observation	time observation	time observation
Avarage time for loading, carrying and unloading	202,41	196,68	211,24	251,31	798,61
Minimum time for loading, carrying and unloading	197,27	192,1	195,18	220,96	628,82
Number of completed parts per day	29709	29739	29756	29767	29795
Avarage per hour(working hours:18 hours/day)	**27,256**	**27,283**	**27,3**	**27,31**	**27,335**
Number of packages of left side floor at the end of the prep. line	0,157	0,2188	0,267	0,305	0,4686
Number of packages of right side floor at the end of the prep. line	0,1444	0,202	0,258	0,302	0,5488
Number of packages of tunnel at the end of the prep. line	0	0	0	0	0

3.3 Analysis of the Results

The criteria to evaluate the manufacturing systems are:

- Quantity of production
- Cycle time
- Workmanship utilization ratios
- Quantity of work in progress

Pull and push systems are compared below, according to these criteria.

3.3.1 Comparison of the Quantities of Production and Cycle Times

The average quantities of production of the present system (push system without improvements) and the improved pull and push systems, are obtained from the simulation study with 10 replications and shown in the Table 3.12-3.13. Results in Table 3.12 are calculated assuming 1 part is pulled per 196cmin, and the results in table 3.13 are calculated assuming 1 part is pulled per 219cmin (as many as capacity).

The quantity of production is increased by 11.05% with the improvements (Table 3.12). The maximum number of vehicles that can be produced is 27.39 for the push system and 27.38 for the pull system. Push system has a better performance of 0.08% than pull system if two systems are compared among their quantities of production. This means there is not an important difference between two systems in these criteria. But pull system has 93.35% better performance in time spent on loading-carrying-unloading. This proves the fact that pull system is better.

Table 3.12 Cycle times and performance values according to the numbers of observation (Assuming 1 part is pulled per 196cmin from the end of the line)

	CYCLE TIMES and NUMBERS OF OBSERVATION			
	Push System Unimproved GH12	Push System Improved GH15 (1)	Pull System Improved GH12-YSN-2 (2)	Differance .-% (1)-(2)
Cycle time of preaparing left side floor	345,45	345,46	346,04	-0,17
Cycle time of preaparing right side floor	414,34	414,24	417,40	-0,76
Cycle time of preaparing tunnel	722,98	635,12	635,07	0,01
Waiting AGV, loading,carrying,unloading	389,49	527,30	196,22	62,79
Time between two parts completed in left side floor preparing line	216,93	217,53		
Time between two parts completed in right side floor preparing line	215,02	217,00		
Time between two parts completed in tunnel preparing line	246,74	218,17		
Time between two vehicles completed in the system	246,74	218,18	219,25	-0,49
Time for operators waiting AGV at the SC020 post	9826,66	4949,70	4828,57	2,45
Avarage number of vehicles completed in the system(vehicles/50 days)	26504,00	29974,00	29828,00	0,49
Number of vehicles completed in the system per hour(vehicle per hour)	24,32	27,50	27,37	0,49
Maximum number of vehicles completed in the system(vehicles/50 days)	24,32	27,55	27,45	0,37

In the case of pulling 1 part per 196cmin, the maximum number of vehicles that can be produced will be 27.55 for the push system and 27.45 for the pull system. Considering these performance criteria, improved push system is 11.7% and improved pull system is 11.4% better than the push system before the improvements. But the performance of pull system is 62.79% better than push system's in "the spent time for waiting AGV and loading-carrying-unloading the parts" criterion.

In the case of pulling 1 part per 219cmin (Table 3.13), cycle time of "tunnel" is decreased by 12.16% for push system and 12.18% for the pull systems, with the improvement of the bottleneck posts.

Table 3.13 Performance values of the systems according to the cycle times and numbers of observation (Assuming 1 part is pulled per 219cmin from the end of the line)

	CYCLE TIMES AND NUMBERS OF OBSERVATION			
	Push system Unimproved GH15	Push system Improved GH15	Pull system Improved GH12-YSN-2	Differance %
Cycle time of preparing left side floor	345,45	345,54	346,05	-0,15
Cycle time of preparing right side floor	414,34	414,51	417,32	-0,67
Cycle time of preparing tunnelr	722,98	635,06	634,92	0,02
Waiting AGV, loading,carrying,unloading	409,81	3.155,30	209,94	93,35
Time between two parts completed in left side floor preparing line	217,17	219,58		
Time between two parts completed in right side floor preparing line	215,27	219,69		
Time between two parts completed in tunnel preparing line	246,74	219,51		
Time between two parts completed in the system	246,74	219,47	219,64	-0,08
Time for operators waiting AGV at the SC020 post	9.809,70	658,10	4.337,55	-84,83
Avarage number of vehicles completed in the system(vehicles/50 days)	26.504,00	29.798,00	29.775,00	0,08
Number of vehicles completed in the system per hour(vehicle per hour)	24,32	27,34	27,32	0,08
Maximum number of vehicles completed in the system(vehicles/50 days)	24,32	27,39	27,38	0,02

3.3.2 Comparison of the Workmanship Utilization Rates

The average operator utilization rates, which are acquired from 10 replications of the simulation models, made for current (unimproved, push system) system, improved push system and improved pull system, are shown in Table 3.14-3.15. Results in table 3.14 are calculated assuming 1 part is pulled per 196cmin, and the results in table 3.15 are calculated assuming 1 part is pulled per 219cmin (full of the capacity).

