CHALMERS

Assembly line design and optimization

Restructuring and balancing of the bus pre-assembly line at MAN Nutzfahrzeuge AG Ankara factory

Master of Science Thesis in the International Master's Programme Automotive Engineering

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Department of Product and Production Development
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Cover: *Restructuring of stations for the single pre-assembly line at MAN Türkiye*

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ABSTRACT

MAN Türkiye A.Ş. is one of the three bus production sites of MAN Nutzfahrzeuge AG with a yearly production of about 2000 vehicles. Production of MAN and NEOPLAN branded vehicles is handled at the factory with a total of 16 models and more than 200 variants.

The bus production system at MAN Türkiye is divided into five operational lines that are chassis welding, paintshop, pre-assembly, assembly and finish. Production runs on a single line with 65 minutes of takt time with an exception in the pre-assembly line of two parallel lines of 19 stations and 130 minutes of takt time. With this structure, the pre-assembly line acts as a factory within a factory, bringing out its own problems of high operational and inventory costs. In order to eliminate the complications of this structural difference, the company management aims to construct a single assembly line by merging the pre-assembly and assembly lines at the same building, which requires the current pre-assembly system to be switched to a single line of 65 minutes of takt time.

This project analyses the operations and balance losses at the current pre-assembly line, and intends to create a framework for the restructuring process that will optimize resource utilization. To conduct this study, the assembly line is observed and analyzed in order to evaluate the balance losses and their reasons, and determine which operations are inappropriate for an assembly line. Eliminating the most evident wastes and building up a simplified pre-assembly operations list, the pre-assembly line is balanced for the desired number of stations in parallel with operator and line layout planning tasks. Considering the difficulty of the task of balancing a line that assembles 16 different models, the most complex model of each bus type - city, intercity and coach- is selected as base models.

The simplified operation list provides an improvement of vehicle operation time of about 30%. The achieved results suggest that, in addition to according the whole production system with its line flow properties, the new line structure makes it possible to reduce inventory costs by 40%, operator demand by 17%, and idle time and takt overdue by about 80%. With a new line layout, it is also possible to reduce total distance from the sub-assembly stations to main assemblies by about 20%, which will improve material flow activities within the facility.

Keywords: Bus Assembly, Assembly Line Design, Assembly Line Balancing, Operator Planning, Waste Reduction, Resource Utilization

PREFACE

This report is the result of the Master's Thesis project carried out at MAN Nutzfahrzeuge AG bus factory in Turkey from February 2009 to July 2009 as part of the International Master of Science programme in Automotive Engineering at Chalmers University of Technology, Sweden.

It was expected to be a challenging task to simultaneously assimilate and apply knowledge on a subject that hasn't been a part of Automotive Engineering education and yet it hasn't been less than what was predicted. This project, however, has proven that once the determination and dedication is possessed to reach a goal, lack of knowledge cannot last long. With the experienced engineers and crew, and high-level multi-disciplinary engineering applications, MAN Türkiye has been a crash-course laboratory in Production Engineering; observing the real time applications of concepts instantly after learning from books has been an invaluable opportunity for me to gain the practical knowledge and experience I required to move the project forward. I hope MAN Türkiye will benefit from the results of my study as much as I did from the study itself.

I would like to thank Barış Arpacı for his belief in my aptitude and recommendation, and Yenal Gündüz for giving me the opportunity to do this project and the responsibility of such an assignment. Without their support I would not be able to initiate and carry out this project.

Special thanks to Hüseyin Özsert for his ideas and consistent patience in giving answers to my countless questions, Emrah Arslantaş for helping me by-pass the bureaucracy within the company while trying to get things done, Galip Başköprü for providing all required information about the factory that is unreachable for the most, and the team leaders for helping me figure out the dynamics at the shop floor by sharing their first hand experience.

I would also like to thank Bertil Gustafsson for accepting to be my examiner for this project and Åsa Fasth for her help with bringing this report to a conclusion.

Gothenburg, September 2009

Artun Törenli

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1 INTRODUCTION

This chapter includes corporate presentation of the company and the background of the problem that constitutes the motivation of the project. Furthermore, the scope, objectives and organization of the project are also presented along with the brief outline of the report.

1.1 About MAN Türkiye A.Ş.

MAN Aktiengesellschaft (MAN AG) is among Europe's leading manufacturers of commercial vehicles, engines and mechanical engineering equipment with annual (2008) sales of €14.9 billion and about 51,000 employees worldwide. As the inventors of the diesel engine and with a business history of 250 years, the company supplies trucks, buses and diesel engines as well as turbo machinery, and holds leading market positions in all its business areas. Centered in Munich, the group hosts the four companies MAN Nutzfahrzeuge AG, MAN Diesel SE, MAN Latin America and MAN Turbo AG.

Holding 69% of the total turnover of the MAN Group, MAN Nutzfahrzeuge AG is the largest company within the group and among the leading international suppliers of commercial vehicles. The company includes MAN Trucks, MAN Buses, and NEOPLAN Buses. MAN Nutzfahrzeuge AG has 15 different production sites worldwide that are distributed to 8 countries; Germany, Austria, Poland, Turkey, India, Saudi Arabia, South Africa and Mexico.

Figure 1.1 - Global production sites of MAN Nutzfahrzeuge AG

MAN Türkiye A.Ş. is one of MAN Nutzfahrzeuge AG's global production sites and located in Ankara, Turkey. The company is founded in 1966 in Istanbul under the name of MANAŞ (MAN Truck and Bus Industry Ltd.) with MAN Nutzfahrzeuge AG's partnership of 33,3% and started production of trucks and buses. In 1985, MANAŞ launched a new facility in Ankara for manufacturing engines and trucks. The company's management is taken over by MAN Nutzfahrzeuge AG in 1995, and the production of trucks, city buses and coaches is conjoined in Ankara. By 2002, the share of MAN Nutzfahrzeuge AG is increased to 99,9% and the company is retitled as MAN Türkiye A.Ş. The company terminated truck production in Ankara in 2006 and the facility became the production center for MAN branded coaches, city buses and intercity buses as well as NEOPLAN branded coaches and intercity buses with a maximum yearly production capacity of 2375 vehicles. The company exports 85% of its production; the buses produced in Ankara are exported to 41 countries worldwide.

Figure 1.2 - MAN Türkiye A.Ş. facility

Table 1.1 - Company profile of MAN Türkiye A.Ş.

Area (m^2)	Open	320,000
	Closed	88,500
	Offices	18,000
	Total	426,500
Employees	White collar	281
	Blue collar	1,654
	Total	1,935
	Woman / Man (%)	5,8/94,2
Production 2008 (units)	Internal market	260
	Exported	1,464
	Total	1,724
Sales 2008 (Million €)	Turnover	277,3
	Profit (%)	~3

1.1.1 *Products and properties*

There are currently 16 bus models that leave the production line at MAN Türkiye A.Ş.. MAN and NEOPLAN Coaches, MAN and NEOPLAN intercity buses and MAN city buses are produced in this facility. Production is not to stock; production planning is made according to customer order. Besides the large number of variants, customer requests (KundenSonderWunsch) add a great variety of configurational difference to the same type of bus. The total number of variants of the 16 different bus models –excluding KSWs- reaches up to 226. A simplified table for the current product range and their engine variants can be seen in Table. 1.2.

Table 1.2 - Bus types and engine variants

	CLASS	NUMBER OF AXLES	TYPE	MODEL	EMISSION CLASS	FUEL TYPE	ENGINE
CITY BUSES	A20	Two	MAN City Bus	Lion's City Ü	Euro 4	Diesel	10,5 l D20 / 270, 310 PS
					EEV		10,5 l D20 / 280, 320, 360 PS
						CNG	12,8 l E28 / 310 PS
	A21	Two	MAN City Bus	Lion's City	Euro 4	Diesel	10,5 l D20 / 270, 310 PS
					EEV		10,5 l D20 / 280, 320, 360 PS
						LPG	12,8 l G28 / 270 PS
						CNG	12 l E28 / 245, 310 PS
	A74	Two	MAN City Bus	Lion's Classic	Euro 4	Diesel	6,9 l D08 / 280 PS
					EEV	CNG	12,8 l E28 / 310 PS
	A78	Two	MAN City Bus	Lion's Classic LE	Euro 3	Diesel	6,9 l D08 / 280 PS
					Euro 4		6,9 l D08 / 280 PS
					EEV		6,9 l D08 / 290 PS
SERVICE (INTERCITY) BUSES	R12	Two	MAN NAG	Lion's Regio	Euro 4	Diesel	10,5 l D20 / 310, 350, 390 PS
					Euro 5		10,5 l D20 / 320, 360, 400 PS
					EEV		10,5 l D20 / 320, 360 PS
	R13	Three	MAN NAG	Lion's Regio L	Euro 4	Diesel	10,5 l D20 / 350, 390 PS
					Euro 5		10,5 l D20 / 360, 400 PS
					EEV		10,5 l D20 / 320, 360 PS
	R14	Three	MAN NAG	Lion's Regio C	Euro 4	Diesel	10,5 l D20 / 310, 350, 390 PS
					Euro 5		10,5 l D20 / 320, 360, 400 PS
					EEV		10,5 l D20 / 320, 360 PS
	P23	Two	NEOPLAN NAG	Trendliner	Euro 4	Diesel	10,5 l D20 / 310, 350 PS
	P24	Three	NEOPLAN NAG	Trendliner L	Euro 4	Diesel	10,5 l D20 / 390 PS
	P25	Two	NEOPLAN NAG	Trendliner C	Euro 4	Diesel	10,5 l D20 / 310, 350, 390 PS
COACHES	R07	Two	MAN Coach	Lion's Coach	Euro 3	Diesel	10,5 l D20 / 430 PS
					Euro 4		10,5 l D20 / 400, 440 PS
					EEV		10,5 l D20 / 400 PS
	R08	Three	MAN Coach	Lion's Coach L	Euro 3	Diesel	12,5 l D26 / 460 PS
					Euro 4		10,5 l D20 / 440, 440 PS
					EEV		12,5 l D26 / 440, 480 PS
	R09	Two	MAN Coach	Lion's Coach C	Euro 4	Diesel	10,5 l D20 / 440 PS
					EEV		12,5 l D26 / 440, 480 PS
	P20	Two	NEOPLAN Coach	Tourliner C	Euro 4	Diesel	10,5 l D20 / 440 PS
					EEV		12,5 l D26 / 440, 480 PS
	P21	Two	NEOPLAN Coach	Tourliner	Euro 3	Diesel	10,5 l D20 / 430 PS
					Euro 4		10,5 l D20 / 400, 440PS
					EEV		10,5 l D20 / 400 PS
	P22	Three	NEOPLAN Coach	Tourliner L	Euro 3	Diesel	12,5 l D26 / 460 PS
					Euro 4		10,5 l D20 / 440 PS
					EEV		12,5 l D26 / 440, 480 PS

1.2 Background

Production at MAN Türkiye is held in four main buildings and completed in -excluding sub-assembly stations- 117 stations. The production line is divided into five operational divisions that act as individual lines within the production system. With the other four being single, pre-assembly line is the only segment of the production line that flows as two parallel lines. The operational segmentation of the production system is as shown in table 1.3.

Table 1.3 - Main buildings, work centers and performed operations at MAN Türkiye A.Ş.

Department	Number of stations	Building	Type of work
Bus Chassis Assembly	29	U1	Chassis welding
Paintshop	14	U1	Anti-corrosive chemical application and painting
Bus Pre-assembly	19 (+19)	U1 and G	Assembly of infrastructural systems and glasses
Bus Assembly	27	U2	Assembly of seats and other interior&exterior accessories
Bus Finish	28	U3	Paint polish and final revisions

The steps of bus production at MAN Türkiye can be summarized as following. The production of a bus starts at the bus chassis department. Welding of the beams and side plate covering operations are held in this section. When the chassis of the bus is complete, the vehicle is taken to the paintshop. In the paintshop, anti-corrosive chemicals are applied to the chassis, which is followed by priming, cleaning of surfaces, and application of final paint. This is when the vehicle is taken to the bus pre-assembly line. The operation of bus pre-assembly line can be simplified as performing the infrastructural operations that are required to make a vehicle run. That is, a vehicle that leaves the pre-assembly line is fully functional and can operate normally. Operations such as wiring, assembly of brake systems, assembly of powertrain, floor and side covering, and assembly of glasses are held at the pre-assembly line, which is partitioned into U1 and G buildings. When a vehicle leaves this line, it is brought to U2 building, where all accessories of the vehicle are installed. Finally, the vehicle is taken to the finish building U3 for final inspections and paint polish operations.

The existing production system is established in 2004 as part of the development project “EVOLUTION 2004” and the production lines have been balanced for the contemporary models of the time. However, the assembly lines haven’t been revised as new models are added to the product range, which cumulatively increased the balance losses up to date.

The Work Preparation Group is aiming to rearrange the assembly lines to achieve a lean production line that fulfills the requirements of the current product range. As the segment that breaks the uniformity within the production system, restructuring of the pre-assembly line is the most prominent prerequisite of the desired single production line. This requires a thorough analysis of the current pre-assembly line operations and elimination of wastes in the whole process. This work will form the basis for the company’s planned future action of changing over to joint-assembly by merging the pre-assembly and assembly operations in one building.

1.2.1 *Area of focus*

The focus of this thesis work is only the bus pre-assembly line that is located in U1 and G buildings. The factory layout and the location of buildings of interest can be seen in figure 1.3.

Figure 1.3 - MAN Türkiye A.Ş. facility layout

Operational division of U1 and the setting of the pre-assembly line within is shown in figure 1.4.

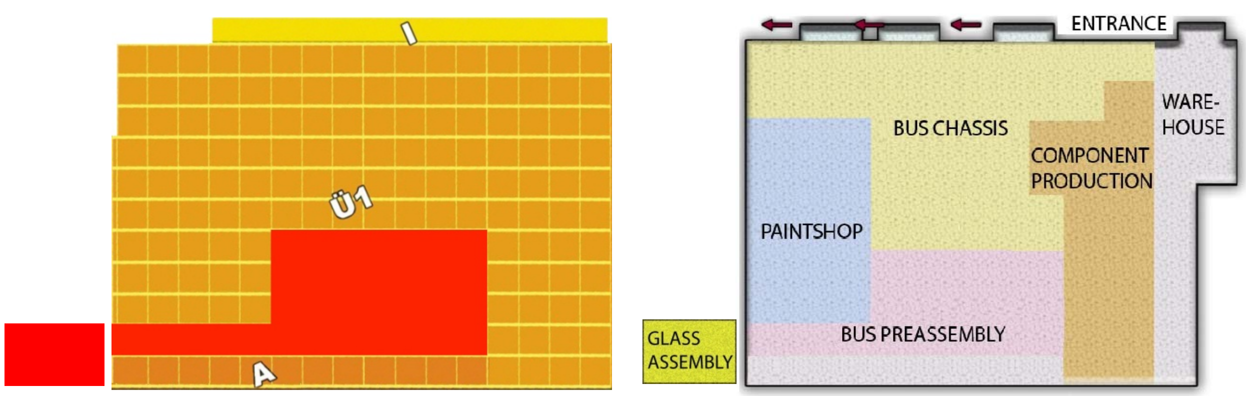


Figure 1.4 - Layout of the pre-assembly line in U1 building

1.3 Scope

The planned operation for restructuring the assembly system is to merge the pre-assembly and assembly stations in U1 building as a single and continuous assembly line. Switching to single line production at the pre-assembly line is the framework of this process. The scope of this work is to take the necessary actions for reorganizing the production system and rebuilding a more efficient pre-assembly line. This includes analysis of operations at these pre-assembly stations by considering lean assembly fundamentals and balancing of the line. Performing changes in the sequence of operations at stations, removing/replacing stations, addressing/readdressing operations to stations, layout planning, operator planning and line balancing are among the expected work to be done within this study.

1.4 Objectives

Through analysis of operations at the pre-assembly line and processes at the corresponding workstations at MAN Türkiye A.Ş., the objectives of this study are,

a. *to investigate the balance losses in the current pre-assembly line,*
b. *to achieve a lean assembly line by eliminating wastes in current production system and performing necessary revisions with the current station setup,*
c. *to close one of the parallel pre-assembly lines and switch to single line production,*
d. *to change takt time from 130 to 65min. as it is applied at other single lines in the factory,*
e. *to complete the pre-assembly processes at maximum 22 stations,*
f. *to balance the new pre-assembly line for the most complex models of each of City, Intercity and Coach bus types, which are A21, R13 and P22,*
g. *to evaluate different layout possibilities for the new station setup,*
h. *and to perform these tasks with minimum costs.*

1.5 Delimitations

The focus area of this study is only the two-line pre-assembly line that consists of 30 (15+15) stations in U1 and 8 (4+4) stations in the glass assembly building. No other lines or stations in the facility except these 38 stations are of concern of this study. Delays in internal logistics are neglected and it is assumed that all parts are ready at the corresponding stations for assembly on time. Task times will not be recalculated for all processes but for those that are not known, and the existing task times will be regarded as the optimum duration for the given processes on the line.

1.6 Project organization

This Master's thesis project is carried out with the contribution of the following persons.

Master's Thesis Author
Artun Törenli

Supervisor at MAN Nutzfahrzeuge AG
Yenal Gündüz, Work Preparation Group Manager, MAN Türkiye A.Ş.

Master's Thesis Examiner
Bertil Gustafsson, Production Engineering Master's Programme Director, Chalmers University of Technology

Master's Programme Coordinator
Malin Kjelberg, Automotive Engineering Master's Programme Coordinator, Chalmers University of Technology

Tutor
Åsa Fasth, Ph.D. Candidate, Chalmers University of Technology

1.7 Disposition

This Master's thesis report consists of 9 chapters. Chapter 1 develops a general presentation of MAN Türkiye A.Ş. and explains the nature and organization of this thesis study. Chapter 2 provides the theoretical framework that this thesis study is built on. Chapter 3 describes the project steps and applied methodology to carry out this study, and explains the course of the performed work by presenting the details of the approach to the given problem. Chapter 4 projects the current state analysis of the production system. Chapter 5 analyzes the complications with the current production system, suggests solutions to eliminate these problems and proposes the future state mapping of the system. Chapter 6 evaluates the proposed system and investigates the advantages it yields over the current system. Chapter 7 includes the discussion of results of the study and generates methodology on how to implement and improve the proposed system. Chapter 8 concludes the whole report and summarizes what is achieved throughout this study and Chapter 9 shows the references that are used to complete this study.

2 THEORY

This chapter contains definition of common terminology and concepts, and the theoretical framework of this project.

2.1 Assembly

2.1.1 *Common terminology and concepts*

A *product*, according to Askin et al, ([2] p. 1) is "*any item that is designed, manufactured and delivered with the intention of making a profit for the producer by enhancing the quality of life of the customer*. Most products are made up of various *parts*, where a *part* can be described as a single unit of a product that are brought together with others to form the finished product. *Assembly*, therefore, can be explained as the operation of bringing parts together, either manually by operators or automatically by robots, to form a finished product. Fixing of more complex parts that have more than one component before being assembled to the work-piece as a single unit is called a *sub-assembly*. A *work-piece* is an unfinished product whose assembly is in progress.

In order to establish a comprehensive understanding of the dynamics of assembly, it is essential to be familiar with the stages and various elements involved in the assembly process. Figure 2.1 attempts to provide a brief overview of a typical assembly process by highlighting the major constituents of an assembly line.