According to the data in Table 3.14, and in the case of pulling 1 part per 196cmin from the BR070 post, utilization rates of operator 06 (TU010-TU015) and operator 07 (TU020)-who works in the tunnel post- and operator 07 -who helps the spot welding in the TU030 post- will increase considerably.

Table 3.14 Comparison of the systems according to the utilization rates of the operators. (Assuming 1 part is pulled per 196cmin)

OPERATOR UTILIZATION RATES					
	Push System Unimproved GH12 (1)	Push System Improved GH15 (2)	Pull System Improved GH12-YSN-2 (3)	(1) (2) ifference-	(1) (3) fference-
Operator01	0,91	0,91	0,90	-0,28	-1,06
Operator02	0,99	0,99	0,99	-0,18	-0,25
Operator03	0,91	0,90	0,89	-0,93	-1,98
Operator04	0,99	0,98	0,99	-0,92	0,08
Operator05	0,34	0,72	0,74	**52,78**	**53,70**
Operator06	0,75	0,84	0,84	**11,58**	**11,15**
Operator07	0,92	0,98	0,98	**6,22**	**5,83**
Operator08	1,00	1,00	0,99	-0,16	-0,52
Operator09	0,73	0,84	0,82	**13,92**	**11,08**
Operator10	0,73	0,84	0,82	**13,92**	**11,08**
AVARAGE	0,83	0,90	0,90		

Table 3.15 Comparison of the systems according to the utilization rates of the operators. (Assuming 1 part is pulled per 219cmin)

OPERATOR UTILIZATION RATES					
	Push System Unimproved GH12 (1)	Push System Improved GH15 (2)	Pull System Improved GH12-YSN-2 (3)	(1) (2) ifference-	(1) (3) fference-
operator01	0,91	0,90	0,90	-1,11	-1,16
operator02	0,99	0,98	0,99	-1,01	-0,45
operator03	0,91	0,89	0,89	-2,10	-2,07
operator04	0,99	0,98	0,99	-1,42	-0,03
operator05	0,34	0,72	0,74	**53,39**	**54,30**
operator06	0,75	0,84	0,84	**11,04**	**10,96**
operator07	0,92	0,98	0,98	**5,68**	**5,68**
operator08	1,00	0,99	0,99	-0,52	-0,65
operator09	0,73	0,98	0,84	**26,23**	**13,04**
operator10	0,73	0,98	0,84	**26,23**	**13,04**
AVARAGE	0,83	0,92	0,90		

According to the results which are given in Table 3.15, after the improvements in the bottleneck posts;

- Utilization rate of Operator06 -works at the TU010 and TU015 posts- increases by 11.04% in the push system and 10.96% in the pull system,
- Utilization rate of Operator07 –works in the TU020 post- increases by 5.68% in the push system, 5.68% in the pull system,

- Utilization rate of Operator05 –works in the SCD010 post and also helps tunnel operation in the post TU030 in the new occasion- increases by 53.39% in the push system, 54.30% in the pull system,

- Utilization rates of Operator09 and Operator10–work in SC020 post- increases by 13.04% in the push system, 26.23% in the pull system.

3.3.3 Comparison of Works In Progress

The quantities of work in progress which are obtained from the simulation model with 10 replications are given in Table 3.16 and Table 3.17.

As it seems in Table 3.16, in the case of pulling 1 part per 196cmin of time, quantity of work in progress at the end of preparing line, after 50 days will be 20,79 in the push system and it will be 0,56 in the pull system. According to these criteria, the pull system is 96.72% better than the push system.

Table 3.16 Comparison of the systems according to the quantities of work in progress (Assuming 1 part is pulled per 196cmin)

QUANTITY OF WORK IN PROGRESS						
	Push System Unimproved GH12 (1)	**Push System Improved GH15 (2)**	**Pull System Improved GH12-YSN-2 (3)**	**(1) (2) Difference-%**	**(1) (3) Difference-%**	**(2) (3) Difference-%**
BR030 queue	**0,20**	**0,47**	**0,45**	58,35	-3,66	99,23
BR070 stock area	**0,00**	**0,01**	**0,01**	26,82	34,44	10,42
BR040 queue	0,01	0,01	0,02	-0,44	11,22	11,61
BR050 queue	0,00	0,00	0,00	0,00	0,00	0,00
BR060 queue	0,00	0,00	0,00	0,00	0,00	0,00
SC030 queue	0,19	0,41	0,21	53,63	10,62	-48,12
SC040 queue	0,62	0,77	0,70	19,82	11,44	-9,47
SC050 queue	0,00	0,01	0,01	30,69	32,29	2,31
SC060 queue	0,01	0,01	0,01	40,14	43,09	4,93
AGV queue	0,05	0,05	0,00	-2,45	-98,39	-98,35
quantity of the packages of completed left side floor	**183,61**	**5,91**	**0,28**	**-96,78**	**-99,85**	**-95,27**
quantity of the packages of completed right side floor	**199,97**	**14,88**	**0,27**	**-92,56**	**-99,86**	**-98,17**
quantity of the packages of completed tunnel	0,00	0,00	0,00	0,00	0,00	0,00

Table 3.17 Comparison of the systems according to the quantities of work in progress (Assuming 1 part is pulled per 219cmin)

RK IN PROGRESS						
	Push System Unimproved GH12 (1)	**Push System Improved GH15 (2)**	**Pull System Improved GH12-YSN-2 (3)**	**(1) (2) ifference-**	**(1) (3) ifference-**	**(2) (3) fference-**
BR030 queue	**0,24**	**10,22**	**5,55**	97,61	-45,74	94,32
BR070 stock area	**0,73**	**13,63**	**13,48**	94,63	94,57	-1,09
BR040 queue	0,78	0,99	0,96	21,12	18,60	-3,09
BR050 queue	0,71	0,99	0,94	0,00	0,00	0,00
BR060 queue	0,74	0,99	0,96	0,00	0,00	0,00
SC030 queue	0,19	0,93	0,30	79,28	35,85	-67,70
SC040 queue	0,62	0,98	0,74	36,93	16,13	-24,80
SC050 queue	0,01	0,78	0,17	98,84	94,67	-78,31
SC060 queue	0,01	0,83	0,22	98,83	95,54	-73,77
AGV queue	0,06	0,23	0,00	75,59	-99,64	-99,91
Quantity of the packages of completed left side floor	183,46	1,41	0,26	**-99,23**	**-99,86**	**-81,69**
Quantity of the packages of completed right side floo	199,81	2,94	0,25	**-98,53**	**-99,87**	**-91,35**
Quantity of the packages of completed tunnel	0,00	0,00	0,00	0,00	0,00	0,00

According to Table 3.17, quantity of packages of “left side floor”, “right side floor” and “tunnel”, in the queue of AGV -waiting to be transported to the main preparation line- decreases by 98.9% in the push system and 99.86% in the pull system, compared to the unimproved push system. In the suggested pull system, the quantity of packages waiting in the queue of AGV is 75.59% less than the push system. The quantity of the stock of completed-assembled parts will be average of 4.35 in the push system and 0.51 for the pull system (working without stock) for the 50 days of time.

CHAPTER FOUR
RESULTS AND DISCUSSION

In this Project, improvements are made for the new models L38/B32 to avoid the disorder in the flow of materials between preparation and main assembly lines, high quantity of work in progress, necessity of using high amount of workmanship that causes the loss of productivity in the former model L84. The changes that provided improvements can be grouped under 3 titles which are listed below:

- Changes in the transportation system,
- Changes in the locations of the producing areas,
- Changes that provide an increase in the capacity.

Two new systems –push and pull systems- are tested. It is proved with numeric results that the new production line layout, changes in the sources and improvements in the system, provides an increase in the production and regular-flow transportation. The summary of these results are given in Table 4.1 and Table 4.2.

Table 4.1 Comparison of the systems according to various performance criteria (Assuming 1 part is pulled per 196cmin)

	Push System Unimproved GH15 (1)	Push System Improved GH15 (2)	Pull System Improved GH12-YSN-2 (3	(1) (2) fference-	(1) (3) fference-	(2) (3) fference-
BR030 queue	**0,20**	**0,47**	**0,45**	58,35	-3,66	99,23
BR070 stock area	**0,00**	**0,01**	**0,01**	26,82	34,44	10,42
Avarage number of vehicles completed in the system(vehicle/ho	24,32	27,50	27,37	11,58	11,14	-0,49
Maximum number of vehicles completed in the system(vehicle/h	24,32	27,55	27,45	11,73	11,41	-0,37
Waiting AGV loading-carrying-unloading	389,49	527,30	196,22	26,14	-49,62	-62,79
Utilization rate of Operator05	0,34	0,72	0,74	52,78	53,70	1,96
Utilization rate of Operator06	0,75	0,84	0,84	11,58	11,15	-0,48
Utilization rate of Operator07	0,92	0,98	0,98	6,22	5,83	-0,42
Utilization rate of Operator09	0,73	0,84	0,82	13,92	11,08	-3,20
Utilization rate of Operator10	0,73	0,84	0,82	13,92	11,08	-3,20
Utilization rates of all of the operators	0,83	0,90	0,90	7,97	7,79	-0,20
Number of carriages of completed parts at end of prep.line	383,58	20,79	0,55	-94,58	-99,86	-97,35

In the case of pulling 1 part per 196cmin, the number of vehicles at the BR070 post will be average of 0.01 for both push and pull systems. The capacity of BR070 post is 15 vehicles.