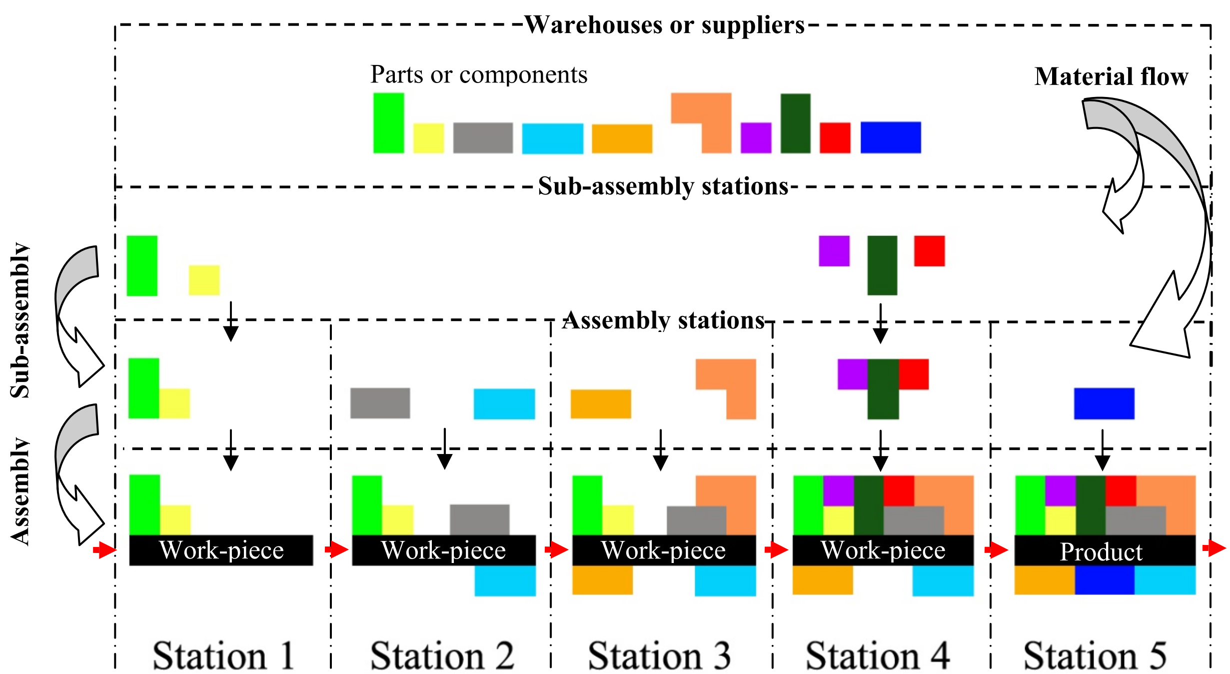


Figure 2.1 - Demonstration of work and material flow at a 5-station assembly line

Work station

A (work) station is a segment of the assembly line where a certain amount of the total assembly work is performed. Each station on an assembly line is set up with all the materials, machines, tools, jigs/fixtures, instructions and operators needed for the operation(s) assigned. A work-piece does not return to the station it has already visited at an assembly line. (Baudin [3] p. 86, Scholl [19] p. 4)

Operation (task)

The assembly process of a product consists of a sequenced set of actions that are applied to the work-piece as it moves on the line. Each of these indivisible actions is called an *operation*.

Operator

Who performs an operation on an assembly line is an operator. Operators perform their tasks either manually by using hand tools, or semi-manually by using automatic tools or task-specific machines. Minimum number of operators required to complete all tasks on an assembly line is calculated as,

Minimum number of assemblers= Total assembly time of the product/ Takt time

However, this is only a theoretical calculation and in most cases, due to some restrictions, this calculation does not give reliable results. For instance,

- this calculation gives the minimum number of operators required for the assembly of a specific product. However, total assembly time of different products processed at the same line can differ, which results in different assembler demands.

organization of the assembly line is an important factor while defining operator demand, i.e., assemblers do other time consuming work than assembly at the line such as material handling, walking, picking etc. Therefore, assembly time data only is not enough to evaluate operator demand. (Baudin [3] p. 50)

Material handling

Material handling can be explained as the extra work that a part is subjected to from the time it becomes ready for assembly until it is assembled. This work includes transportation, storage and sequencing of parts as well as rework on the parts to be assembled. In an ideal system, a part that is ready for assembly should directly be transported to the site of assembly in order to eliminate the extra cost that will emerge for storage and further transportation. Material handling does not add any value to the finished product and is the greatest source of waste in a production system that should be minimized.

Material flow
Continuous transportation of raw materials, parts and components from their source locations, i.e., suppliers, warehouses, sub-assembly stations etc, to their assembly locations until they are used in the production system is called material flow. Material flow is a very critical aspect of production since any problem that occurs during this process can affect the whole production system, which may even cause the whole system to stop until the required item is received.

Product process pattern
Product process pattern defines the production strategy of a facility decided by the producer according to production capacity and product features. The two main product process systems are job shop production system and flow line production system. Scholl ([19] p. 1) defines job shop production systems as job-oriented workshops where machines performing similar operations are combined, and flow line production systems as facilities that are arranged according to the technological sequence of operations.

The product process matrix proposed by Hayes and Wheelwright (1979) describes the dynamic nature of product and process choices and represents the strategic choices available to firms in both product and process dimensions. According to Schroeder ([20] p. 64), "*The diagonal of the matrix represents a match between the product and process; a low-volume product with high variety would be produced by a job shop, while a highly standardized product with high volume would be produced by a continuous process. Any firm operating off the diagonal is likely to have either the wrong product or the wrong process to remain competitive.*"

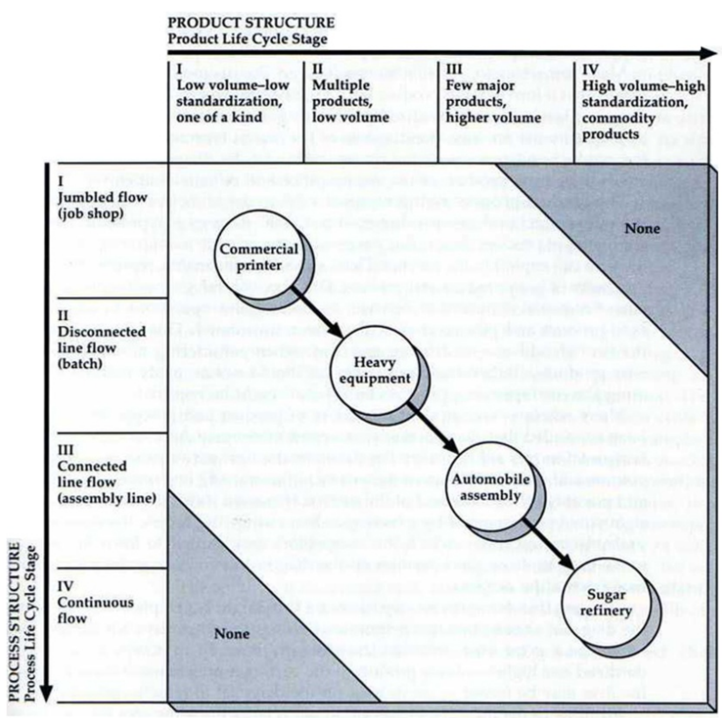


Figure 2.2 - Product – Process Matrix (Schroeder [20] p. 63)

According to Scholl [19], the main advantages of flow line systems relative to job shop production systems are,

- high capacity utilization and small throughput times,
- low in process inventories,
- regular and simple material flow,
- reduced need for material handling due to transferring of workpieces by mechanical handling equipment like conveyor belts,
- less space need for storage and material movement, which reduces the required shop floor space,
- ability to use less skilled operators who can be trained more quickly due to strict division of labor,

On the contrary, he emphasizes the disadvantages of these systems as,

- high capital requirements for the installation of the system,
- low job satisfaction of workers employed at flow lines due to high degree of labor division, which creates simple and monotonous job contents as well as leading to high absenteeism and turnover rates of workers,
- inflexibility of systems due to high degree of specialization, which becomes disadvantageous especially with respect to the steady shortening of product life cycles,
- system failure risks due to machinery; maintenance and repairs become critical issues since machine brake-downs may stop the complete system. The same is true if the requisite material is not available.
- system failure risks due to quality; the quality control must directly be included into the production process with the existence of inspection stations. When failures occur the complete line may be affected.

Regarding these aspects; standardized products, high volume production, stable product demands and continuous supply of material is mandatory for successful installation of flow line systems. (Scholl [19] p. 2)

Order initiation

Decision of production is customer-oriented; producers define what and how to produce according to the demand of customers. Producers design production process with three major strategies; Make-to-Stock (MTS), Make-to-Order (MTO) and Assemble-to-Order (ATO).

In the MTS system, producers specify a product range according to customer demands and the finished products are stocked. The strategy behind this system is to stock the products that are assumed to be demanded, and to supply these products immediately on demand. Forecasting, inventory management and capacity planning play very important roles in this process. Although

MTS system can provide fast service with lower costs, product customization is not an issue in this system.

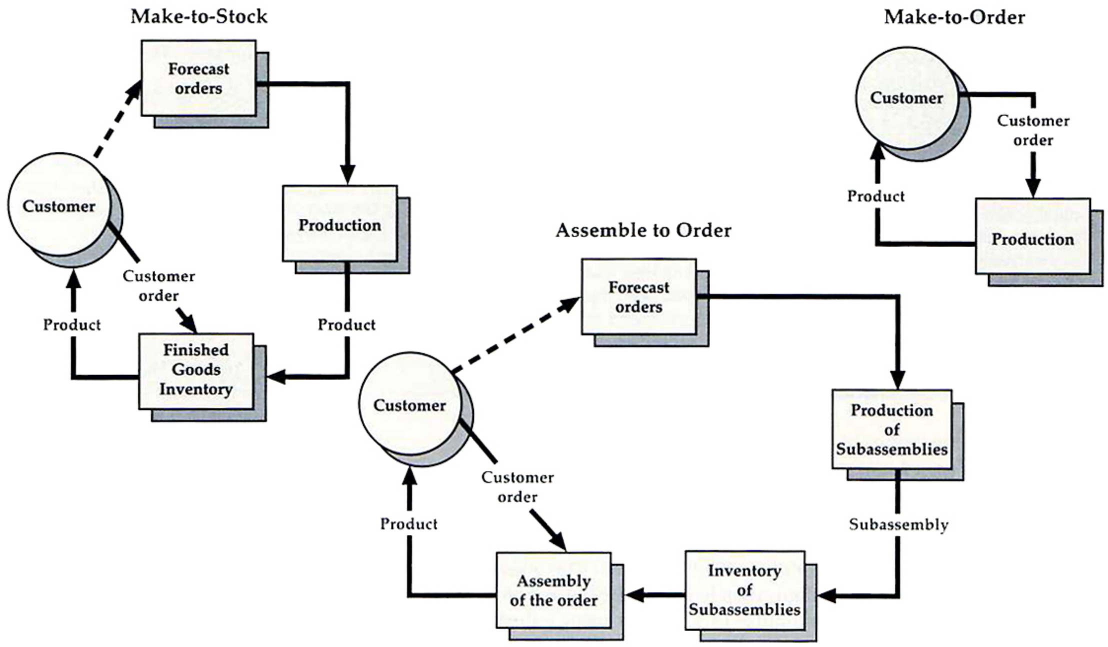


Figure 2.3 - Comparison of MTS, MTO and ATO production processes (Schroeder [20] p. 59)

In the MTO system however, products are designed and produced according to customer specifications. In this sense, MTO system provides higher flexibility for product customization, but production costs are higher than the MTS system.

The ATO system is in a way a combination of the MTS and MTO systems. In the ATO process, subassemblies that form the products are Made-to-Stock, and when customer order is received, the product specifications are configured and final product is Made-to-Order. Modularity in product design is therefore critical for this production process to be used. (Schroeder [20] p. 58-59)

2.1.2 *Time constraints*

The following sections describe different time parameters that exist in a production system.

Operation time

Operation time is the time required to start and finish an operation at a station. (Scholl [19] p. 4) Measurement of operation time studies are either made manually by stop-watch, or digitally by image processing techniques. (Scholl [19] p. 5)

Cycle time

Starting from the moment a work-piece is delivered to a station, the required time for all operations at that station to be completed on that work-piece is called cycle time. Cycle time at a station is a function of the total operation time and number of operators at that station. (Scholl [19] p. 5)

Takt time

Depending on the production plan shaped according to customer demands, number of products that will leave a production system on a daily basis is a known data. Takt time can simply be defined as the required time that must elapse between two consequent product completions, which is also equal to the time for each work-piece on the line taken from its arrival to the current station until its arrival to the next station. Takt time is a function of product volume and available production time. (Ortiz [15] p. 48)

$$\text{Takt time} = \text{Net available production time} / \text{Demand}$$

From the definition, takt time is the same for all stations on an assembly line, and it should not be confused with cycle time. Takt time is the time for which a work-piece stays at a station; cycle time is the time for which operations are completed while the work-piece is at the station.

Takt overdue

The case when all assigned operations at a station could not be completed within the takt time is called takt overdue.

Idle time

Idle time (waiting time) defines the period in which no operations are held at a station after all operations are completed and the work-piece stays idle until being moved to the next station. Since cycle time differs for different stations of a line, idle time is also different for each station. For individual stations it can be expressed as,

$$\text{Idle time} = \text{Takt time} - \text{Cycle time}$$

The sum of idle times for all stations of the line is called the *balance delay time*. (Scholl [19] p. 5)

Tolerance time

The required time for a work-piece to be delivered to the next station after it is processed at the current station is called tolerance time. (Scholl [19] p. 5)

Throughput time

Throughput time is the total time for a work-piece to enter a production line and leave the line as the finished product, which is equal to the total processing and waiting times of that production system. (Scholl [19] p. 25)

Labor productivity

Labor productivity is the amount of output that an operator produces in unit time. This can be formulated as,

$$P_a = F_v / I_a \,,$$

where F_v and I_a represents the number of buses that leave the pre-assembly line in a given time and number of operators at the pre-assembly line respectively. (Slack et al, [21] p. 50)

2.2 Assembly methods

There are two primary methods of assembly in the industry, which are bench assembly, and line assembly.

In bench assembly, the work-piece stays stationary on a bench; all required parts and equipment for assembly are brought to the bench and assemblers move around the bench to perform the assembly. (Schroeder [20])

Line assembly is an assembly method where work-pieces move through a sequence of stations for assembly one piece at a time. (Schroeder [20]) An assembly line is the production system in which assembly stations are organized in a serial layout and line assembly method is applied.

2.2.1 *Line assembly methods*

Depending on the production strategy, assembly lines can be designed such that assembly of different products can be held at same line. According to the diversity of products assembled at the line, assembly lines are divided into three main categories; single model, mixed model and multi model assembly lines. (Scholl [19])

At a single model assembly line, assembly of a single product without any variants is handled. All operations at same stations of the line are standard and the same for all work-pieces, and products leaving the line are identical.

At a mixed model assembly line, assembly of variants of a single product is performed. Operations at a mixed model line are similar for different variants since they undergo similar processes, but may have different operation times for different models. Model sequencing does not have resource constraints for a mixed model line; different models can be processed without the need of any modifications at the line.

Figure 2.4 - A section of the bus pre-assembly line from stations D/E 09 to D/E 13

A multi model line is the most complex among the other assembly methods in terms of operational requirements. At a multi model assembly line, assembly of different products that require different assembly processes is held. For the assembly of another product to start, station setup has to be changed. In order to minimize change over costs, assembly on the line is made in separate batches.

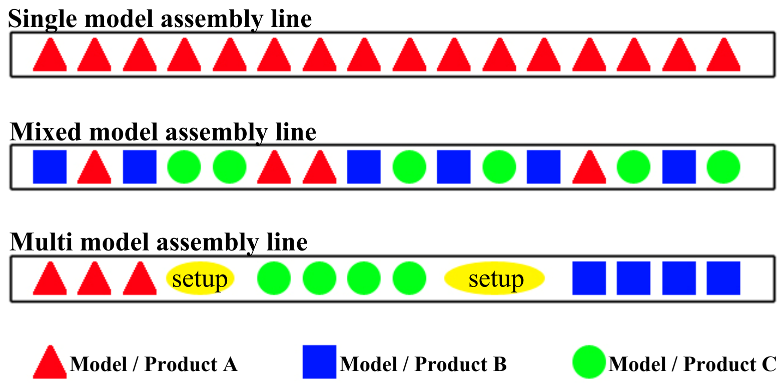


Figure 2.5 - Different line assembly methods (Scholl [19] p.7)

2.3 Flexibility

Schroeder ([20] p. 198) defines flexibility as "*the time it takes to change volume or product mix by a certain percentage or amount*." From this perspective, the supply chain and the physical setup of the production system is the determining factor of the flexibility of the whole system.

Production process design has the most crucial effect on the flexibility of the production system. Slack et al, [21] express this phenomena under the concept of series and parallel process configurations (or short-fat versus long-thin) and use box analogy as an example shown below. In the figure, three different arrangement options of the same system are discussed.

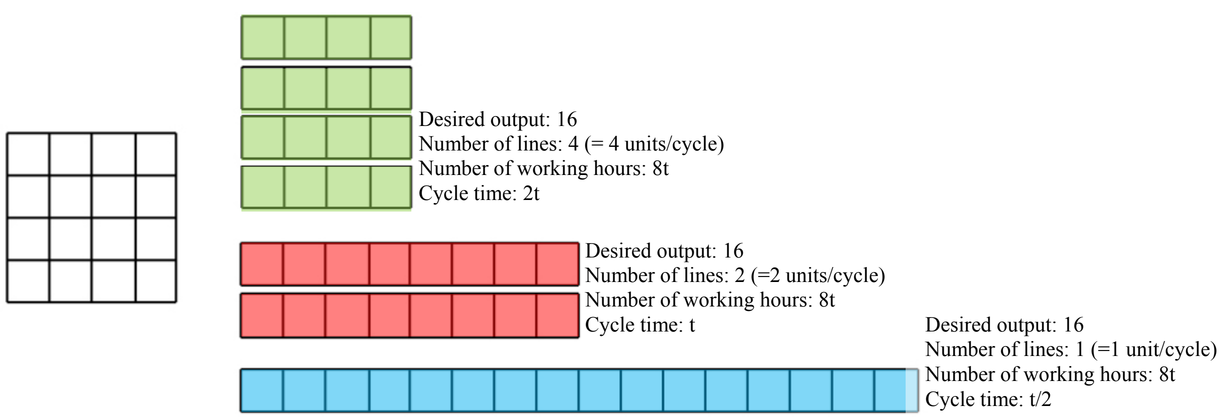


Figure 2.6 - Short-fat versus long-thin process configurations

As shown in figure 2.6, the same production process can be arranged in different ways depending on the expected outcome from the system. Assuming that the production capacity is constant for all options, as the line gets “shorter” and “fatter”,

- product mix and volume flexibility increases due to increased number of individual production lines which may be specialized for different models or which can be closed for capacity reduction,
- the whole system becomes less vulnerable to problems since there are multiple individual lines and any problems that occur will only affect the corresponding line instead of affecting the whole line,
- cycle times at stations increase since more operations are held due to reduced number of stations at the line,
- risk of making errors for operators increase due to the long cycle times at stations which reduce attention,
- logistics become a more critical issue since there are multiple individual lines,
- station working environment becomes less motivating due to the increased number of operators at the same station,
- specialization for operators becomes less possible since the same operator may have to make multiple operations in a longer cycle time.

2.4 Lean production

Womack et al, [25] describes lean thinking as a powerful antidote to “muda”, which in Japanese means any *human activity that absorbs resources but creates no value*, and concludes that “*lean thinking provides a way to do more and more with less and less – less human effort, less equipment, less time, and less space – while coming coming closer and closer to providing customers with exactly what they want.”* (Womack et al, [25] p. 15)

Lean production can be defined as the application of lean fundamentals to all levels of a production system in order to minimize production wastes. It denotes “*that a company or an organization works at the most effective level and at a level suited to the purpose in combination with a relentless pursuit of eliminating waste and all non value adding activities.*” (IVF [9] p.3).

Baudin [3] highlights the 7 wastes that exist in a production system as,

- over-production
- process
- transportation
- excess inventory
- motion
- waiting
- rework

Over-production is regarded as the greatest waste since it creates other wastes such as motion, conveyance and inventory. It increases need for extra storage space, additional parts, additional materials and energy to operate machines, and creates extra materials to handle and demand for extra material handling equipment. It also requires additional work force to handle all these additional work.

Processing becomes a waste when more work is done than what the customer demands. It is very difficult to detect process wastes since it requires detailed knowledge of the assembly process.