In current situation, the capacity of the line is 26.90vehicles/hour. According to 10 different observations for 50 days simulation run, maximum number of completed vehicles is 27.77 in the push system and it is 27.45 in the pull system. Increase in the capacity will be 2.36% in the case of applying push system, and it will be 2% if pull system is applied. It is seen from Table 4.1 that, in the pull system, waiting-loading-carrying and preparing-unloading times of AGV is 62.79% shorter than the push system. The total utilization rate of all of the operators is 90% for both pull and push systems. The quantity of work in progress (number of carriages) at the end of the preparation line is 20.79 for the push system while it is 0.55 for the pull system. Although push system has better results in the performance criteria, shortened waiting-loading-carrying and preparing-unloading times of AGV and smaller quantity of work in progress at the end of the preparation line makes pull system better. There is not enough space for 21 packages at the end of the preparation line. And Because of the fact that, the pull system works with lower quantity of work in progress which provides stock control and solves the package-area problem. Pull system also needs 62% less spent time for AGV which overally shows suggested pull system has more advantage.

In the case of using pull system, the maximum number of parts completed at the end of the line per hour will be 27.45 and the time spent for waiting-loading carrying and preparing-unloading the AGV will be average of 196.22cmin. Quantity of work in progress at the end of the preparation line will be 0.55 and the system works with the principle of “working without stock”.

In the case of using push system, the maximum number of parts completed at the end of the line per hour will be 27.55 and the time spent for waiting-loading carrying and preparing-unloading the AGV will be average of 527.30cmin. To prevent this high level of stock, it can be suggested to stop production if the quantity of packages of “left-side-floor” and “right-side-floor” reaches a certain number. The quantity of packages of “left-side-floor”, “right-side-floor” and “tunnel” should be limited with 2 for each of them to provide stock control because of the limited capacity of the area.

Table 4.2 Comparison of the systems according to various performance criteria (Assuming 1 part is pulled per 219cmin)

	Push System Unimproved GH12 (1)	Push System Improved GH15 (2)	Pull System Improved GH12-YSN-2 (3	(1) (2) fference-	(1) (3) fference-	(2) (3) fference-
BR030 queue	**0,24**	**10,22**	**5,55**	97,61	-45,74	94,32
BR070 stock area	**0,73**	**13,63**	**13,48**	94,63	94,57	-1,09
Avarage number of vehicles completed per hour	24,32	27,34	27,32	11,05	10,99	-0,08
Maximum number of vehicles completed per hour	24,32	27,39	27,38	11,20	11,18	-0,02
waiting the AGV-loading-carrying-unloading	409,81	3.155,30	209,94	87,01	-48,77	-93,35
Utilization rate of Operator05	0,34	0,72	0,74	53,39	54,30	1,96
Utilization rate of Operator06	0,75	0,84	0,84	11,04	10,96	-0,08
Utilization rate of Operator07	0,92	0,98	0,98	5,68	5,68	0,01
Utilization rate of Operator09	0,73	0,98	0,84	26,23	13,04	-15,17
Utilization rate of Operator10	0,73	0,98	0,84	26,23	13,04	-15,17
Utilization rate of all of the operators	0,83	0,92	0,90	9,97	7,79	-2,37
Number of carriages at the end of the prep.line	383,27	4,35	0,51	-98,86	-99,87	-88,21

In the case of pulling parts as many as the capacity from the line BR070, the maximum number of completed vehicles is 24.32 vehicles/hour for the unimproved push system while it is 27.39 vehicles/hour for improved push system and it is 27.38 in the pull system. According to these performance criteria, there is not an important difference between push and pull systems. But if time spent for waiting-loading-carrying-unloading at the AGV is considered, there is a 87.01% decrease in performance of the improved push system, and an 48.77% increase in performance of the improved system compared to the unimproved push system. This difference between push and pull system is important and pull system is better than pull system according to this criteria. The utilization rate of all of the operators is increased 9.97% in the push system and also increased by 7.79% in the pull system according to the unimproved push system. Push system is better compared to these criteria. The quantity of carriages at the end of the preparation line is decreased by 98.86% in the push system and also decreased by 99.87% in the pull system compared to the unimproved push system. There will be average of 0.51 unit of completed carriages at the end of the line for 50 days long.

As it seems, there is not a noticeable difference between push and pull systems if two systems are compared about their production capacity. Push systems gives better results about utilization rates of the operators while pull system is better than push system if they are compared about quantity of carriages at the end of the preparation line.

According to the performance criteria, alternative designs provide more advantage than the current system and alternative pull system is better among the alternative designs.

4.1 The Process of Suggested Push System

The flow of materials in the suggested pull system will be as shown in Figure 4.1. There are the points needed to pay attention listed below.

1. It is determined in the simulation study that the cycle time of "left side floor" will reduce if operator01 who works at the TSG010 and SCG010 posts carries the finished assembled part to the carriage instead of operator02. Operator01 should carry the finished part to the carriage.

2. The parts processed in the SCD010 post should be loaded to the enterpost by operator04 who works at the SCD010 post.

3. Operator05, who works at the SCD015 post should help operator08 for the welding operation at the TU030 post.

4. At the preparing line the operator05 who work in the SCD015 post will load the full packages to the AGV and attach them to AGV. And this operator also will unload the empty packages.

5. The simulation study shows that the SC020 post waits the preparing line. When the packages at that post empties, the operators09&010 who work there will call the AGV, load the empty packages to the AGV and send them to the preparing line. If the preparing line waits the SC020 post in exceptional occasions -such as the robot stops- , unloading operations will be done as it is explained in 3.2 (unloading operation).

6. The quantity of completed parts at the end of the preparation line reaches a certain number (At most two carriages for each left-side-floor, right-side-floor and tunnel lines), “Stop production order” will be given to the beginning of preparing line.

4.2 The Process of Suggested Pull System

1, 2, 3, 4 and 5.topics which are about the process of suggested pull system are the same for the suggested pull system. Additionally, there is another topic to take into account:

7. The “Production order” will be given to the preparing line if there is 2 parts left on the packages at the SC020 post. Preparing line will start production with this order. AGV’s are capable of communicating automatically with the factory devices. That order could be given by using AGV too.

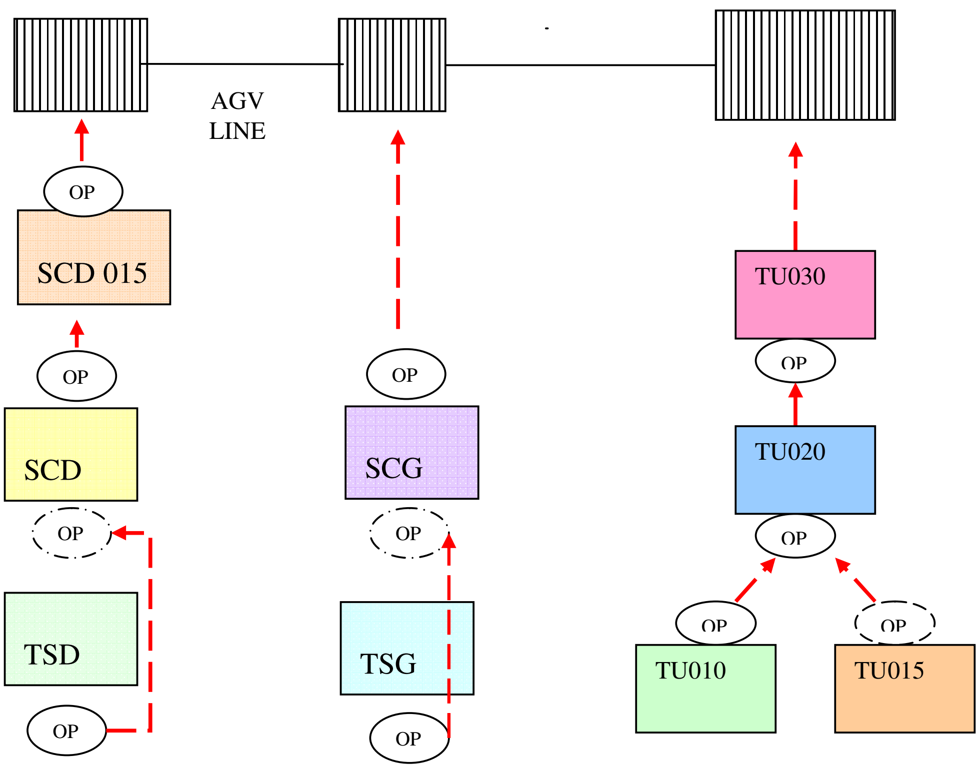


Figure 4.1 Flow of material in the suggested pull and push system

CHAPTER FIVE
CONCLUSION

In this thesis, the aim is to determine problems of an automotive company where instead of one model, two different car models each with two different diversities will start being produced on the same assembly line, and then to propose some improvements to solve these problems. By the production of two different car models, there will be a facility layout problem in the preparing area. In the current state, there is not an effective material handling and stock control system in the company. The distances between departments are so long that parts are being damaged and delays are occurring during the transportation. In order to solve these problems and make production system more flexible some improvements are needed to be proposed. By this aim, in the first stage of the thesis, current production system, facility layout and transportation activities are examined and those are questioned to identify the problems: whether *i)* the transportation is realizing as close as to posts *ii)* the movements of materials, raw materials, works in progress, products and workers are minimum, and *iii)* the comfortable and safety working environment for operators are provided. Then, a set of improvements are proposed. A simulation study is conducted by using ARENA 10.0 to see at what degree the amendments increase the system performance, and to find the optimum value of decision variables.