Transportation is regarded as the movement of operators and stocks around the production system without any purpose. Since moving does not add any value to the end product, it is a waste that should be eliminated.

Inventory is a part of production systems, but when anything more than is required to perform the job is stocked, it becomes a waste. Excess inventory causes extra carrying cost and damage, and requires extra storage, containers, handling requirement and time.

Motion is not a work, it is thus non-value added. Therefore it causes time loss within the production process. It is mainly caused by disorganized work sequence of layout and should be minimized.

Waiting includes waiting for a machine to finish its process, a part or component to arrive from an upstream activity, or an adhesive to dry. Waiting does not add value to the final product, therefore it is non value added and should be minimized.

Rework is correcting a faulty operation, which means that additional time is spent for the same operation twice and makes this operation a waste in the production system.

(Baudin [3], Womack et al, [25])

2.4.1 *Value added – non-value added operation*

The cost of a product is determined by the cost of all resources used in the production of the product such as raw materials, labor, storage, transportation and etc. Every operation is therefore evaluated for the value it adds to the final product. In this sense, the value of each operation for which the customer is willing to pay is calculated as,

Value of operation = Value of product after operation - Value of the product before operation

A part of an operation that adds and does not add value to the product is therefore called value-added and non-value-added operation respectively. To give an example, glass assembly operation includes steps of unpacking the glasses, laying glasses on tables, sorting glasses in the order of assembly, holding glasses, assembling glasses and cleaning surfaces. Among the steps of glass assembly, only assembly of glasses and cleaning of surfaces add value to the final product, which makes them the value-added steps of the glass assembly operation. The non-value-added rest is capacity loss that must be eliminated. (Ortiz [15])

2.5 Layout planning

Layout is the physical setting of a production system in a designated production facility. Layout planning is the physical organization of elements of a production system by considering the physical constraints and resource requirements of and expected outcome from the system. Physical setting of a production system can affect the efficiency of a production system, i.e. supply chain performance in a facility can be improved by quick delivery of parts in a system with short distances between related locations, and it is very critical to consider specific requirements of the designed system and customize the layout plan accordingly. According to Sule [22], production system layout is a critical issue because material handling costs are up to 75% of total manufacturing costs, and rearranging an existing production facility is costly in terms of time and money.

Among numerous sources on the subject, the most valid guide on this concept is introduced by Muther et al, [13] who introduced a systematic approach to production system layout planning that is organized under six steps. Called *Simplified Systematic Layout Planning*, this method suggests,

1- identification of relationships between the elements of the production system and desired closeness between them,
2- identification of physical space and resource requirements of the elements,
3- graphical expression of findings in step 1 and 2 by emphasizing the desired closeness with different line weights, i.e. stronger relations are indicated with greater number of lines,
4- laying out the elements of the production system inside the real facility by considering their specified relationship with each other and the physical structure of the facility itself,
5- creation of different layout proposals for different priorities, i.e. availability for new lines in the future, lowest cost, etc. and make a selection,
6- detailed planning of the selected plan.

2.6 Assembly line balancing

Balancing an assembly line indicates distribution of total workload of the line among each station at the line equally so that idle times and the difference between the idle times at different stations are as low as possible. The key here is to balance the workload of operators at every station; reducing operator idle times at stations over a takt means reduction of unused station capacity, which is the expected result of line balancing and which helps minimization of losses and costs.

Production is a dynamic process with multiple dimensions, i.e., products, operations, operators, material handling, production planning, machines, assembly line characteristics etc., and a production system needs to adapt itself to changes that occur in any of these dimensions as quickly as possible in order to minimize losses. From this perspective, anything “fixed” in the production system is a potential source of loss for the entire system, which should be analyzed and eliminated within the balancing process periodically.

Balance losses at an assembly line are inevitable; there is very small possibility to achieve and preserve a perfect balance of workload at a flow line production system due to the dynamic characteristics of this type of system. Also, it is not possible to distribute the process precisely equally among stations in this system. Therefore it is clear that at flow line production systems there are always balance losses. However, by understanding the sources of these losses, balance losses at assembly lines can be minimized. Figures 2.7 and 2.8 demonstrate two different balancing conditions of the same line.

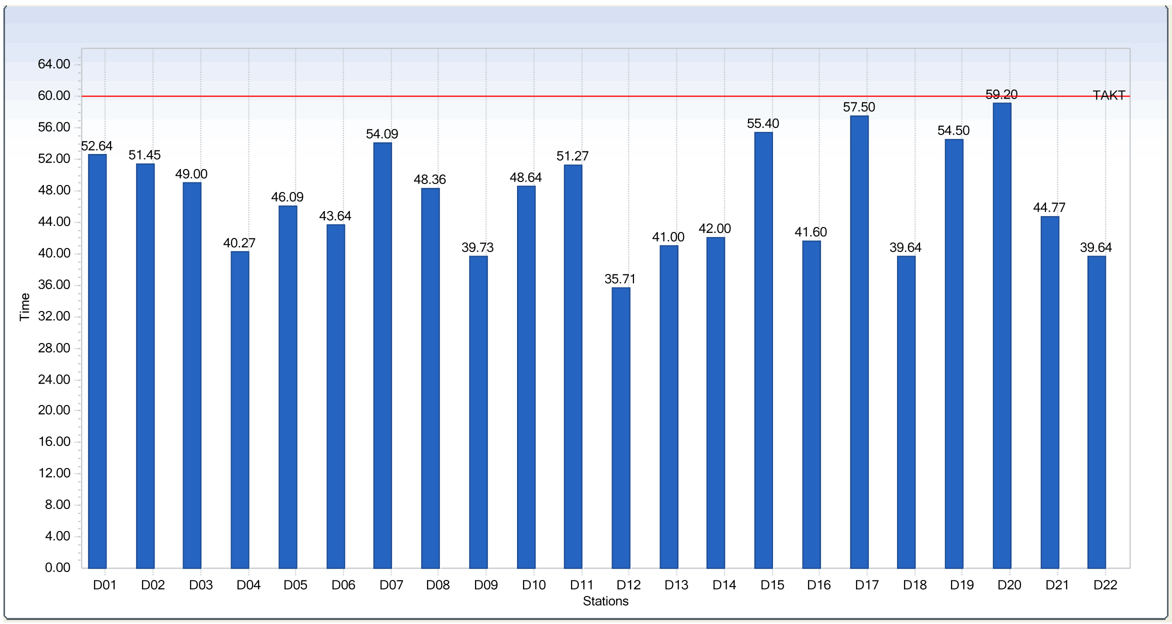


Figure 2.7 - Demonstration of an unbalanced assembly line of 22 stations ($\Delta cycle_{max}$= 23.49 min)

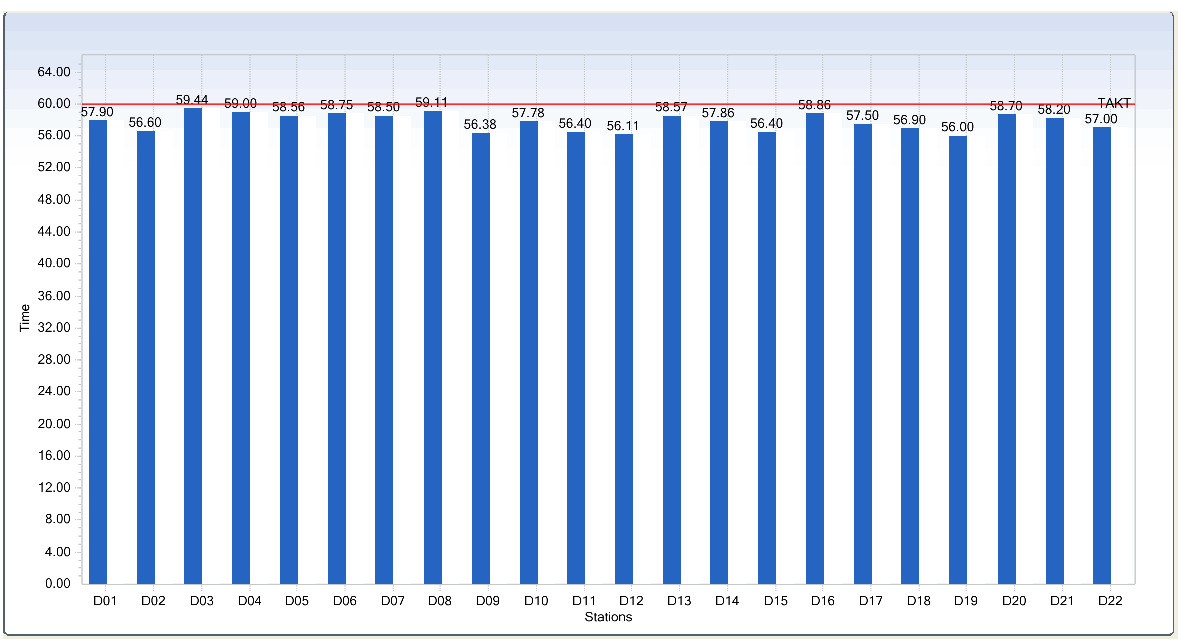


Figure 2.8 - Demonstration of a well-balanced assembly line of 22 stations ($\Delta cycle_{max}$= 3.44 min)

Idle times at stations are the primary indicators of balance losses at an assembly line. Idle time at a station shows that there is excess capacity at that station, which is undesired. For a line producing multiple types of products, variant losses are the main reason for station idle times. Same operation may require different operation times for different product models, but when the operator number is fixed at a station for the most complex model and when a less complex model comes to the station, operators finish their work early and the be idle for the remaining time. As number of variants produced at an assembly line increases, so do variant losses.

There are also other factors that cause losses that are not related to number of operators or unequal distribution of operations to stations. These losses are primarily caused by other factors of the production system and more difficult to determine. Among these factors, supply chain related losses have the major effect. Supplying wrong parts or incomplete components to the assembly stations causes operators to leave their stations for looking for those parts or do rework when they receive them. Besides, the location and packaging of the supplied material seriously affect the non value added work ratio of the operator at a station, i.e., walking to the parts, unpacking the parts, sorting the parts, in some cases making the sub-assembly at the station etc. These losses can be eliminated by improving the supply chain organization of the production system.

Scholl [19] brings out the two objectives for balancing an assembly line as capacity oriented goals and cost oriented goals, both of which are directly related to cycle time and number of stations.

For capacity oriented balancing, he suggests the following should be considered;

- number of stations should be minimized for a given cycle time and cycle time should be minimized for a given number of stations,
- flow time and waiting time of pieces should be minimized,
- sum and percentage of idle times over all stations should be minimized.

He also indicates investment and operating costs should be minimized, and identifies some of these costs as,

- inventory costs; *non-productive storage of work-pieces causing tied-up capital*
- wage costs; *relies on number of workers, which makes planning of operators a critical issue*
- idle time costs; *unused capacity of machines and workers that should be utilized*
- incompletion costs; *cause rework by stopping or off the line, thus loss of capacity*
- material costs; *affected by wastage rates, and should be minimized by process improvement* (Scholl [19] p. 20-21)

2.6.1 ***Precedence***

Precedence information of operations is the most important data while sequencing and distributing operations among stations. Precedence indicates the order and priority relationship between operations in the same process. In order to determine the most efficient sequence of operations at the line, i.e., by minimizing the risk of dismantling of a part for assembly of another part or rework, correct formation of the precedence relation of operations is very critical.

Operations are classified as series and parallel, implying that series operations must be done one after the other and parallel operations can be done at the same time without interfering each other. After the precedence relation is determined, distribution of operations to stations and to operators at stations is held according to the order and classification of operations. Figure 2.9 features an example precedence diagram of 10 operations. Operation 2_1 is the predecessor of all the following operations; after 2_1, 2_2 and 2_5 can start in parallel. 2_2, 2_3 and 2_4 are series operations. Operation 4_4 can only be made after 4_1, 4_2 and 4_3 are completed.

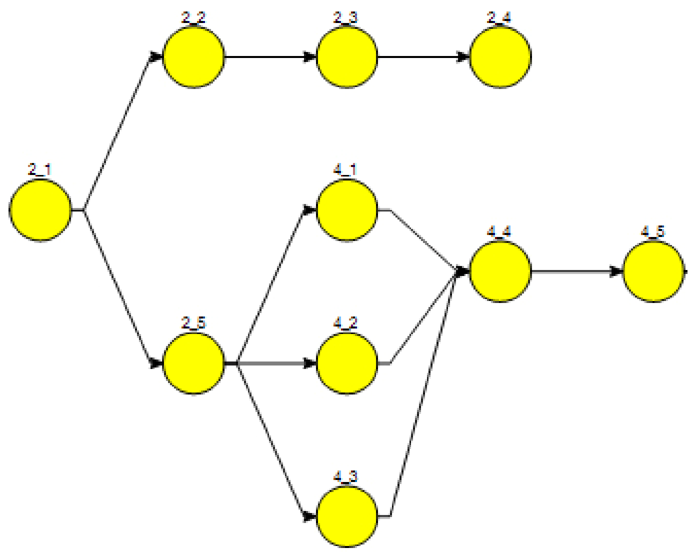


Figure 2.9 - Example precedence diagram

2.6.2 ***Operator job design***

There are some key issues for assigning operations to operators at the assembly line.

The first and most critical limitation about performance of operators making manual assembly is explained by Ortiz [15] as 85% rule, which simply suggests cycle time at a station not to exceed 85% of the takt time. According to Ortiz ([15] p. 49), "*Operators cannot work at optimum rate or speed, 100% of their shift, or they will become less productive, create more defects, become injured, and miss more days on the job. A realistic operator load of 85% allows for a smooth and efficient flow of product, without jeopardizing quality, productivity, or health. The 85% loading is not slow; it simply allows operators to work at a productive rate, which results in properly built, quality products.*"

In order to minimize non-value added work during assembly such as walking, sequencing etc.,

- supplied materials should be ready to assemble and positioned at arms reach or behind the operator which can be reached by simply turning behind
- working environment should allow the operator to use both hands during operations
- and work instructions should be clearly stated; assemblers should not spend time thinking about how to make the assembly. (Ortiz [15] p. 82)

Different takt times require different job designs in terms of operator performance. (Baudin [3] p. 55) explains this as "*For instance, at very short takt times the work is too repetitive which threats human endurance and causes repetitive stress injuries, while at very long takt times it is not repetitive enough for the assembler to fall into a routine that he or she can follow without having to think about it.*". Operators run the risk of forgetting where they are and skipping a step by mistake. Therefore, while assigning tasks, physical and mental capacity of operators should be considered as well as the ergonomic requirements of the tasks.

2.6.3 ***Bottleneck***

Schroeder ([18] p. 288-289) defines bottleneck as, "*a work center whose capacity is less than the demand placed on it and less than the capacities of all other resources. A bottleneck resource will constrain the capacity of the entire shop and an hour added to the bottleneck will add an hour of capacity to the entire factory. An hour added to the non-bottleneck work center will not help the schedule at all since the excess capacity exists there.*"

A bottleneck station determines the capacity of the whole production system; in a balanced assembly line, if 5 minutes' of work is added to the tasks of a station, all the following stations will have to wait for 5 minutes for all assembled products. This shows that, in fact each operator on the line is a bottleneck for the line and it is of crucial importance to eliminate the balance losses for maximizing line capacity. (Baudin [3] p.173)

2.6.4 ***Joker worker (andon)***

Not assigned to a specific operation or a station, a joker worker functions to meet the on-demand extra labor or operator replacement requirement at any station of the assembly line. This need may arise if a complex model with heavy assembly work is at a station and there is a risk of takt overdue, or if an operator is absent at a station. Joker workers can be involved in various works at the facility such as Kaizen activities, maintenance, sub-assembly stations etc. when they are not required at the assembly line.

Number of joker workers at an assembly line is determined during balancing of the line regarding the workload at the line. Instead of keeping a fixed number of operators at stations for complex but rare models, in order to eliminate idle operators at the stations, fixing the least number of operators to stations and providing the extra labor on demand by joker workers is a better option in terms of station efficiency. On the other hand, it is not acceptable to have idle joker workers at the facility when they are not needed at the main line. Therefore, the number of joker workers and how to use them when they are not doing assembly work should be well-planned.

2.7 Sustainability

The term "sustainability" has been spelled for the first time in 1974 in the World Council of Churches and highlights the importance of maintaining the living and non-living resources of our planet. In 1987, Gro Harlem Brundtland, who was the Norwegian Prime Minister and the UN World Commission on Environment and Development Chair of the time, published the report "Our Common Future", where the idea of sustainable development has been introduced for the first time. This idea can be basically summarized as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainability can be maintained in the three main domains; economy, society and environment, which are also known as the three pillars of sustainability. The relationship of these three pillars is expressed by Porritt ([16] p.46) such that "The economy is, in the first instance, a subsystem of human society, which is itself, in the second instance, a subsystem of the totality of life on the biosphere. And no subsystem can expand beyond the capacity of the total system of which it is a part". According to Adams [1], however, these pillars have cooperative relationship with each other unlike being subsystems of each other.

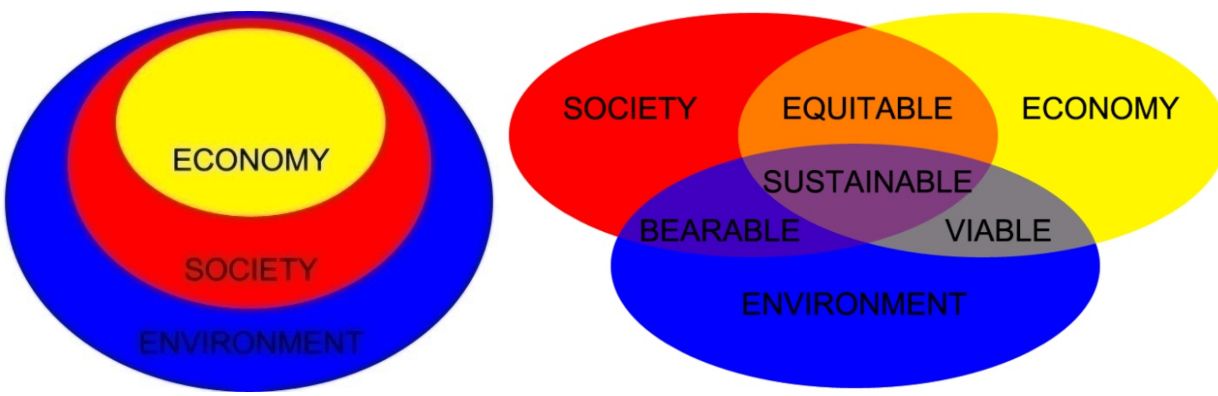


Figure 2.10 - Relation of three pillars of sustainability according to Porritt (left) and Adams (right)

The resources that are used for technological developments, industrialization and supporting the needs of increasing population are not more than what is provided by the planet we are occupying. Considering that the resources of the Earth are used above sustainable limits, in order not to edge away from a livable world for both ourselves and the following generations, every operation should be evaluated from the sustainability perspective. The main aspect of doing so should be to use the energy and raw material sources in the most efficient and effective way.

3 METHODOLOGY

The objectives of this project, which are to restructure and balance an existing assembly line, requires a set of compulsory procedures to be followed in order to achieve reliable results. First of all, it is crucial to have a complete list of operations of the assembly line and their times, because this data is the basic reason for a line to exist, and evaluation of the balance of a line cannot be made without this data. As the next step, it is important to evaluate the balance losses of the existing line for determination of factors that cause these losses. Finally, after eliminating these factors, the assembly line is structured according to desired specifications.

This first section of this chapter introduces the stages of the project and highlights the steps taken at each stage. In the second section, the applied methodology to carry out this study is portrayed in a detailed structure.

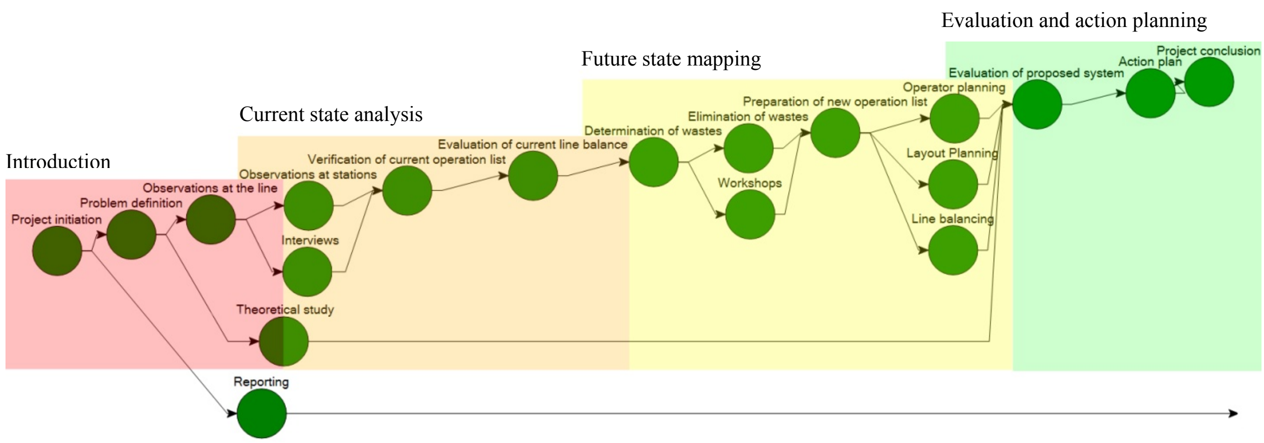


Figure 3.1 - Project steps and flow

3.1 Verification of operations lists

Individual operations lists for the bus models of interest have been completed and verified by applying four different data gathering methods;

- data mining
- time studies
- observations
- interviews

The theoretical basis and the application of these methods are described in the following sections.

3.1.1 *Data mining*

Data mining can be defined as collecting the information that will be used throughout the work to be conducted. Quality of collected information, which is defined by McGilvray ([12] p. 12) as "the degree to which information and data can be a trusted source for any and/or all required uses", is the most crucial aspect of data mining since it directly affects the outcome of the project.

The data of pre-assembly operations of vehicles of interest has been collected from the summary sheets provided by the Work Preparation Group and different databases within the factory. However, encountered unconformities between different sources indicated problems with updating of the databases, which reduced the reliability of the collected data for a line balancing procedure. Therefore, having the data from these sources as the guideline, three additional data gathering techniques have been applied to complete and verify the information to be used throughout this study.

3.1.2 *Time studies*

Glassey ([8] p. 18) defines the purpose of time study as "*to determine the time that a worker, or group of workers, should take to do a specified job at a defined level of performance*." He uses the term "performance" as a rate of output expressed as an average over the working shift, and "specified job" as a job where there is a written specification that concerns standard quality to be achieved, the tools and materials to be used, the working conditions under which the job should be performed, and the method to be followed by the operator. (Glassey [8] p. 18) From these definitions, it can be concluded that the primary objective of making time studies at the pre-assembly line is to determine the standard times –total time in which a job should be completed at standard performance- of assembly operations at the line. (Glassey [8] p. 19)

Standard operation times for tasks held at the bus pre-assembly stations are provided by the Work Preparation Group as Standard Operation Forms (SOF). An SOF is a company-specific data sheet that includes detailed analysis of individual operations with their steps and times. For tasks that do not have this information, time studies are made at the stations by using stopwatch and applying the procedure given by Glassey [8], which is explained in the following section.

In order to keep the cycle times at stations 85% of the takt time as indicated by Ortiz [15], all operation times are increased by 15% so that this distribution ratio would be included for each operation during the balancing task.

3.1.3 *Observations*

Observations have been a supplementary method to double-check the data of operations lists that was provided by the Work Preparation Group, and to make time studies for operations whose times were not recorded/updated on the summary sheets.

Operations lists were completed by visiting the stations with the summary sheets of the corresponding stations, and matching the assembly operations with the items listed on the existing sheets. Any difference between the operations and lists were recorded and asked to the team leaders for confirmation of the actual information.

Observation method is also used to measure the duration of operations whose time data is missing on the summary sheets. Glassey ([8] p. 49-55) explains how observation method can be used in standard operation time measurement and briefly divides the process into three main stages. In the preparatory stage, the observer determines the operation to be timed and its steps, and makes sure that the operator is aware of the time study and all necessary equipment for the operation is available. The second stage, which is the time study itself, is where the observer records the time of day when the measurement started, the duration of each step and evaluates the performance of the operator. In the concluding stage, the observer records the time of day that the study ended, calculates the total time of the operation and completes the summary sheet. Time measurements at the pre-assembly line are made by applying the procedure explained by Glassey [8].

3.1.4 *Interviews*

Interviews have been the greatest investigation tool for verification of the operations lists and provided the critical ideas that affected the decisions taken throughout this study.

Bunting [5] indicates a range of interview question types that are determined according to the information sought during the interview. The interviews made in this project aimed validating data and figuring out if the theoretical assumptions could be applicable in the shop floor. From this perspective, the questions that lead the interviews were either closed or probing open questions.

Closed questions, which can be regarded as yes-no questions, were used during the initial interviews held at the line with the operator team leaders while performing the verification of operation lists. The purpose of those interviews was to check if there is an inconsistency with the acquired operation lists from the management and the assembly operations at the stations.

The second set of interviews aimed to receive more detailed information from the team leaders and assembly operators about operations, and to dig deeper in order to reveal as much about the limitations as possible. Being the most experienced about the operations, each of the ten team leaders were asked about indeterminate constraints that define precedence, and the operations whose times were not possible to reduce by increasing number of operators. Besides, assembly operators that were selected randomly at the line according to the complexity of the operations they handled were asked about the steps of their work and if they had any suggestions for improvement. Therefore, the prepared questions for these interviews were open, which allowed them to tell as much about the operations as possible.

3.2 Line balancing

In order to achieve and a well-balanced assembly line, it is important to eliminate factors that cause losses; the wastes. For that purpose, before starting the balancing procedure, the production system is analyzed for determining wastes and the factors that create losses.

3.2.1 *ProPlanner® Line Balance*

The tool that is used for maintaining the optimum balance on the production line is ProPlanner® Line Balance (ProBalance 3.0.0.0) software. The software calculates the best balance with respect to the input data, which can then be manually manipulated for further modifications. It is possible to modify all input data in a matter of seconds, making visualization of different options and their results in a short time, and bringing in a great flexibility for the evaluation process. The quality of results generated by the software is strongly related to the quality of the input data; the more details are provided, the better solutions are received.

The data input to ProBalance for this work includes;

- Production type (mixed model),
- Operation names and times,
- Time unit (minutes),
- Work zones of operations,
- Product model (important for mixed model balancing),
- Resources required for the corresponding operations,
- Number of stations,
- Number of operators at each station,
- Monumental resources at stations,
- Desired takt time,
- Precedence of operations.

The most critical information required for this software to generate reliable results is the precedence relation of operations. The software assigns operations to stations according to the precedence of tasks. If this relation is defined incompletely or not correctly, violation of task sequence during assignment of tasks to stations is inevitable. This problem becomes more serious when dealing with the sequence of hundreds of operations, i.e., the number of bus pre-assembly operations for the least complex bus model was 536. The precedence graph of first 99 operations of A21 model is as shown in figure 3.2.

3.3 Line layout planning

Drawings of the facility and current layout of the line are provided by the Work Preparation Group. Alternative layout options for the new station setup are created by applying the *Simplified Systematic Layout Planning* method (Muther et al, [13]) by considering the constraint of minimum reorganization cost. Therefore, while planning the layout, stations with high replacement costs are tried to be kept at their existing locations. Sub-assembly stations are planned after the pre-assembly stations are lined.

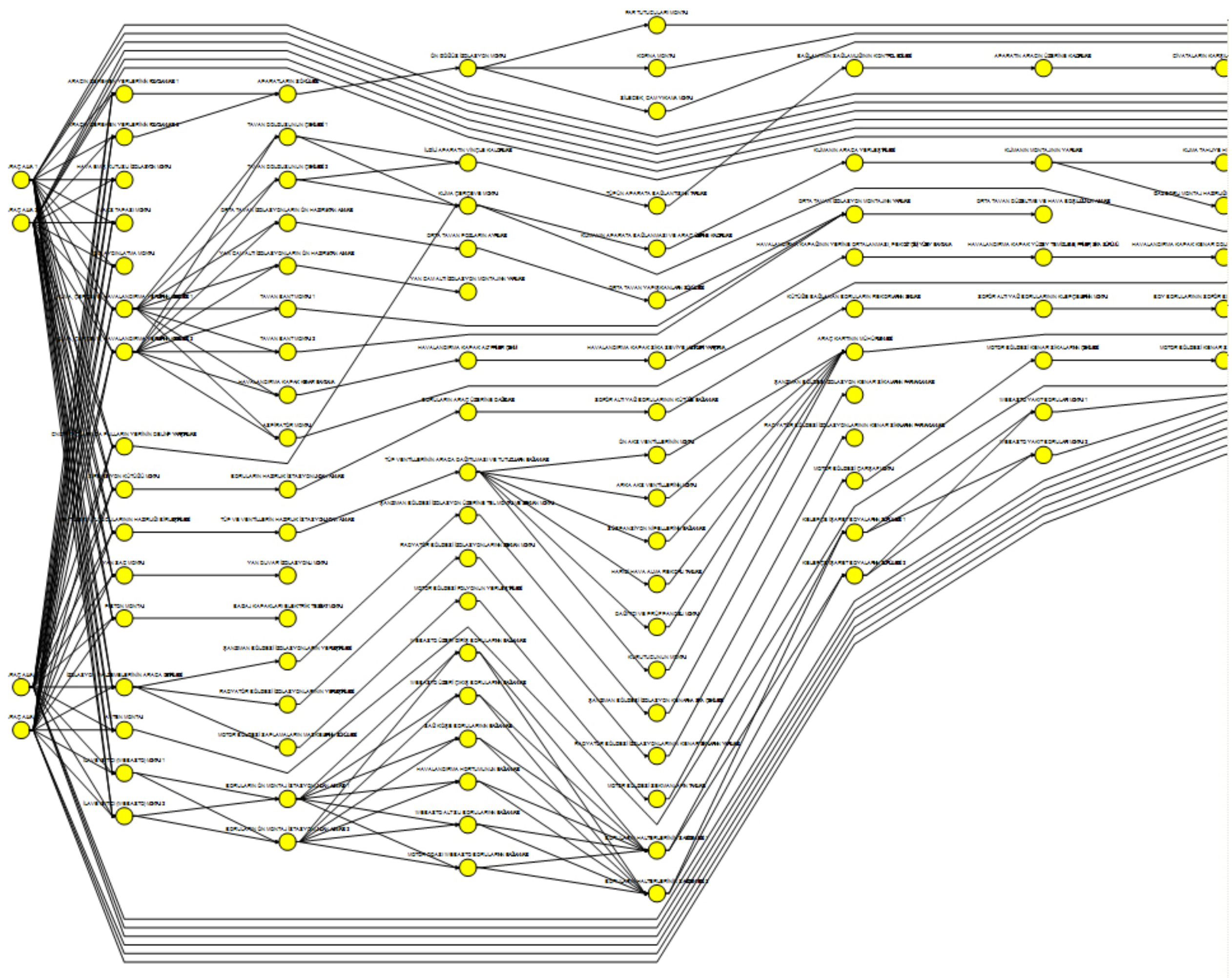


Figure 3.2 - ProBalance® precedence graph example for the first 99 operations of A21 model

3.4 STATEMENT OF APPROACH

In order to balance an assembly line, it is mandatory to have knowledge of all assemblies that are made on the line of interest, their sequence and precedence relation and the operation times.

At the assembly line that is to be analyzed, the assembly of 16 different bus types and their variants is handled. Even though similar processes are applied to all vehicle types, there are some processes of different operation times for different vehicles, or some type-specific processes for vehicles. Therefore it is of great importance to clarify and consider these differences while maintaining the line balance.

The method applied to perform the balancing study at the bus pre-assembly line is stated below.

1. Total number of stations at the line is determined.

2. The operations applied at these stations are crosschecked with the process lists of the Work Preparation Group and a complete process list of the pre-assembly line is prepared. This is done in two steps.
   - The existing process list of the assembly line is divided according to their distribution to stations. These lists are printed out and taken to the corresponding stations. The processes applied at the stations are both visually observed and also checked by interviews with the operators at the stations so that the missing / misaddressed / readdressed operations are determined and updated on the list.
   - Factory database is used to enlist all materials that are addressed to the pre-assembly stations for assembly. This database shows which item is addressed to which station in the factory for all vehicle models. This list is used to check the assemblies at the pre-assembly stations through the items that are addressed to these stations for assembly.

3. This updated list shows all processes that are applied at the pre-assembly stations. However, there are operations that differ for different vehicle models (i.e., only coaches have WC assembly or only CNG vehicles have CNG tank assembly) and also some similar operations are completed in different durations for different models (i.e., task time of electrical systems assembly of city buses is nearly half of that of coaches). Therefore a complete process list for all three vehicle types of interest is prepared by using the updated process list.

4. Operation times and number of operators for all processes of each of the three vehicle types are calculated. This is done by checking the existing operation time list and making time studies for missing operations.

Total nr. of operators
Nr. of operators
Station nr.
Station name
Operation

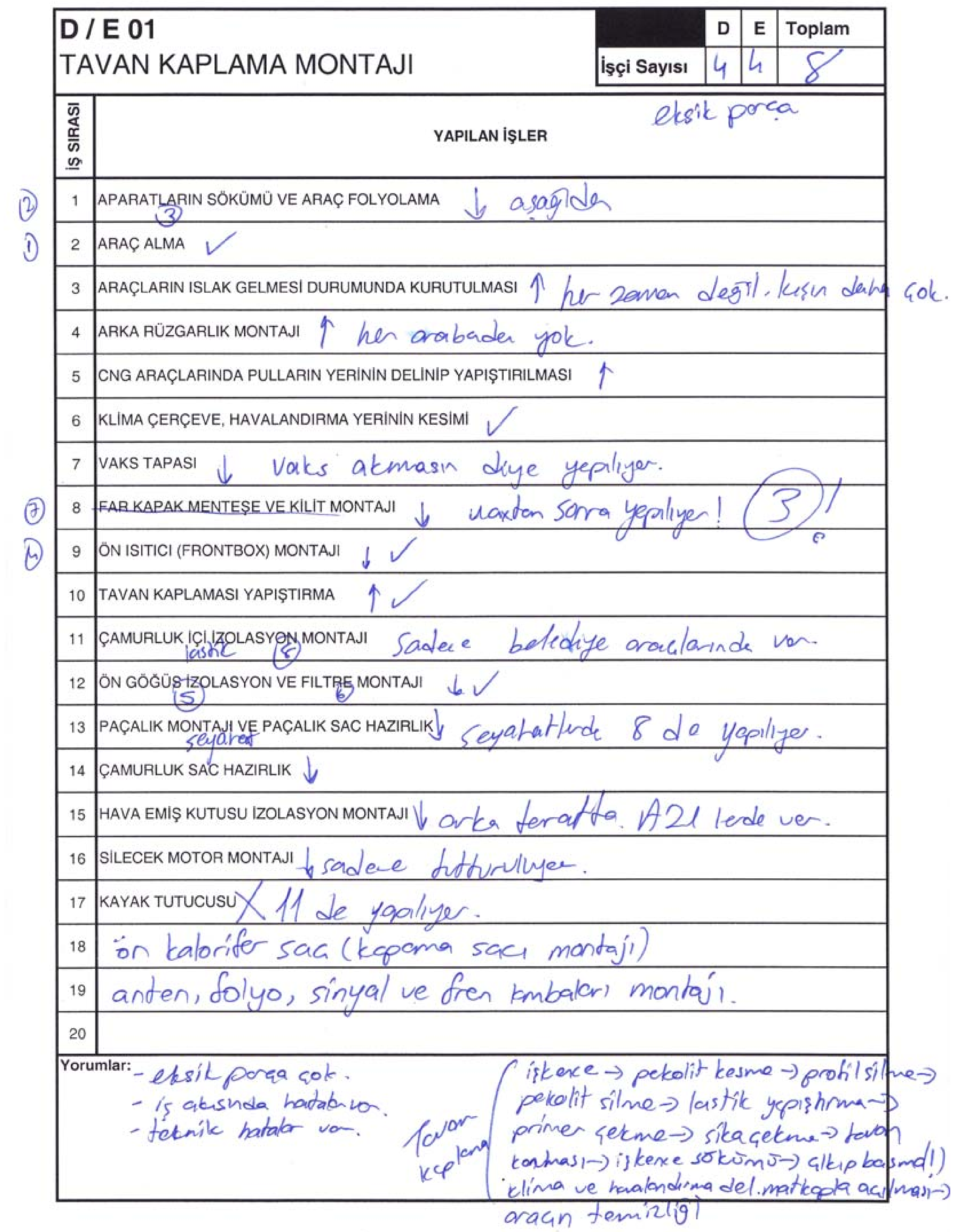
D / E 01 TAVAN KAPLAMA MONTAJI		D	E	Toplam
	İşçi Sayısı			

İŞ SIRASI	YAPILAN İŞLER
1	APARATLARIN SÖKÜMÜ VE ARAÇ FOLYOLAMA
2	ARAÇ ALMA
3	ARAÇLARIN ISLAK GELMESİ DURUMUNDA KURUTULMASI
4	ARKA RÜZGARLIK MONTAJI
5	CNG ARAÇLARINDA PULLARIN YERİNİN DELİNİP YAPIŞTIRILMASI
6	KLİMA ÇERÇEVE, HAVALANDIRMA YERİNİN KESİMİ
7	VAKS TAPASI
8	FAR KAPAK MENTEŞE VE KİLİT MONTAJI
9	ÖN ISITICI (FRONTBOX) MONTAJI
10	TAVAN KAPLAMASI YAPIŞTIRMA
11	ÇAMURLUK İÇİ İZOLASYON MONTAJI
12	ÖN GÖĞÜS İZOLASYON VE FILTRE MONTAJI
13	PAÇALIK MONTAJI VE PAÇALIK SAC HAZIRLIK
14	ÇAMURLUK SAC HAZIRLIK
15	HAVA EMİŞ KUTUSU İZOLASYON MONTAJI
16	SİLECEK MOTOR MONTAJI
17	KAYAK TUTUCUSU
18	
19	
20	

Yorumlar:

Comments

Figure 3.3 - Station operation list template prepared for and to be completed at D01



D / E 01
TAVAN KAPLAMA MONTAJI

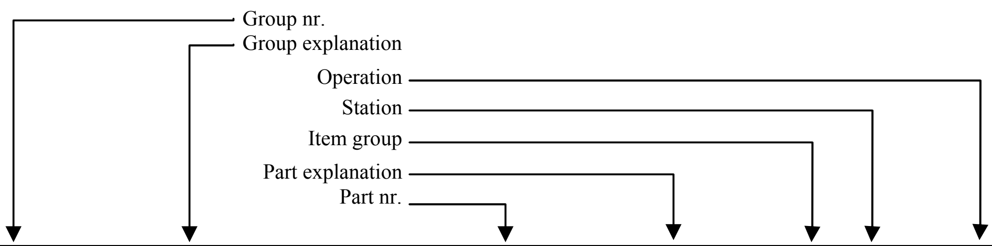
[redacted]	D	E	Toplam
İşçi Sayısı	4	4	8

İŞ SIRASI	YAPILAN İŞLER	eksik parça
1	APARATLARIN SÖKÜMÜ VE ARAÇ FOLYOLAMA	↓ aşağıda
2	ARAÇ ALMA	✓
3	ARAÇLARIN ISLAK GELMESİ DURUMUNDA KURUTULMASI	↑ her zaman değil. kışın daha çok.
4	ARKA RÜZGARLIK MONTAJI	↑ her arabada yok.
5	CNG ARAÇLARINDA PULLARIN YERİNİN DELİNİP YAPIŞTIRILMASI	↑
6	KLİMA ÇERÇEVE, HAVALANDIRMA YERİNİN KESİMİ	✓
7	VAKS TAPASI	↓ Vaks akmasın diye yapılıyor.
8	~~FAR KAPAK MENTEŞE VE KİLİT MONTAJI~~	↓ uzaktan sonra yapılıyor! 3
9	ÖN ISITICI (FRONTBOX) MONTAJI	↓ ✓
10	TAVAN KAPLAMASI YAPIŞTIRMA	↑ ✓
11	ÇAMURLUK İÇİ İZOLASYON MONTAJI (lastik)	Sadece belediye araçlarında var.
12	ÖN GÖĞÜS İZOLASYON VE FİLTRE MONTAJI	↓ ✓
13	PAÇALIK MONTAJI VE PAÇALIK SAC HAZIRLIK (seyahat)	↓ seyahatlerde 8 de yapılıyor.
14	ÇAMURLUK SAC HAZIRLIK	↓
15	HAVA EMİŞ KUTUSU İZOLASYON MONTAJI	↓ arka tarafta A21 lerde var.
16	SİLECEK MOTOR MONTAJI	↓ sadece tutturuluyor.
17	KAYAK TUTUCUSU	✗ 11 de yapılıyor.
18	ön kalorifer sac (kapama sacı montajı)	
19	anten, folyo, sinyal ve fren lambaları montajı.	
20		