In summary, definition of problems and the expected improvements are listed below.

1. *Problem: Necessity of generating permanent solutions for the new coming products and diversities, instead of temporary solutions.*

   Solution: "Left-side-floor", "right-side-floor" and "tunnel" parts which belong to different models and diversities will be produced in the same preparing line. There will not be a change in the process of the system, the layout and number of package, in the case of changing model or diversity. The system will be more adaptable and flexible.

2. *Problem: Disorderliness in the flow of material between the preparing line and the main line.*

   Solution: Using AGV for the transportation between preparing line and the main assembly line. Control of material flow will be provided and work order will be given to the preparing line in a fast way with the help of AGV's ability of communicating with the factory devices.

3. *Problem: High quantity of work in progress.*

   Solution: Preparing line will produce when it is needed according to the suggested pull system. So the risk of overstock at the end of the preparing line, will be prevented. In current situation, the quantity of work in progress at the end of line is about 12. This number will be average of 0.50 in the case of using the suggested pull system during 50 days of time. As it seems, the system will almost work without stock.

4. *Problem: High amount of transportation cost (energy and workmanship).*

   Solution: Using AGV's instead of forklifts will reduce the energy and the workmanship costs.

5. *Problem: Delay and causing damage on the parts during the transportation.*

   Solution: Using the forklifts for transportation needs human control, and therefore it can cause delay and also damage on the parts. Using AGV will prevent this risk.

6. *Problem: Lack of efficient stock control.*

   Solution: The maximum number of work in progress will be one at the end of the preparing line in the case of setting up the suggested pull system. According to the results obtained from the simulation study, the average number of work in progress at the end of the preparing line is 0.50. This low and steady quantity of work in progress proves that suggested pull system provides efficient stock control.

The results and the expected improvements by the end of the study are given below.

- Permanent solution is generated for the new coming products and diversities.

- Material flow between the preparing line and the main line will be put under control.

- Work in progress will be minimized.

- The cost of transportation (workmanship and energy) will be reduced.

- The products will be transported in a fast and safe way.

- An efficient stock control system is set up.

- The increase in capacity will occur because of the eliminating bottlenecks. The capacity of the main assembly line will increase from 26.9vehicle/hour to 27.39vehicle/hour.

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APPENDIX A: Workflow charts

A.1. Workflow chart for right side floor

WORK FLOW CHART		
PAGE NUMBER: 1		
PART: RIGHT SIDE FLOOR		
LOCATION: L38/B32 PREPARING LINE		
PREPARED BY GİZEM KAYA		

SUMMARY	CURRENT	PROPOSED
PROCESS	31	
TRANS.	8	
DELAY	2	
CONTROL	3	
STORAGE	1	
TOTAL TIME	**229,06**	

OPERATIONS	PROCESS	TRANSPORTATION	DELAY	CONTROL	STORAGE	TIME
SCD010 (op.1)						
Taking parts (Walking)						3,00
Putting parts (Walking)						3,00
Installation						17,84
SAISIR SIMPLE+POSERINDETER.						5,16
Pushing the button						2,43
Seraj						3,00
Taking Pens						6,80
Positioning Pens						9,03
Welding 8 points						17,60
Pens process						10,11
Removing Pens						6,45
Leaving Pens						2,72
						87,13
TSG010						
Taking parts (Walking)						6,00
Putting parts (Walking)						12,00
Installation						17,84
Pushing the button						4,43
Taking Pens						5,80
Positioning Pens						10,97
Welding 8 points						17,60
Pens process						6,88
Removing Pens						7,74
Leaving Pens						3,72
Pushing the button						3,47
Walking for the unloading TCD010 post						3,00
Unloading TCD010 post						4,95
Turning back						3,00
UNLOADING THE SCD10 POST						
Waiting						12,10
Pushing the button						5,43
Walking for the unloading the SCD10 post						9,00
Unloading the SCD10 post						4,01
Turning back						4,00
						229,06