Yorumlar:
- eksik parça çok.
- iş akışında hatalar var.
- teknik hatalar var.

tavan kaplama
(işkence → pekolit kesme → profil silme → pekolit silme → lastik yapıştırma → primer çekme → sika çekme → tavan takması → işkence sökümü → alkıp basma!) → klima ve havalandırma del. matkapla açılması → aracın temizliği

Figure 3.4 - Station operation list edited and completed at D01



VKGR	VKGR AÇIKLAMA	PARÇA	PARÇA AÇIKLAMA	KALEM GRUBU	I.M.	PROSES
83.#0650.0Q09	ON CAM SILECEK VE YIKAMA SISTEMI	81.26401.6137	SILECEK MOTORU	300100	D01	SİLECEK, CAM YIKAMA MONTAJI
83.#08X5.0003	ON IZOLASYONU	83.72010.6109	IZOLASYON	200100	D01	TAVAN IZOLASYONU
83.#0H10.0015	TAVAN PLAKALAMA ,TAVAN YAN PARCASI ,PLASTIKTEN	88.73110.4101	TAVAN KAPLAMA	900100	D01	TAVAN MONTAJI
88.#05R0.0019	ON ISITICI AURORA Klimator R134A Aurora	83.72010.6110	IZOLASYON	300100	D01	FRONTBOX IZOLASYONU
88.#05R0.0019	ON ISITICI AURORA Klimator R134A Aurora	83.72010.8835	IZOLASYON MONTAJI	900100	D01	ÖN ISITICI FRONTBOX IZOLASYONU
88.#05R0.0019	ON ISITICI AURORA Klimator R134A Aurora	83.77915.0581	KAPATMA	200108	D01	ÖN ISITICI FRONTBOX KAPATMA
88.#05R0.0019	ON ISITICI AURORA Klimator R134A Aurora	88.77901.8012	ISITICI MONTAJI	900100	D01	ÖN ISITICI FRONTBOX MONTAJI
88.#05R0.0019	ON ISITICI AURORA Klimator R134A Aurora	88.77971.6092	KLIMA BORU MONTAJI	200100	D01	ÖN ISITICI FRONTBOX MONTAJI
88.#3510.0041	ANTEN,RADYO ICIN ,D/E VE GPS BAGLANTILI	83.73110.4567	ILAVE RESIM	900100	D01	ANTEN MONTAJI

Figure 3.5 - Station summary report for D01 from factory database

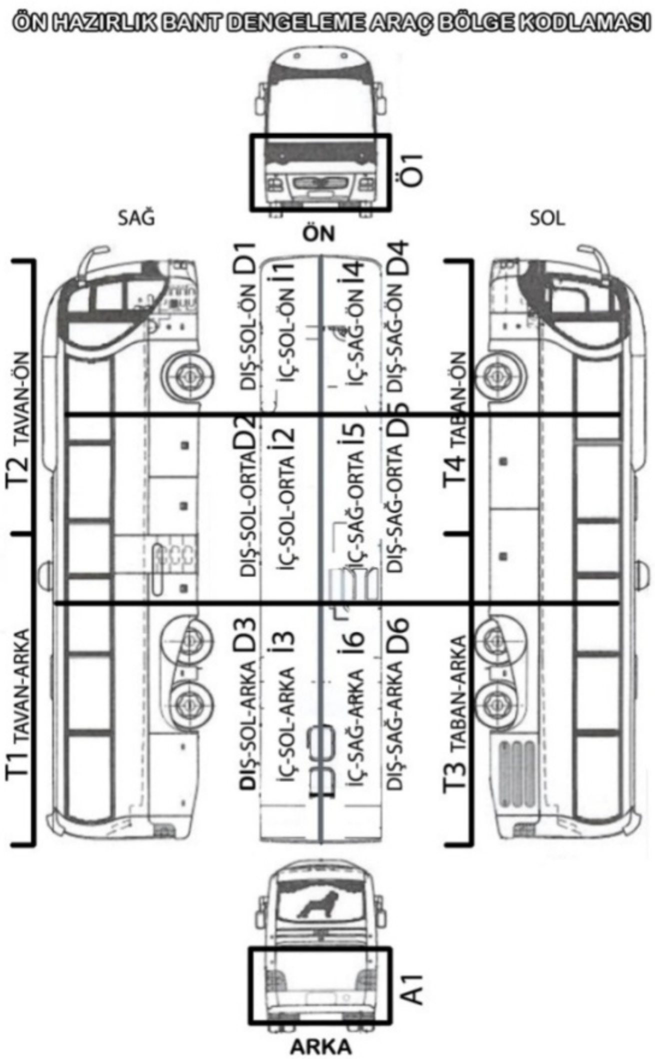
5. Analysis of the balance losses at the current line is made with this information.

For the next step of the work, which is to reorganize the production line and balance the operations at the stations, further studies are made and added to the existing data, which is to be used for running ProBalance®.

6. In order to achieve a leaner assembly line, sources of wastes at the production process are determined.

7. Operations at the stations are analyzed and improvement options such as removal of stations, merging stations or cancelling processes by improving prior operations etc. are evaluated.

8. In order to maintain a standard expression of vehicle regions, a coding scheme is prepared. The primary objective of coding is to prevent assignment of two operations to the same region at the same time in order to provide sufficient workspace for operators during assemblies.



Code	Work zone
A1	REAR
Ö1	FRONT
T1	ROOF-REAR
T2	ROOF-FRONT
T3	UNDERBODY-REAR
T4	UNDERBODY-FRONT
D1	OUT-LEFT-FRONT
D2	OUT-LEFT-MIDDLE
D3	OUT-LEFT-REAR
D4	OUT-RIGHT-FRONT
D5	OUT-RIGHT-MIDDLE
D6	OUT-RIGHT-REAR
i1	IN-LEFT-FRONT
i2	IN-LEFT-MIDDLE
i3	IN-LEFT-REAR
i4	IN-RIGHT-FRONT
i5	IN-RIGHT-MIDDLE
i6	IN-RIGHT-REAR

Figure 3.6 - Vehicle region codes and definitions

9. Clusters are created in ProBalance® for related tasks and these clusters are sequenced according to their precedence relationship. The purpose of this is to collect similar tasks under the same clusters and making mapping the precedence of operations easier since total number of tasks reaches a few hundreds.

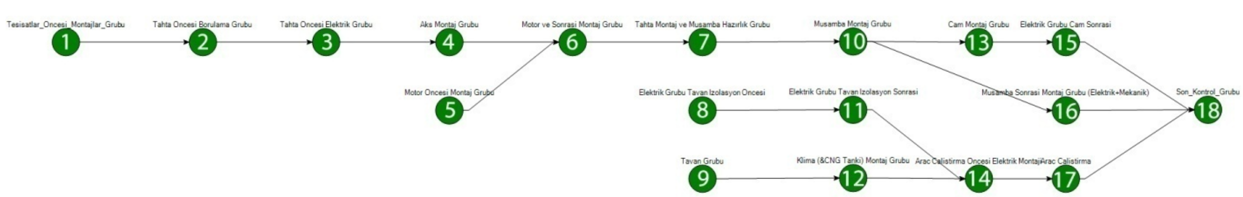


Figure 3.7 - Precedence relation of clusters

Table 3.1 - List of related operations and corresponding clusters

Group number	Group name
1	Assemblies before piping and electrical systems
2	Piping before floor board assembly
3	Electrical systems assemblies before floor board assembly
4	Axle assembly
5	Assemblies before engine assembly
6	Engine and following assemblies
7	Floor board assembly and oil cloth assembly preparation
8	Electrical systems assemblies before roof inner isolation
9	Roof assemblies
10	Oil cloth assemblies
11	Electrical systems assemblies after roof inner isolation
12	Air conditioner and CNG tubes assemblies
13	Glass assemblies
14	Electrical assemblies before vehicle start
15	Electrical assemblies after glass assemblies
16	Assemblies after oil cloth assemblies
17	Vehicle start
18	Final check and rework

The master precedence graph is mapped by applying the following procedure. Example figures are used for demonstration purposes.

- Precedence of clusters is mapped.

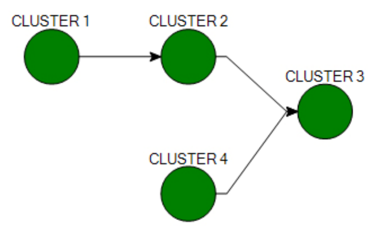


Figure 3.8 - Precedence diagram of clusters

- Precedence of tasks within each cluster is mapped individually.

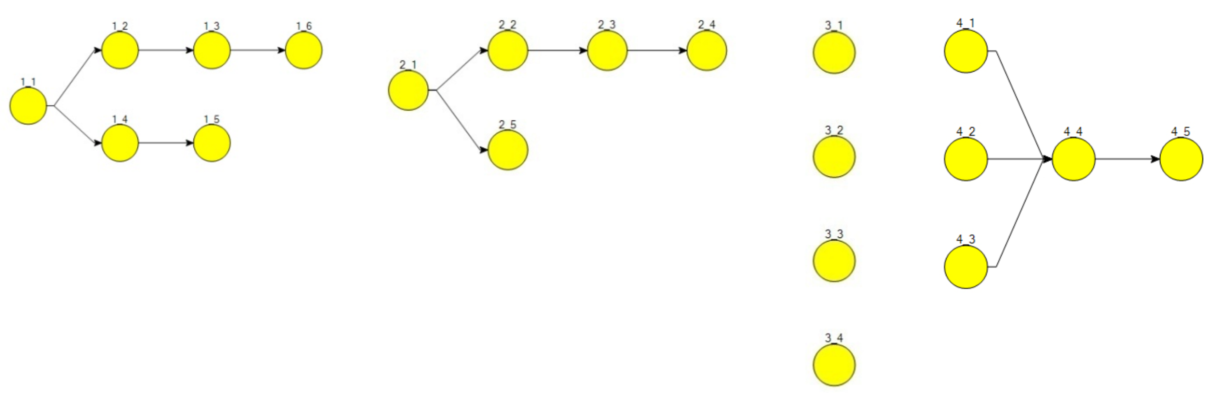


Figure 3.9 - Precedence of tasks in each cluster

- Clusters are deleted so that tasks with precedence relation are available together on the main screen

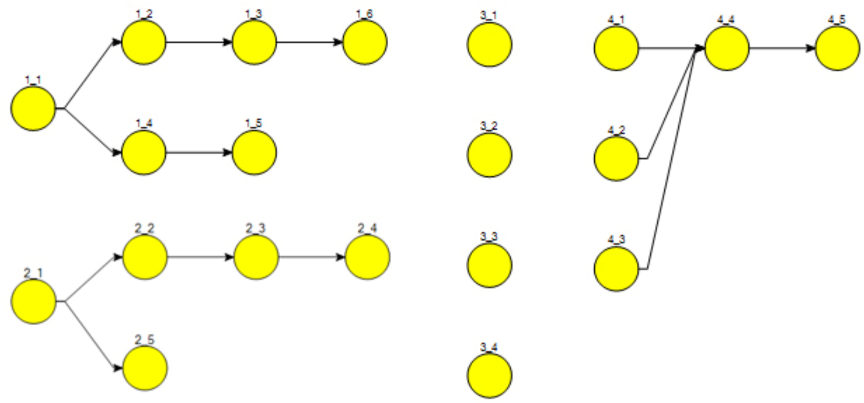


Figure 3.10 - Tasks on default view after clusters are deleted

- Precedence among tasks belonging to different groups is mapped and master diagram is prepared.

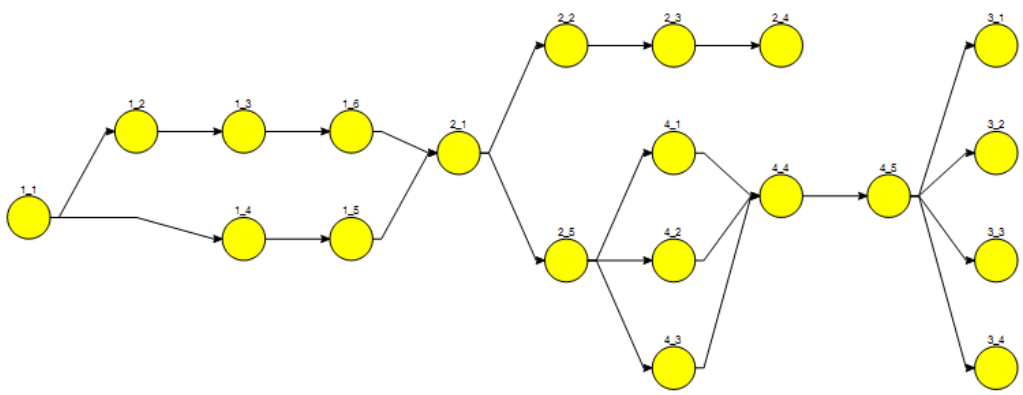


Figure 3.11 - Mapped master precedence diagram

This procedure is applied for all three vehicle models individually. In order to make the procedure less complicated because of the high number of operations, instead of deleting all clusters at the same time, they are deleted and mapped one-by-one.

10. A data sheet template for collecting the required data to run ProBalance® is prepared. This template is shown in figure 3.12.

11. In order to collect the required data for running ProBalance®, a weekend workshop is planned and arranged with the attendance of production engineers and 10 operator team leaders of the pre-assembly line, and Work Preparation Group.

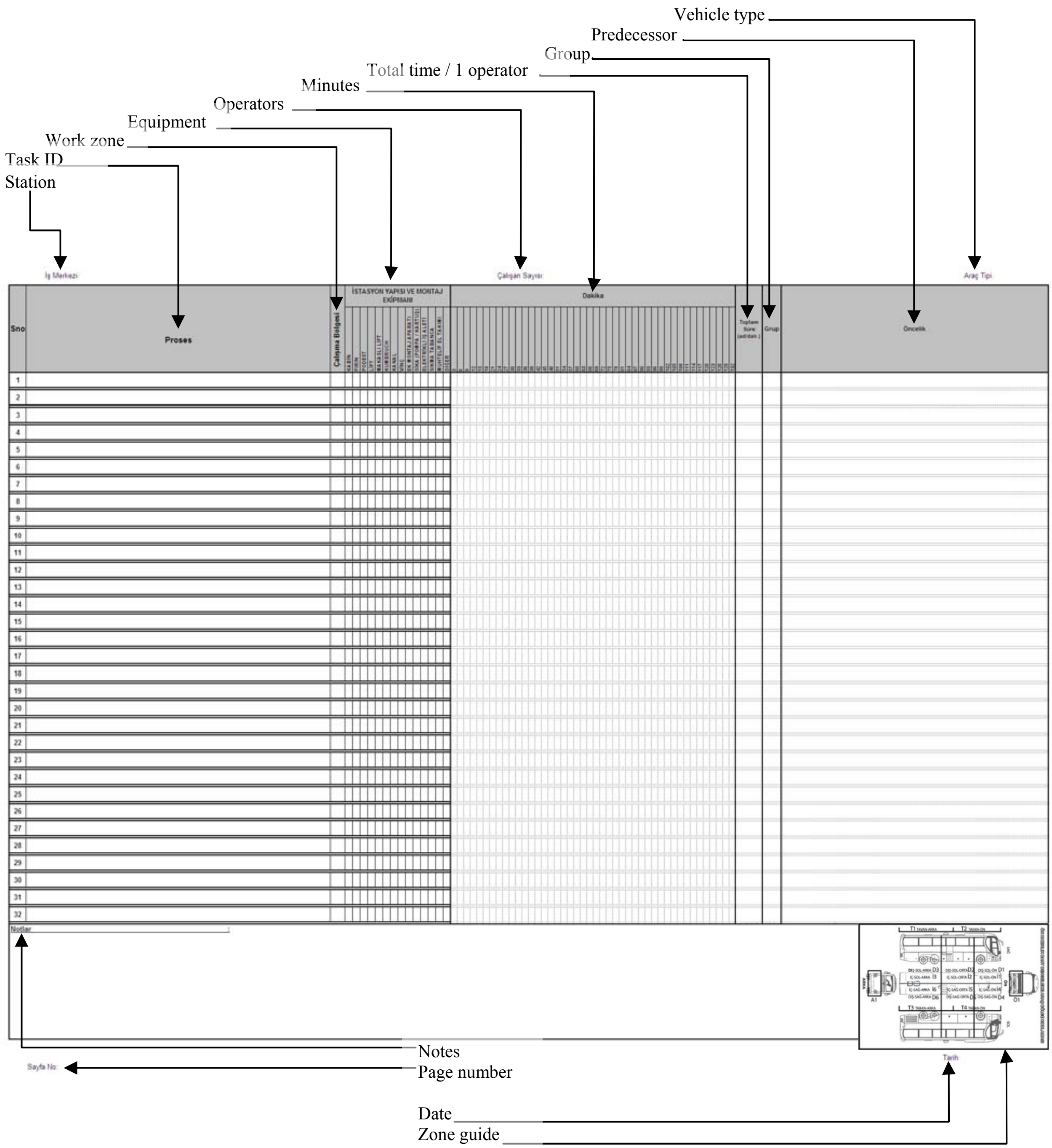


Figure 3.12 - Data sheet template

During the workshop;

- participants are informed about the running procedure of line restructuring and balancing,
- participants are informed about how line balancing will be done, and a short presentation of ProBalance® is made,

- team leaders are informed about vehicle region coding and how to determine the region of operations under their responsibility,
- team leaders are informed about the structure of the data sheet and how to enter data,
- line improvement proposals are discussed.

On the first day of workshop, all team leaders are provided with complete task lists, empty data sheets printed on A3 size paper, and large vehicle code schemes. They are expected to write down all tasks under their control, to put a cross for the equipment used to perform the corresponding operation, indicate the task time and number of operators doing the task, indicate which group (cluster) that operation belongs to and order of the preceding task. All tasks on the complete list are given an individual number so that addressing of tasks are standard and less confusing for later work.

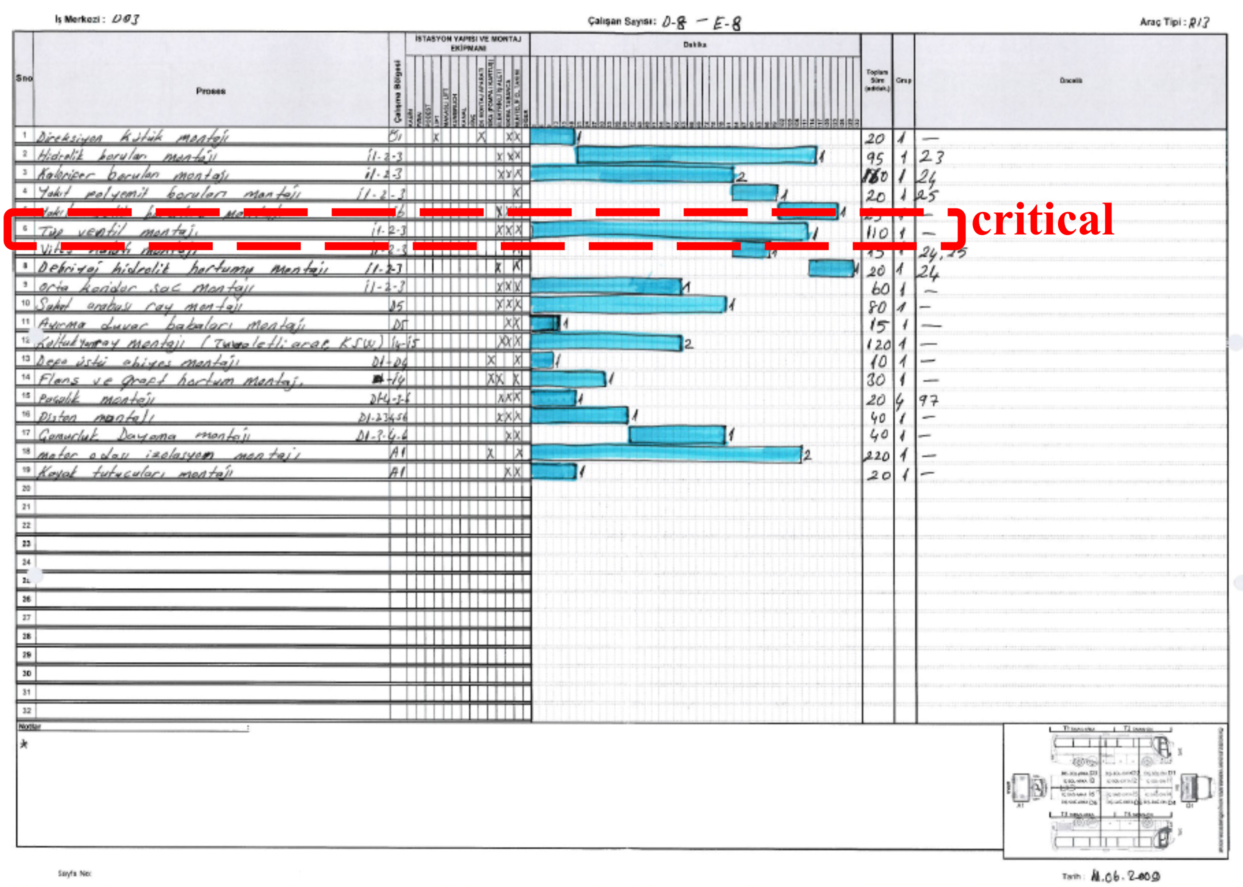


Figure 3.13 - Sample data sheet from Workshop 1

Having collected the data from the team leaders, the data is analyzed for critical processes after the workshop. A critical process is a task whose duration is longer than the new takt time of 65 minutes. All critical processes are listed and distributed to the team leaders according to their responsibility, which makes about 5 critical processes per team leader.

On the second day of workshop, the team leaders are provided with the lists of all critical processes under their control, and the same empty datasheets with the takt line indicated. They were asked to evaluate their processes and to;

- divide the processes into their steps,
- indicate the number of operators that do every step of the processes,
- comment if application of any method, i.e., increasing operator number, can reduce the task time,
- state if there are any limitations with these processes

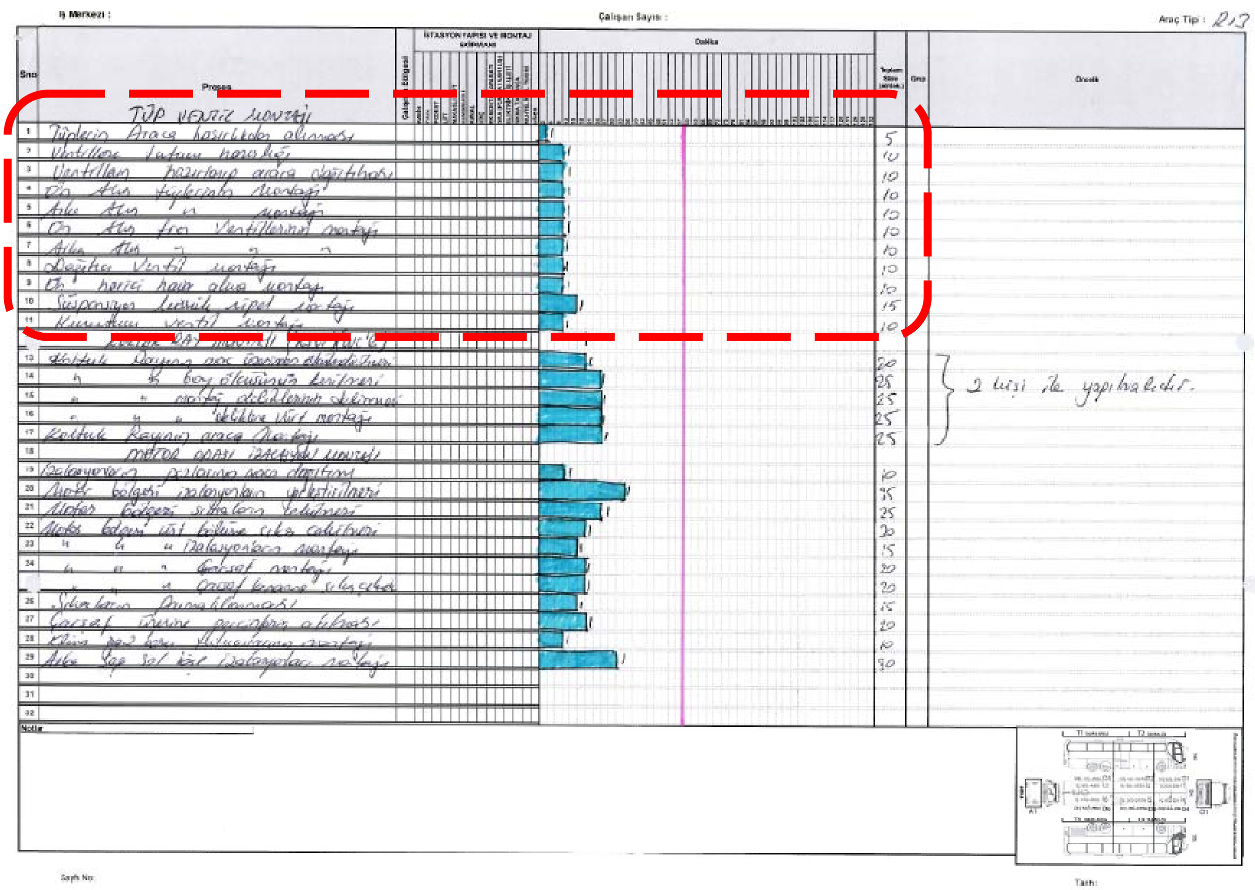


Figure 3.14 - Sample critical process analysis from Workshop 1

12. After Workshop 1;
    - according to the data collected, task lists for the 3 primary vehicle models are prepared,
    - tasks are divided such that, if a task of 80 minutes/operator is done by 4 operators, that task is modified on the list as 4 different tasks of 20 minutes. This change is mandatory for the balancing work.
    - considering the accepted change propositions for the line, task lists are finalized.

13. All collected data is sorted on Microsoft Excel and input to ProBalance®.

14. Precedence diagrams for the 3 primary models are prepared by following to the procedure stated previously.
15. Balance algorithm is run for 3 bus models individually, but by applying the same station constraints. That is, same equipment is assigned to the same stations for all models so that similar operations are kept at the same stations for all models.
16. Demanded operation distribution to stations is made by manual manipulation on ProBalance®.
17. In order to prevent the balance losses caused by fixed number of operators at stations, joker workers are assigned.
    - Planning of operators at the bus pre-assembly line is done by calculating the number of operators that is fixed for each station. This is done by using the balancing results of the 3 vehicle models. For three models, number of operators at each of the 22 stations is calculated. For each station, demand for the least number of operators is taken as the base operator number for that station. For instance, for station D01; A21, P22 and R13 models require 10, 9 and 13 operators respectively. Thus, since the least number of demanded operators is 9 among the 3 models, fixed number of operators at station D01 is calculated as 9. When another model is at the station, the extra work force is provided by the joker workers. The same method is applied while calculating the fixed number of operators for all 22 stations. These calculations are shown in more detail in Chapter 5.
18. Considering the new number of stations, the factory space available and other constraints, a layout proposal is prepared.
19. Comparison and evaluation of the current state and the new state of the bus pre-assembly line is made.

4 CURRENT STATE ANALYSIS

This chapter contains the current state analysis of the bus pre-assembly line by focusing on certain characteristics such as production process and operations, workload of operators, current layout and balance of the line.

4.1.1 ***Production system and properties of the pre-assembly line***

General information

Production in the factory is performed on a mixed-model flow-line system. The whole assembly system consists of 136 serial workstations, 38 of which are two parallel lines of 19 stations. Bus production line is controlled by 5 main departments in three buildings in the factory. They are;

- bus chassis assembly
- paintshop
- bus pre-assembly
- bus assembly
- bus finish

Each department is responsible from the segment of the production line where the processes under their control are held and each of these sections is regarded as independent lines. That is, there are 5 consequent lines in the factory that make up the bus production line. Chassis assembly, paintshop and bus pre-assembly lines are located in building U1, and bus assembly and bus finish lines are located in U2 and U3 respectively. All lines except the bus pre-assembly line are single assembly lines. Bus pre-assembly line functions with two parallel lines D and E. Working process inventory of the whole bus assembly line – including buffers- is 225 units, however, current number is 287 because of the pauses in production due to the global economic situation. This difference is caused by the increased number of vehicles waiting at the buffers. Among the 5 lines, bus pre-assembly line has the highest working process inventory with 38 buses.

Production is low-volume with about 2000 units per year. There is no automation throughout the production process. Conveyance between stations is unpowered. All tasks -including moving the vehicles to the next stations- are performed by human operators.

Product variance is high. There is no limitation for distribution of products and their variants to lines; assembly of each bus model can be handled in both lines. City buses, intercity buses and coaches of MAN and NEOPLAN brands, making 16 different bus models, are produced on the same line. Every single vehicle is configured individually due to customer requests, which increases the complexity of the assembly process. Task times vary for different bus models, i.e., roof wiring for A21 takes 180 minutes/operator while it takes 60 minutes/operator for P22.

However, in the current setting, number of workers is fixed for stations. While planning production, total task times of vehicles are considered, i.e., two complex models are not planned consecutively on the same line.

There are no joker workers. Division of labor among operators is high, which makes replacement for absent operators problematic.

Material flow within the factory is managed with the KANBAN system. Produced and outsourced parts are collected in the warehouses and distributed to the stations by the internal logistics unit just-in-time. No outsourced parts are directly delivered to the assembly location. The main problem with the logistics is the missing parts, which results in the operator to leave his/her station, walk to the warehouse and take the part himself/herself. Frequently, this causes takt overdue, causing the operator to leave his station and complete his/her work in the next station. For circumstances when the missing part is not in the warehouse, in order not to stop production, the assembly continues with that part missing, causing a rework after it is received.

Manual material handling needs are high, having a dramatic effect on the efficiency of assembly process, i.e., before assembling the glasses, two operators take out the randomly packed glasses from the commissioning trolleys of the supplier onto the glass holding tables, after that they need to sort these glasses in the order of assembly because glasses need to be assembled in a pre-defined order, and only then they can take them and assemble.

Production process is built on assemble-to-order system; every bus is taken to the line after they are configured individually by their customers and the payment is made. Production capacity of the factory is planned for 8 vehicles per day. Daily working time is 520 minutes. Takt time is 65 minutes and throughput time is 15600 minutes for the whole line. Buffers are the primary reason for this long throughput time. In the two line bus pre-assembly line only, this takt time is applied as 130 minutes. The line delivers two vehicles in 130 minutes, one of which is directly delivered to the bus assembly line of takt 65 minutes while the other vehicle is taken to the parking area for waiting. In the next takt, while the operations in the pre-assembly line continue, this waiting vehicle is delivered to the assembly line. Throughput time for the bus pre-assembly line is 2470 minutes.

The reason for the bus pre-assembly line to operate as two parallel lines is the time requirement for operations that take longer time than the takt time. These processes are mainly indivisible, i.e., waiting for adhesives or isolation tools to dry, and due to the precedence relations of the operations, it is not possible to start the following process while the previous is in progress, i.e., wiring cannot begin before piping is completed since both systems are installed to the same sections of the vehicle that do not allow two operators work together.

Although the production system is flow line, the advantages of flow line production systems pointed out by Scholl [17] are not valid for the bus pre-assembly line; throughput times are high, in-process inventory is high, material handling requirements are high due to unpowered conveyance and it is not possible to train unskilled operators quickly for the tasks held at the main line. Also, the production system is off the diagonal of the product-process matrix of Hayes and Wheelwright (1979) with its low volume production.

Layout

The current layout of the pre-assembly line in U1 and the glass assembly buildings is as shown in figure 4.1. A higher resolution layout can be found in appendix.

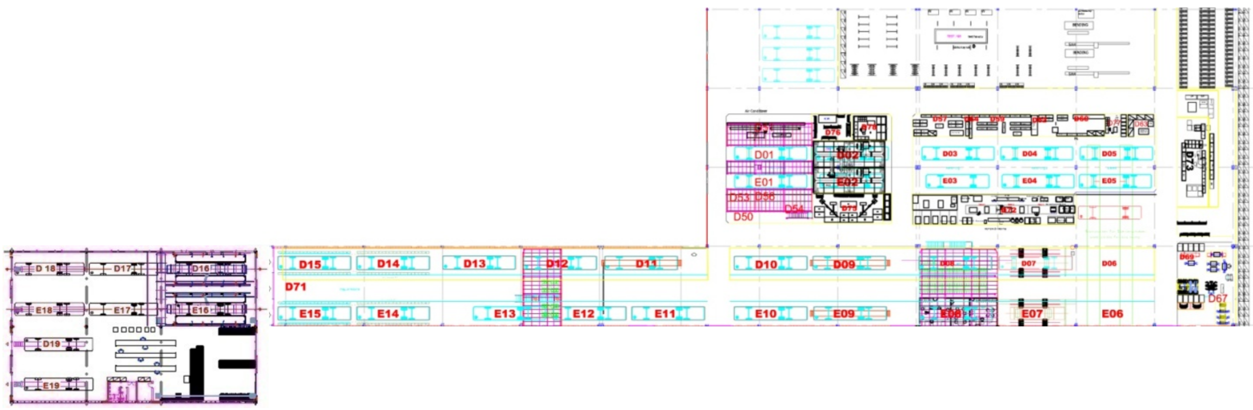


Figure 4.1 - Current layout of the pre-assembly line

Line flow plan

Precedence of the pre-assembly line in the bus production line is after Paintshop and before Bus assembly. After the tasks in the paintshop are complete, buses are taken to the parking area. These buses are then pushed to the D01 and E01 stations of Bus pre-assembly line by fork-lifts. It should be noted that the vehicles are delivered in the reverse direction to this station. From stations D/E 01 until D/E 05, bus flow in the line is in the reverse direction. At every takt, buses are manually pulled by the operators of the next station. As seen in the layout, stations D/E 05 and D/E 06 are parallel, meaning that buses are pulled sideways to D/E 06 stations. From D/E 06 until D/E 15, bus flow direction is forwards.

Station D/E 15 is the last pre-assembly station in the U1 building. Stations D/E 16-17-18 and 19 of the line are located in the glass assembly building, which is approximately 30 meters to the U1 building. From D/E 15 to D/E 16, again fork-lifts are used to pull the buses in between these buildings. At D/E 19, bus pre-assembly operations are completed and the vehicles are started. Buses are therefore driven to the Bus assembly line when the operations in the Bus pre-assembly line are completed.

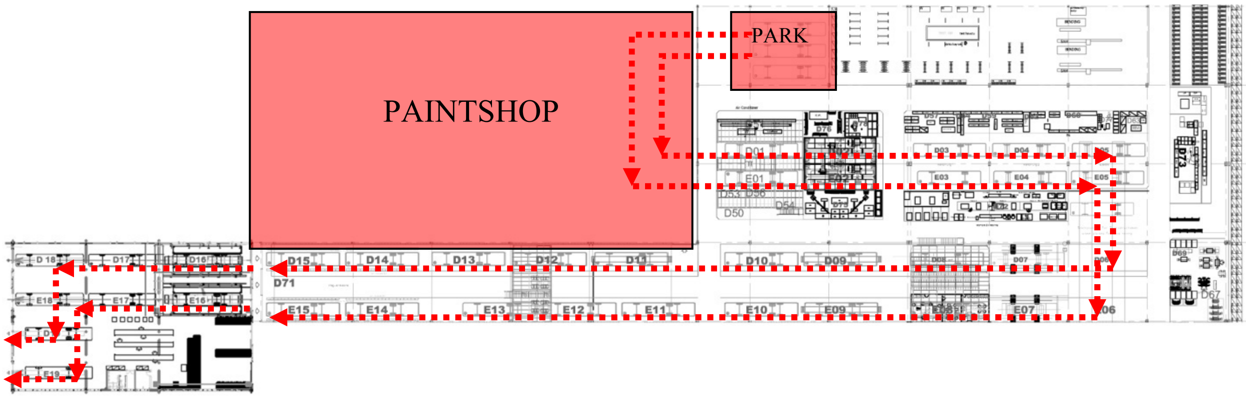


Figure 4.2 - Bus pre-assembly line flow

4.1.2 *Analysis of work-stations*

Work-flow at the stations

There are 19 assembly stations and 26 sub-assembly stations at the Bus pre-assembly line. The tasks performed at these stations are shown in table 4.1.

Table 4.1 - Tasks held in the sub-assembly and assembly stations at the Bus pre-assembly line

Pre-assembly Station	Definition
D / E 01	Roof cover assembly
D / E 02	Protective wax assembly
D / E 03	Brake system preparation
D / E 04	Brake system assembly
D / E 05	Electrical system assembly
D / E 06	Roof filling and switch board assembly
D / E 07	Axle assembly
D / E 08	Floor board adjustment
D / E 09	Floor board and engine assembly
D / E 10	Air conditioner compressor assembly
D / E 11	WC and roof isolation assembly
D / E 12	Door handle - aspirator - air conditioner gas pipes assembly
D / E 13	Papering
D / E 14	Oil-cloth assembly
D / E 15	Oil-cloth welding and baggage side profile assembly
D / E 16	Glass assembly
D / E 17	Pedal assembly and air conditioner gas leak test
D / E 18	Vehicle start - Quality control
D / E 19	Rework

Sub-assembly Station	Definition
D50	Door handle preparation
D51	Roof air conditioner pipes preparation
D52	Side plate preparation
D53	Piston, mudguard support, light holders, mudflap preparation
D54	Lift and maintenance covers preparation
D56	Roof preparation
D57	Oil pipes and clutch pipes preaparation
D59	Heater pipes preparation
D60	Polyamide brake pipes preparation
D61	Isolation preparation
D62	Brake valves preparation
D63	Electrical systems preparation
D65	Wheel preparation
D67	Axle preparation
D70	Glass preparation
D71	Oil cloth preparation
D72	Engine preparation
D73	Fuel tank and air conditioner compressor preparation
D74	Radiator preparation
D75	Brake - steering hydraulic pipes preparation
D76	Steering wheel and pedal preparation
D77	Webasto preparation
D78	Piping preparation
D79	Baggage covers preparation

Work flow diagram of the bus pre-assembly line is as shown in figure 4.3.