A.1. Continue- Workflow chart for right side flor

SCD010 (OP.2)									
Taking parts (Walking)	●	➡	D	■	▼	3,00			
Putting parts (Walking)	●	➡	D	■	▼	3,00			
Installation	●	➡	D	■	▼	10,68			
Waiting	●	➡	D	■	▼	12,30			
Pushing the button	●	➡	D	■	▼	2,43			
Taking Pens	●	➡	D	■	▼	9,73			
Positioning Pens	●	➡	D	■	▼	10,43			
Welding 31 points	●	➡	D	■	▼	71,70			
Pens process	●	➡	D	■	▼	46,66			
Removing Pens	●	➡	D	■	▼	4,73			
Leaving Pens	●	➡	D	■	▼	8,01			
Kurs process	●	➡	D	■	▼	24,01			
Pushing the button	●	➡	D	■	▼	5,43			
Walking for unloading parts	●	➡	D	■	▼	3,00			
Unloading parts	●	➡	D	■	▼	4,95			
Turning Enterpost	●	➡	D	■	▼	7,30			
						227.36			
SCD015 OP.3									
Taking parts (Walking)	●	➡	D	■	▼	3,00			
Putting parts (Walking)	●	➡	D	■	▼	3,00			
Installation	●	➡	D	■	▼	6,67			
Pushing the button	●	➡	D	■	▼	4,86			
Taking Pens	●	➡	D	■	▼	5,94			
GOUJON	●	➡	D	■	▼	32,10			
Leaving Pens	●	➡	D	■	▼	5,29			
Pushing the button	●	➡	D	■	▼	2,86			
Unloading parts	●	➡	D	■	▼	5,81			
TOTAL						**69,52**			

A.2. Workflow chart for left side flor

WORK FLOW CHART		
PAGE NUMBER: 1	CURRENT	PROPOSED
PART: LEFT SIDE FLOOR	31	
LOCATION: L38/B32 PREPARING LINE	8	
	2	
PREPARED BY GİZEM KAYA	3	
	1	
	229,06	

OPERATIONS	PROCESS	TRANSPORTATION	DELAY	CONTROL	STORAGE	TIME			
SCG010 (op.1)									
Taking parts (Walking)						3,00			
Putting parts (Walking)						3,00			
Installation						17,84			
SAISIR SIMPLE+POSERINDETER.						5,16			
Pushing the button						2,43			
Seraj						3,00			
Taking Pens						6,80			
Positioning Pens						9,03			
Welding 8 points						17,60			
Pens process						10,11			
Removing Pens						6,45			
Leaving Pens						2,72			
						87,13			
TSG010									
Taking parts (Walking)						6,00			
Putting parts (Walking)						12,00			
Installation						17,84			
Pushing the button						4,43			
Taking Pens						5,80			
Positioning Pens						10,97			
Welding 8 points						17,60			
Pens process						6,88			
Removing Pens						7,74			
Leaving Pens						3,72			
Pushing the button						3,47			
Walking for the unloading TCG010 post						3,00			
Unloading TCG010 post						4,95			
Turning back						3,00			
UNLOADING THE SCG10 POST									
Waiting						12,10			
Pushing the button						5,43			
Walking for the unloading the SCG10 post						6,00			
Unloading the SCG10 post						4,01			
Turning back						6,00			
						229,06			

A.2. Continue- Workflow chart for left side flor

SCG010 (OP.2)									
Taking parts (Walking)	○	→	D	□	▽	3,00			
Putting parts (Walking)	○	→	D	□	▽	3,00			
Installation	○	→	D	□	▽	10,68			
Waiting	○	→	D	□	▽	12,30			
Pushing the button	○	→	D	□	▽	2,43			
Taking Pens	○	→	D	□	▽	9,73			
Positioning Pens	○	→	D	□	▽	10,43			
Welding 31 points	○	→	D	□	▽	71,70			
Pens process	○	→	D	□	▽	46,66			
Removing Pens	○	→	D	□	▽	4,73			
Leaving Pens	○	→	D	□	▽	8,01			
Kurs process	○	→	D	□	▽	24,01			
Pushing the button	○	→	D	□	▽	5,43			
Walking for unloading parts	○	→	D	□	▽	3,00			
Unloading parts	○	→	D	□	▽	4,95			
Turning Enterpost	○	→	D	□	▽	7,30			
						227,36			

A.3. Workflow chart for tunnel

WORK FLOW CHART	
PAGE NUMBER: 1	
PART: TUNNEL	
LOCATION: L38/B32 PREPARING LINE	
PREPARED BY GİZEM KAYA	

SUMMARY	CURRENT	PROPOSED
PROCESS	31	
TRANS.	8	
DELAY	2	
CONTROL	3	
STORAGE	1	
ZAMAN	**667,05**	

OPERATIONS	PROCESS	TRANSPORTATION	DELAY	CONTROL	STORAGE	TIME
TU010						
Putting parts (Walking)						6,00
Installation						17,99
Turn tunel						3,00
Serrage Montage						4,95
Pushing the button						1,40
Welding						12,00
Clinching						23,26
Pushing the button						4,47
Unloading parts						6,67
SAISIR SIMPLE+POSERINDETER.						4,72
EFFORT DE 6 A 10 KG						0,86
						85,30
TU015						
Taking parts (Walking)						3,00
Putting parts (Walking)						3,00
Installation						5,95
Taking Pens						6,80
Positioning Pens						8,60
Kurs process (Open-close)						17,15
Welding 6 points						15,00
Removing Pens						6,02
Turning Pens						4,30
Pens process						4,84
Leaving Pens						5,72
Opening Seraj						16,56
Unloading parts						4,09
SAISIR SIMPLE+POSERINDETER.						1,72
EFFORT DE 6 A 10 KG						0,86
						103,60