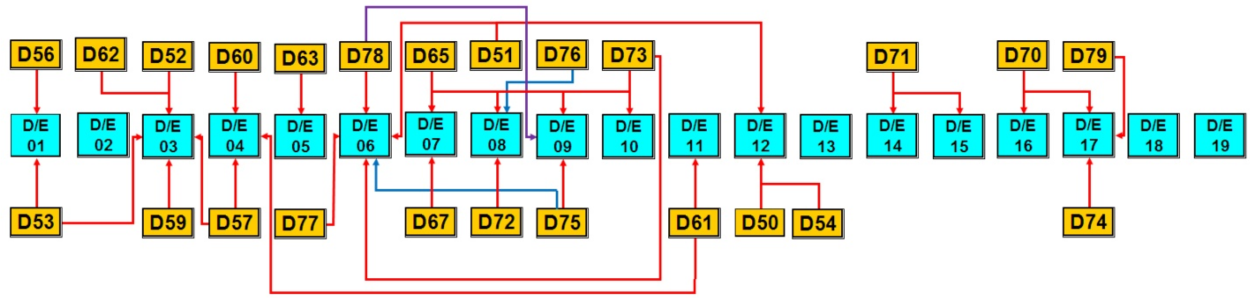


Figure 4.3 - Work flow at sub-assembly and assembly stations at the pre-assembly line

Material flow at the stations

Material flow to the bus pre-assembly stations is from the sub-assembly stations that are located around the assembly stations and from the warehouses. Flow route of materials from the sub-assembly stations to their assembly stations is as shown in figures 4.4 and 4.5. Green rectangles indicate the main doors where materials from the warehouses enter the line.

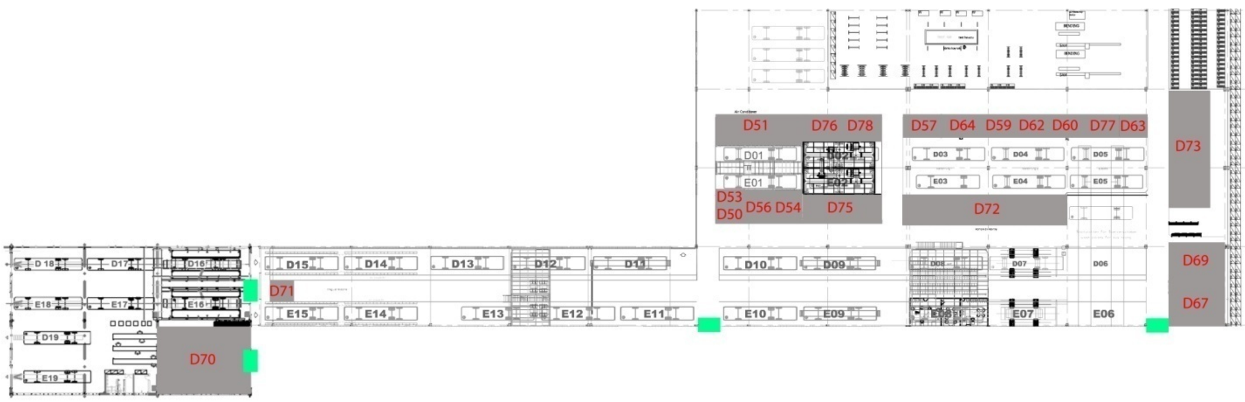


Figure 4.4 - Current layout of sub-assembly stations

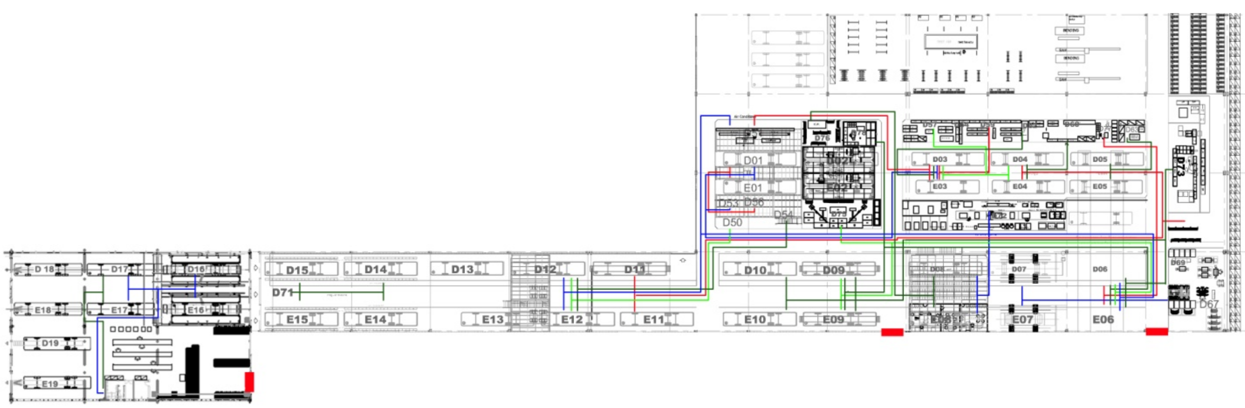


Figure 4.5 - Material flow to the assembly stations from the sub-assembly stations

Number of operators

The number of assembly operators -excluding 10 team leaders and 30 sub-assembly station operators- is 193. Team leaders are excluded because they do not make any assemblies on the line. 48 of these 193 operators perform electrical system assemblies, 24 of which work at stations D/E 05 and D/E 06. Other 24 of the 48 operators are assigned to station D/E 17, but according to the precedence of their work, they work along the whole assembly line.

Distribution of operators to the pre-assembly stations is as shown in table 4.2.

Table 4.2 - Distribution of operators to the pre-assembly stations

	Line	
Station	D	E
01	4	4
02	1	1
03	8	8
04	4	3
05	8	8
06	10	10
07	6	5
08	2	2
09	10	9
10	3	3
11	3	3
12	3	3
13	2	2
14	5	5
15	5	5
16	6	7
17	14	14
18	1	2
19	2	2
Sub-total	97	96
Total	193	

Total cost of one operator is calculated by the production management to be 16,09 €/hour.

4.1.3 *Analysis of the production process*

Grouping and precedence of assemblies

Since most assemblies include infrastructural elements of the vehicle, pre-assembly operations can be grouped according to functional properties of the assembled parts. These primary groups can be listed as;

Piping
Wiring
Floor board assembly
Axle assembly
Engine assembly
Roof assemblies
Oil cloth assembly
Glass assembly

Primary restrictions that determine the precedence relationship of these assembly groups are overlapping workspaces that operators require for the assemblies, and safety issues. For instance, piping and wiring are made on the exact same route inside the vehicle, however, 6 pipe assemblers and 6 electric workers cannot work inside the vehicle at the same time due to space limitations. Or, glass assembly should be made after the oil cloth assembly because hazardous gases are formed during oil cloth welding task and requirement for fast air circulation inside the oil cloth assembly cabin cannot be maintained with the glasses assembled.
The most critical aspect of assembly precedence is that assemblies should be made from the lowest level towards the highest, i.e., parts closest to the chassis should be assembled first. Even though every assembly can be made at any point of the line, in order to prevent dismantling of assembled parts for other assemblies or perform the assembly tasks in the lowest possible time, assembly order of parts should be well-analyzed.

The precedence diagram of primary assembly groups is shown in figure 4.6.

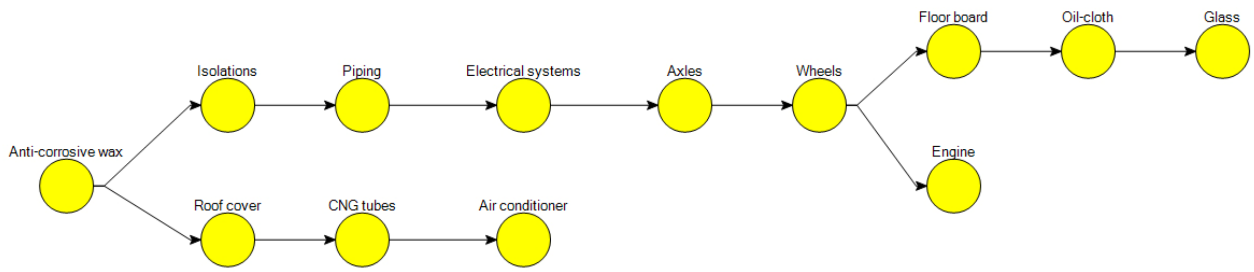


Figure 4.6 - Precedence diagram of primary assembly groups

Anti-corrosive wax assembly is the most critical task that is to be handled after the vehicle is painted and it is the predecessor of all pre-assembly operations.

Floor board assembly can only be made after all piping and wiring is complete in the vehicle, because after the floor board assembly, it is not possible to reach the pipe and wire assembly points. Also, the vehicle has to be on four wheels instead of the donkeys and the engine has to be assembled, because forces acting on the chassis are different in these two cases that result in different bending characteristics and floor boards should be assembled in natural loading conditions.

All infrastructural piping and electrical systems should be assembled before the axles and the engine; later assembly of these parts is not possible due to space limitations.

Engine can only be assembled after the axles and with the vehicle on our wheels, because its weight does not allow it to be assembled when vehicle is carried by another equipment such as a lift due to safety issues. Not being able to assemble axle connection rods due to space limitations is another reason for this precedence relation.

Glasses should be assembled after the oil-cloth due to working safety issues. Solvent-based adhesives and other harmful gases that arise during fixing the oil cloth requires this operation to be held in a ventilated cabin. If the vehicle is in this cabin with glasses assembled, air circulation rate is negatively affected negatively, which is not acceptable.

Considering each group as a different layer, the order and precedence relation of assemblies is shown in figure 4.7.

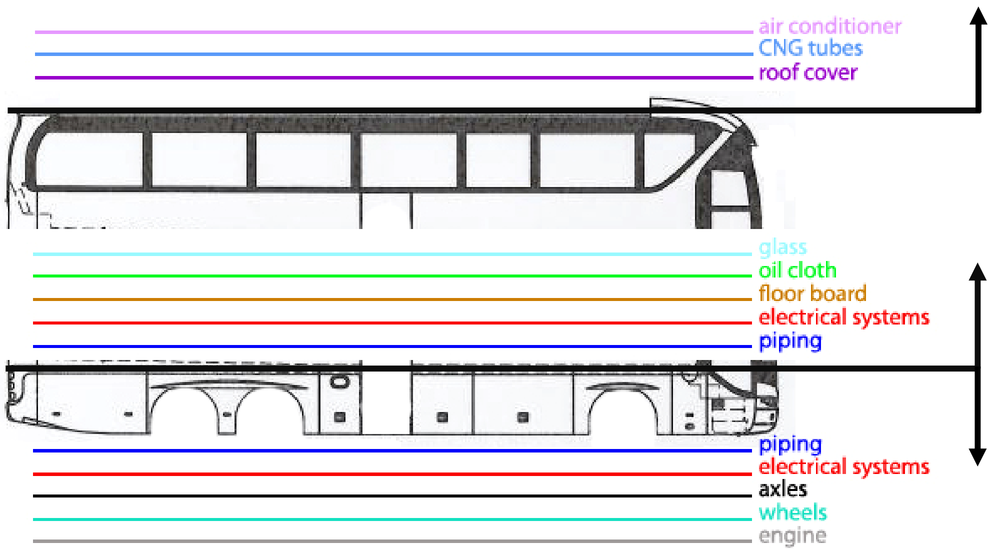


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Figure 4.7 - Precedence relation of assembly groups

4.1.4 *Evaluation of the current line balance*

Operations and operation times at stations

(Details are excluded due to confidentiality.)

Station times

Total operation times and station times for A21, P22 and R13 models at the pre-assembly line is shown in table 4.3. Colors indicate the stations with takt overdue for the corresponding vehicle model.

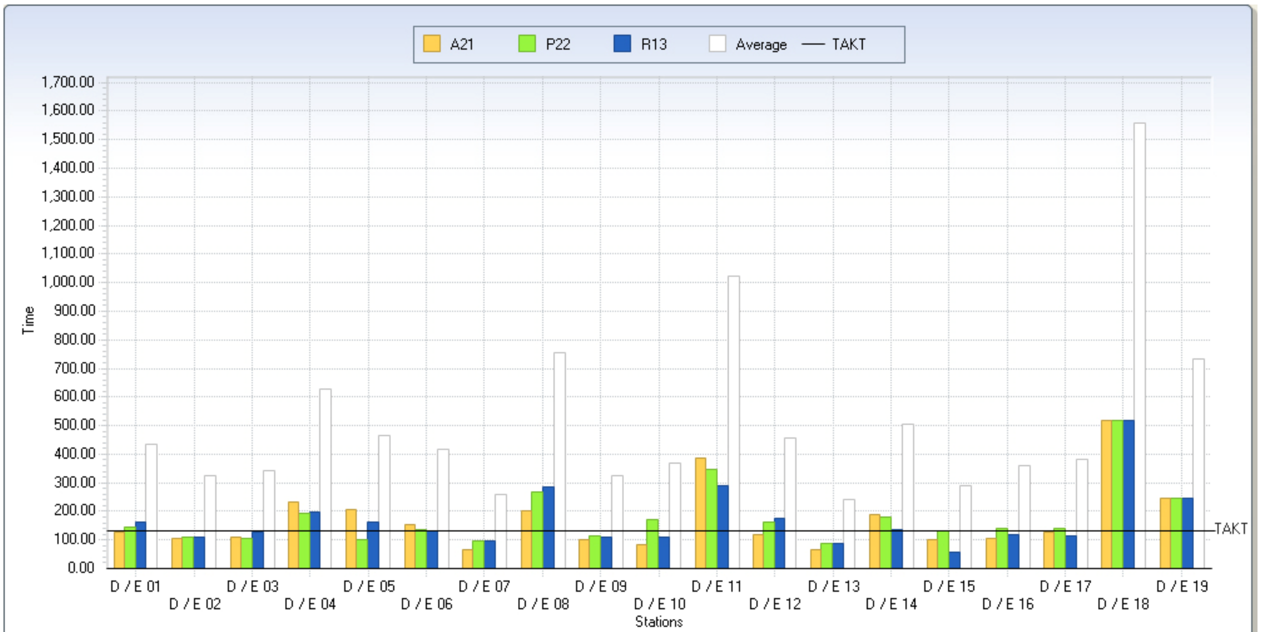
Table 4.3 - Station times for A21, P22 and R13 models

		Station	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	Total
		Number of operators	4	1	8	4	8	10	6	2	10	3	3	3	2	5	5	6	14	1	2	97
Operation time	A21	Total operation time	505	105	890	935	1645	1529	397	400	1014	250	1156	361	130	940	508	640	1789	520	490	14204
		Station time	126	105	111	234	206	153	66	200	101	83	385	120	65	188	102	107	128	520	245	3245
	P22	Total operation time	596	110	840	775	794	1347	587	539	1124	520	1035	486	175	897	655	830	1954	520	490	14274
		Station time	149	110	105	194	99	135	98	270	112	173	345	162	88	179	131	138	140	520	245	3393
	R13	Total operation time	647	110	1009	795	1285	1315	567	574	1090	330	875	522	175	677	290	700	1573	520	490	13544
		Station time	162	110	126	199	161	132	95	287	109	110	292	174	88	135	58	117	112	520	245	3230
	Average	Total operation time	583	108	913	835	1241	1397	517	504	1076	367	1022	456	160	838	484	723	1772	520	490	14007
		Station time	146	108	114	209	155	140	86	252	108	122	341	152	80	168	97	121	127	520	245	3289

Takt time: 130
Time unit: minutes

Evaluation of balance losses

The balance graph of the pre-assembly line is shown in figure 4.8.



	D / E 01	D / E 02	D / E 03	D / E 04	D / E 05	D / E 06	D / E 07	D / E 08	D / E 09	D / E 10
A21	126.25	105.00	111.25	233.75	205.63	152.90	66.17	200.00	101.40	83.33
P22	145.00	110.00	105.00	193.75	99.25	134.70	97.83	269.50	112.40	173.33
R13	161.75	110.00	126.13	198.75	160.63	131.50	94.50	287.00	109.00	110.00
Average	433.00	325.00	342.38	626.25	465.50	419.10	258.50	756.50	322.80	366.67

	D / E 11	D / E 12	D / E 13	D / E 14	D / E 15	D / E 16	D / E 17	D / E 18	D / E 19
A21	385.33	120.33	65.00	188.00	101.60	106.67	127.79	520.00	245.00
P22	345.00	162.00	87.50	179.40	131.00	138.33	139.57	520.00	245.00
R13	291.67	174.00	87.50	135.40	58.00	116.67	112.36	520.00	245.00
Average	1,022.00	456.33	240.00	502.80	290.60	361.67	379.71	1,560.00	735.00

Figure 4.8 - Balance graph of the current assembly line

Idle times and takt overdue at stations for A21, P22 and R13 models at the pre-assembly line is shown in table 4.4. Colors indicate the maximum values for the corresponding vehicle models.

Table 4.4 - Idle times and takt overdue at stations for A21, P22 and R13 models

			Station																			Total
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	
Station time	A21	Idle time	4	25	19	X	X	X	64	X	29	47	X	10	65	X	28	23	2	X	X	315
		Takt overdue	X	X	X	104	76	23	X	70	X	X	255	X	X	58	X	X	X	390	115	1091
	P22	Idle time	X	20	25	X	31	X	32	X	18	X	X	X	43	X	X	X	X	X	X	168
		Takt overdue	19	X	X	64	X	5	X	140	X	43	215	32	X	49	1	8	10	390	115	1091
	R13	Idle time	X	20	4	X	X	X	36	X	21	20	X	X	43	X	72	13	18	X	X	246
		Takt overdue	32	X	X	69	31	2	X	157	X	X	162	44	X	5	X	X	X	390	115	1006
	Average	Idle time	X	22	16	X	X	X	44	X	22	8	X	X	50	X	33	9	3	X	X	208
		Takt overdue	16	X	X	79	25	10	X	122	X	X	211	22	X	38	X	X	X	390	115	1027

Takt time: 130
Time unit: minutes

Takt overdue is the common problem for all vehicle models with an average of 1027 minutes, which usually results rework requirement for almost each bus that leave the pre-assembly line. D18 is the most problematic station from this aspect with 390 minutes of overdue for all three models.

While there is a problem of takt overdue at almost each station, some stations have high idle times that cause capacity loss. Stations D13 have the highest idle time for A21 and P22 models while D15 has even higher idle time when R13 is at the station. A21 model causes the highest capacity loss at the pre-assembly line with a total idle time of 315 minutes. The average idle time at the line is 208 minutes.

For takt time of 130 minutes, assuming that operations are perfectly distributed to stations, i.e., operations that cause takt overdue are equally distributed to idle stations so that no stations have idle times but only takt overdue, the minimum number of extra operators required at the line for A21 and R13 models is 6, and for P22 model 7. However, this is most of the times not possible due to precedence relations of operations at the line. The minimum number of extra operators required for preventing takt overdue of 1027 minutes is 8.

5 FUTURE STATE MAPPING

This chapter includes analysis of stations at the bus pre-assembly line for determination of wastes and solution proposals for elimination, and generation of the future state structure of the line.

5.1 Investigation of operations that require revision

Designing the new pre-assembly system without considering and eliminating the flaws of the current system would be an unreasonable approach regarding the aim of optimizing the line. Therefore, the next task after evaluation of the balance losses has been determining the major problems with the current operations at the stations.

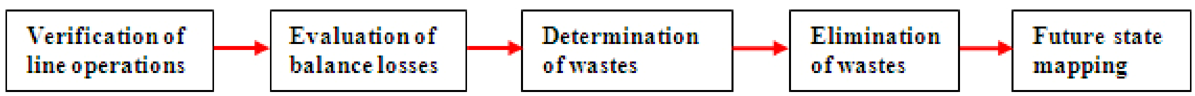


Figure 5.1 - Preceding tasks of future state mapping

By observing the operations at every individual station, the first action has been to figure out problems and generate solution proposals to eliminate them. Mapping the future state of the line could be held only after refining the current line from its wastes and having the final list of operations that should be balanced in a new organization. Elimination process included removing operations from the pre-assembly line and re-addressing them to other more appropriate departments, and to sub-assembly stations.

Determining wastes at a production line is a time-taking and complicated procedure that requires deep analysis of each operation in detail, which was not the target of and cannot be completed within the time limits of this project. Thus, the focus has been set on the most significant operations at each station that are not appropriate pre-assembly operations; non value added parts of individual operations such as walking, processing or material handling are neglected.