A.3. Continue- Workflow chart for tunnel

TU020									
Installation	●	➡	D	■	▼	18,06			
Taking-Putting parts (Walking)	●	➡	D	■	▼	10,00			
Pushing the button	●	➡	D	■	▼	6,15			
Taking Pens	●	➡	D	■	▼	7,01			
Pens process	●	➡	D	■	▼	32,90			
Positioning Pens	●	➡	D	■	▼	28,88			
Welding 24points	●	➡	D	■	▼	60,00			
Removing Pens	●	➡	D	■	▼	18,71			
Turning Pens	●	➡	D	■	▼	9,89			
Turning platform	●	➡	D	■	▼	14,19			
Leaving Pens	●	➡	D	■	▼	5,94			
Unloading parts	●	➡	D	■	▼	6,24			
Walking to Enterpost	●	➡	D	■	▼	3,00			
Turning Enterpost	●	➡	D	■	▼	4,30			
Stock	●	➡	D	■	▼	6,00			
						230,25			
TU030									
Taking parts (Walking)	●	➡	D	■	▼	4,00			
Putting parts (Walking)	●	➡	D	■	▼	4,00			
Installation	●	➡	D	■	▼	12,76			
Pushing the button	●	➡	D	■	▼	4,93			
Clinching	●	➡	D	■	▼	35,31			
Unloading parts	●	➡	D	■	▼	6,09			
EFFORT DE 6 A 10 KG	●	➡	D	■	▼	0,86			
Pens process	●	➡	D	■	▼	25,18			
Positioning Pens	●	➡	D	■	▼	18,28			
Welding 20 points	●	➡	D	■	▼	60,00			
Turning Pens	●	➡	D	■	▼	9,89			
Pens process	●	➡	D	■	▼	27,95			
Removing Pens	●	➡	D	■	▼	12,69			
Leaving Pens	●	➡	D	■	▼	18,88			
Turning platform	●	➡	D	■	▼	7,10			
						247,90			

A.4. Workflow chart for SC020 Post

WORK FLOW CHART	SUMMARY		CURRENT	PROPOSED
PAGE NUMBER: 1	PROCESS	●	31	
PART:	TRANS.	➡	8	
LOCATION: SC020 POST	DELAY	D	2	
	CONTROL	■	3	
PREPARED BY GİZEM KAYA	STORAGE	▼	1	
	TOTAL TIME		169,01	

OPERATIONS	PROCESS	TRANSPORTATION	DELAY	CONTROL	STORAGE	TIME
Taking parts (Walking)	●	➡	D	■	▼	3,00
Putting parts (Walking)	●	➡	D	■	▼	6,00
Installation	●	➡	D	■	▼	10,75
SERRAGE MONTAGE	●	➡	D	■	▼	2,58
Saisie outil rangé inf à 40cm	●	➡	D	■	▼	7,59
*MEPCORDONEXTRUDE30<L<=50	●	➡	D	■	▼	17,2
Pushing the button	●	➡	D	■	▼	2,47
Closing Seraj	●	➡	D	■	▼	3,00
GOUJON SOUDE	●	➡	D	■	▼	2,78
Taking Pens	●	➡	D	■	▼	3,51
Leaving Pens	●	➡	D	■	▼	1,08
Taking Pens	●	➡	D	■	▼	7,51
Positioning Pens	●	➡	D	■	▼	10,32
Welding 14 points	●	➡	D	■	▼	42,00
Pens process	●	➡	D	■	▼	21,29
Removing Pens	●	➡	D	■	▼	7,10
Leaving Pens	●	➡	D	■	▼	4,87
Pushing the button	●	➡	D	■	▼	2,47
Opening Seraj	●	➡	D	■	▼	3,00
Unloading parts	●	➡	D	■	▼	10,52
OPERATOR2						
Taking parts (Walking)	●	➡	D	■	▼	9,00
Putting parts (Walking)	●	➡	D	■	▼	9,00
Installation	●	➡	D	■	▼	16,99
WAITING	●	➡	D	■	▼	12,10
Pushing the button	●	➡	D	■	▼	2,47
Closing Seraj	●	➡	D	■	▼	3,00
Taking Pens	●	➡	D	■	▼	7,01
Positioning Pens	●	➡	D	■	▼	10,32
Welding 14 points	●	➡	D	■	▼	42,00
Pens process	●	➡	D	■	▼	21,29
Removing Pens	●	➡	D	■	▼	7,10
Leaving Pens	●	➡	D	■	▼	7,94
WAITING	●	➡	D	■	▼	4,80
Pushing the button	●	➡	D	■	▼	2,47
Opening Seraj	●	➡	D	■	▼	3,00
Unloading parts	●	➡	D	■	▼	10,52