5.1.1 ***Bottlenecks***

Pre-assembly operations are infrastructural; assembled parts are complex and have many components, and most of the assemblies are made along the whole vehicle, which increases operation times. Precedence relation of the assembly elements is strict, not allowing other tasks to be made at the same time. In addition to the general characteristics of the pre-assembly tasks, high and changing product mix results in multiple and shifting bottlenecks to emerge on the bus pre-assembly line.

The primary reason for the bus pre-assembly line to have multiple and shifting bottlenecks is the fixed number of workers at stations combined with wide product range; different models require different operation times for same tasks, but fixed number of workers cannot provide the required flexibility at the line. Besides, strict specialization of the operators at stations does not allow on-demand task assignments. Thus, depending on the vehicle models on the line, all pre-assembly stations can become bottlenecks. This also results in the idle times to vary at stations typewise.

5.1.2 *Wastes*

Determination of wastes

High frequency of non value added operations is the main problem that is observed at the bus pre-assembly line. Besides, task-specific station setups such as cabins or lifts on the pre-assembly line do not allow task assignment to stations with such equipment due to ISIG, which increases balance losses. In order to maintain a well-balanced assembly line, stations with high idle times and operations that require additional labor and high material handling rates should be eliminated. The operators should only grab and assemble their parts, not do any additional labor for the assembly.

Station 1

Roof cover assembly: Raising and lowering of the vehicle for the roof covering operation does not allow any other assemblies to be made at D/E 01 due to ISIG issues, causing balance loss on the line. Besides, non value added work ratio is almost 20% of the whole operation; preparation and assembly durations are 35 minutes/person and 165 minutes/person respectively, which corresponds to a total work of 200 minutes/person.

The vehicles are taken to the bus pre-assembly line from Park 1 with roof open. With no roof cover, buses are vulnerable to corrosion due to contact with rain and snow. Also, because cutting operations that are held after the vehicle leaves the paint shop harms the surrounding painted surfaces, there is a risk of corrosion at locations such as ventilation cover housing, roof side plate and air conditioner gas pipe routes. It takes 15 minutes to re-paint these surfaces that are harmed during operation. Also, for the cover gluing procedure to be correct, the glue has to be waited for drying for 120 minutes. In the meantime no other assembly operations on the roof can be started.

Station 2

Anti-corrosive wax application: Waxing application is held at 3 different parts of the bus assembly line; in the paint shop wax is applied inside the profile bars; in the pre-assembly line on axles, under-pipe and front instrument panel areas; and at vehicle finish to whole underbody and front instrument panel area of the vehicle. However, this operation is the most obvious bottleneck operation on the bus pre-assembly line. It requires a ventilated cabin for application for a task of 90 min/person, and when waxing is in progress, no other task can be handled at that station.

In order to prevent the ground to get dirty during application, protective foils are used. The cost of this material is 2000-2500€/month. There are also additional cabin management costs of maintenance, ventilation and cleaning. Besides, the sticky nature of and the dirt caused by the wet wax cause motivational problems for the workers, i.e., it is a problem to select the operators who will pull the vehicle to D/E 03 from D/E 02 because of the risk of getting waxed.

Applied wax does not dry for the next takt, which also affects quality of the tasks in the following stations, i.e., while assembling a part, wet wax on the surfaces may be removed when an operator touches the vehicle, affecting the visual quality of the product negatively. Because wet wax shrinks after drying, errors occur in the assembly torque values of tubes and valves assembled at D/E 03.

Station 3

Piping: Assembly of the heating, fuel and braking systems tubes are made at station D/E 03. Polyamide brake system tubes are the most complex among all; they have the highest number of components and there are numerous lines moving along the vehicle from the front to the end. Although all lines follow the same route, they are installed separately. The shorter connection tubes to axles and control valves are also assembled on the vehicle.

Station 6

Roof filling assembly: Roof filling assembly is filling of the gap between the pecolite roof cover and the vehicle body by an isolation filling. Drying time for this material is about 240 minutes. Long drying time does not allow following roof work to be held at the same station, causing the need another lift in the following stations. Besides, during the assembly of heavy parts such as CNG tubes or the air conditioner, this part is damaged, causing a rework.

Webasto assembly: Webasto is the preheater for the engine that helps the engine start at cold weather conditions. It consists of multiple components that are put together at the assembly station before assembly, taking 60 minutes/operator.

Station 8

Engine preparation: Before the engine assembly, some work such as the assembly of engine holders to the engine block and engine to gearbox mechanical connection is made at this station. This is an operation of 20 minutes/operator.

Floor board adjustment: Floor board adjustment operation is the cutting of the floor cover boards according to the shapes of the chassis until they fit together inside the vehicle. It is a time consuming process that cannot be regarded as an assembly operation; there is an adjustment labour of 112 minutes per 1 workers for a single vehicle. Besides, thesawdust that arise during this operation creates a dirty working environment at the line.

For intercity vehicles, primarily baggage compartment floor boards are adjusted. For city vehicles, even though floor boards are received cut according to the technical drawings, work of 60-80 minutes/operator is required for adjustment. The primary reason for this problem is the incorrect technical drawings of the floor boards that are provided to the suppliers.

Station 10

Air conditioner preparation: The top covers of air conditioners and CNG tubes are mounted on the ground next to the vehicle before they are raised and assembled onto the vehicle. This is not a suitable case since assembly line operators spend their operation time for preparation of the part.

Station 12

Papering: After the floor boards are assembled, in order to prepare the vehicle to oil cloth upholstery assembly, the surface of the boards should be cleaned and perfected. This is done by papering the inner surfaces of the vehicle. However, the dust that arises during this application creates a cloudy environment at the pre-assembly line. Literally it becomes impossible for one operator inside the vehicle to see the other working at the back of the vehicle. For this reason, no other assemblies can be assigned to this station because of ISIG issues.

Stations 14-15

Oil cloth upholstery assembly: Adhesives used in oil cloth assembly are solvent based, which is flammable and creates an environment with disturbing odor. Although operators use protective masks during application, this operation requires a specially ventilated cabin. Stations D/E 14 and 15 are located in such cabin. However, because of this working environment and existence of a cabin, no other assemblies can be assigned to these two stations. This creates balance loss.

Station 16

Glass assembly: Glasses are delivered to the corresponding assembly stations D/E 16 with the packaging received from the supplier. However, these glasses are randomly packed. Operators at the stations first unpack these glasses and lay them on the glass holding tables. Secondly, according to the assembly sequence specified, they order the glasses again. The assembly of glasses start after this non value added, 30 minutes/operator time.

Solution proposals

Station 1

Roof cover assembly: The roof cover assembly can be made at the chassis assembly department before the Paintshop. With the roof covered, direct contact of snow and rain water with the vehicle will be prevented. Besides, since any possible damage given to the profile bars during cutting will be followed by the painting procedure at the Paintshop, risk of corrosion will be prevented. Vehicles will not be raised and waiting time for the glue will be eliminated, which will result in assigning following roof tasks as well as other operations to station 1. In addition, flow time of 15 minutes/vehicle will be gained because of the eliminated operation of re-painting.

Station 2

Anti-corrosive wax application: Application of the anti-corrosive wax at the Paintshop together with the profile wax may be a solution to remove this task from the pre-assembly line. There are many advantages of this action for the pre-assembly line, the most important of which is removing the wax cabin from the line and gaining of 1 station. Removing the cabin will save about 2500€/month and the additional cabin maintenance costs.

There will not be any management costs for this transfer operation because there is already a cabin for waxing at the Paintshop. This will also improve product quality since all pre-assembly waxing operations will be made in a single cabin, and also visual quality will be improved. For the following assemblies, because wax will be dry when vehicles enter the line, correct torque values will be achieved in the mechanical assembly areas.

Station 3

Piping: The polyamide brake tubes and smaller connection tubes can be grouped and prepared as a single system at a sub-assembly station before being taken into the vehicle so that only the assembly operation can be held inside the vehicle by the operators.

Station 6
Roof filling assembly: The sequence of this operation can be changed. It can be made after all roof operations are finished.

Webasto assembly: Webasto can be assembled at a sub-assembly station and can be brought to the station as one piece so that 60 minutes of gain can be maintained.

Station 8
Engine preparation: Engine preparation work can be made at the engine sub-assembly station and the time spent for this task by the operators can be gained.

Floor board adjustment: Floor board adjustment operation should be removed from the bus pre-assembly line by updating the drawings that are provided to the suppliers and increasing the tolerance values on the drawings so that only the assembly of floor board is made on the assembly line.

Station 10
Air conditioner preparation: This operation should be handled at a sub-assembly station and the operators should only perform the assembly operation at the line.

Station 12
Papering: Since it is not possible to remove this operation from the line as long as oil cloth assembly remains, a task specific vacuum system that is adapted to the papering equipment should be designed and used at this station.

Stations 14-15
Oil cloth upholstery assembly: These cabins can be removed by using water-based adhesives, or receiving the floor boards covered with oil cloth upholstery. The second option would also help removal of the papering operation from the line.

Station 16
Glass assembly: In order to reduce material handling in this operation, glass supplier should be informed about the sequence of glass assembly and asked to pack the parts in that order.

Assessment of solution proposals

At workshop 1 above-stated solution proposals are discussed with the operator team leaders and the production engineers. It has been accepted by the applicants of the workshop to continue the balancing work assuming that all proposals –except those of the papering and oil cloth assembly operations- are actualized. Therefore, corresponding operations are removed from the bus pre-assembly line process list before starting the balancing procedure.

5.2 Structuring of the proposed line

With the operations and operation times are known, designing an assembly system includes balancing of the desired assembly line by considering the number of operators and expected stations on the line, and organizing the equipment setup at each station according to the results of the balancing process. As the next step, regardless of what is obtained from the balancing study but the desired number of stations, physical positioning of stations inside the production facility is carried out throughout a layout planning procedure. Theoretically, balancing and layout planning of an assembly line are two disassociated procedures that do not influence each other while designing a production system from scratch.

Restructuring of the bus pre-assembly line, however, has constraints that do not allow the balancing and layout planning procedures to be followed independently. The primary constraints that affect the course of the process are time and cost parameters that are defined by the production management. That is, the operating pre-assembly line is expected to be replaced by a new pre-assembly line preferably without stopping the production system with the lowest possible amount of re-organization cost.

These constraints caused the balancing and layout planning procedures to diverge from the ideal approach to the problem and to gain a more practical and case-oriented characteristic. The determined strategy to design the new pre-assembly line turned out to be,

1. keeping the monumental resources that are time consuming and expensive to remove at their existing locations so that transition time and reorganization costs are kept minimum,
2. evaluating alternative station layouts by considering the stationary equipment and trying not to exceed the physical area on which the current pre-assembly line is located,
3. balancing the line by considering these stationary equipment at those positions and the corresponding stations.

The greatest challenge with this strategy was to be forced to handle stationary resources together with layout options and balancing work, which made it very complex to come up with reliable solutions. Any change with the station layout changed the arrangement and thus the order of the corresponding stations that overlap the stationary resources, which caused the distribution of operations to be reviewed completely. Although ProBalance® provided great flexibility with modifying station data, since the software was not able to generate the optimum solution due to the station constraints and the optimum balance required time consuming manual manipulation, it became mandatory to set the station layout prior to balancing the line.

The method applied to balance the new system has been, after fixing which station has which monumental constraint, letting ProBalance® generate the initial line balance and to manually manipulate the distribution of operations afterwards by considering the precedence relations.

5.2.1 ***Layout planning***

The existing pre-assembly line occupies a small section of the U1 building and this limited area has negative effects on the operations of the main assembly and the sub-assembly stations, primarily caused by problems with material flow and space required for assembly operations.

Although an ideal approach to plan the layout of the pre-assembly and sub-assembly stations suggests planning the whole system from scratch according to their relationships among with other, it was not possible to do that due to constraints about time and costs.

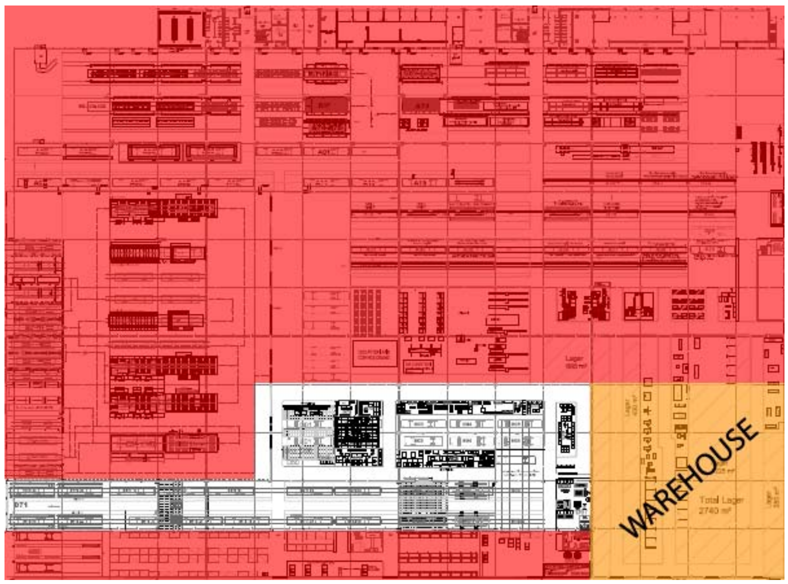


Figure 5.2 - Area of the pre-assembly line inside the U1 building

The long term plans of joining the pre-assembly and assembly stations inside the U1 building includes emptying the area of the warehouse and using that area for assembly stations. From this perspective, designing the layout by considering these future actions would provide a long term solution and enable more effective planning of the stations and their sub-stations. However, in the current case, considering that the new pre-assembly line would be taken into service in a very short time, the expected plan has been using the existing space and equipment in the design of the new line, which did not make it possible to generate several options.

By using the layout planning method suggested by Muther et al, [13] up to an extent, the layout plan of the new pre-assembly line is generated. The main concerns while planning the layout has been,

- using the area of the previous line while planning station positions for the new line,
- positioning the stations by considering the positions of monumental resources,
- positioning the sub-assemblies as close to their main assembly stations as possible.

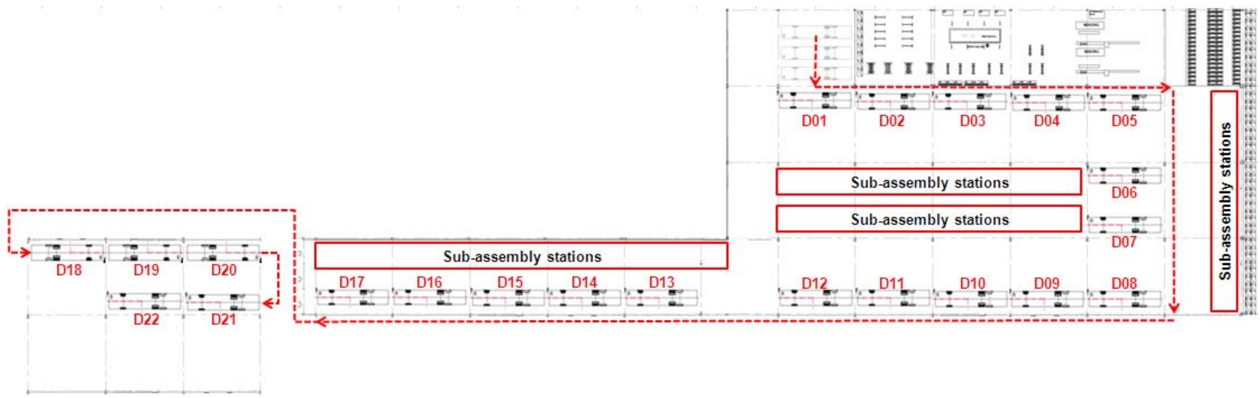


Figure 5.3 - Layout and flow plan of the new pre-assembly line

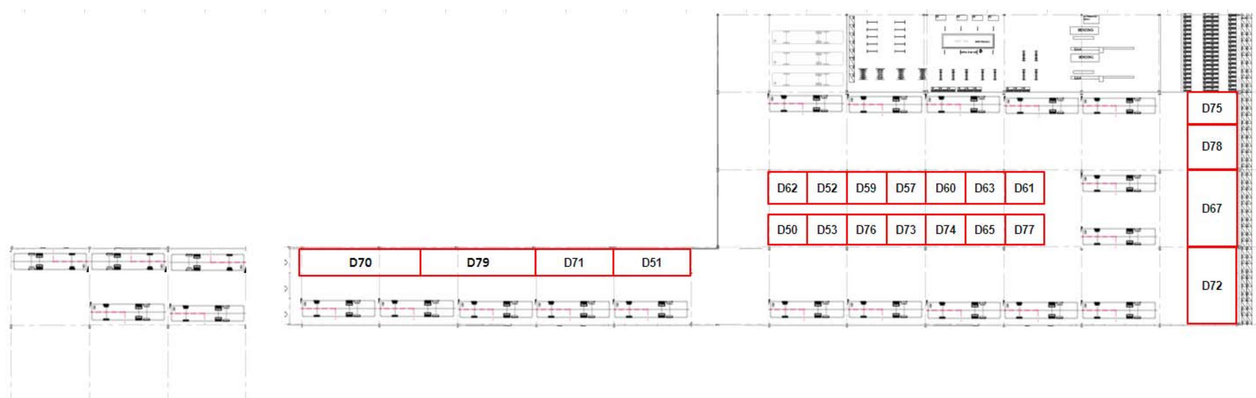


Figure 5.4 - Layout plan of the sub-assembly stations at the pre-assembly line

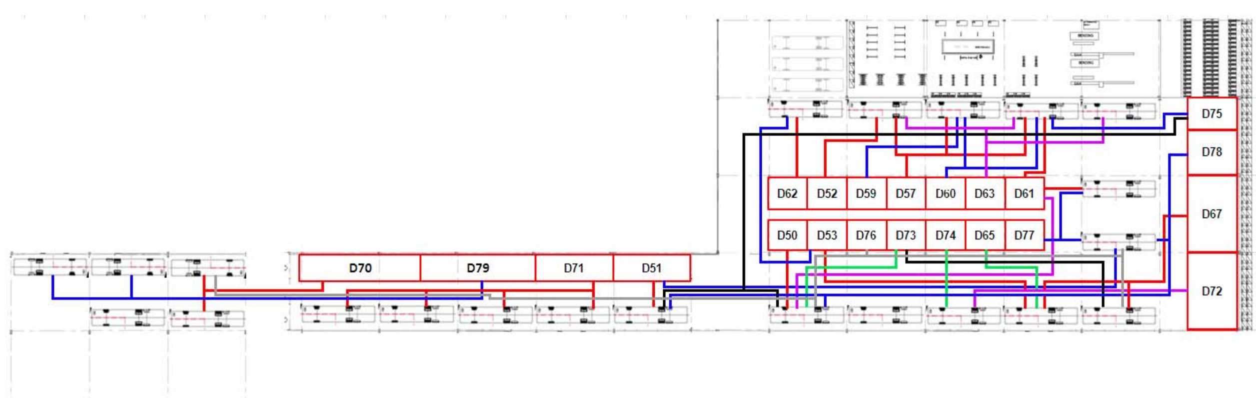


Figure 5.5 - Material flow from the sub-assembly stations to the main assembly stations

5.2.2 *Balancing of the proposed line with respect to current range of products*

Balancing and layout planning of the pre-assembly line are closely interrelated procedures, because the line balancing study could not be started without knowing to which station the monumental constraints correspond in the new line. The primary structures that were assumed to be stationary at their current position are the Kumbruch lifts at station 7, ground canals at stations 9 and 11, air conditioner assembly lift at station 11 and oil cloth assembly cabin at stations 14 and 15.

The main problem can be summarized as following. The assemblies that require these equipment has to be made at the same physical location as before. Taking the Kumbruch lifts as an example, when a different layout is proposed, the station number that these lifts correspond to changes, i.e., if it corresponds to station 10 in one plan, when the plan is changed, it may correspond to station 9. However, in order to run the balancing procedure, all station information has to be exact. That is, the software distributes the operations among stations by taking station equipment into account. Besides, since the balancing work required manual manipulation afterwards for every case, it would be loss of time to repeat the procedure for every layout option. Considering that there are 6 critical equipment that have to be considered, the situation becomes even more complicated. Therefore, since the primary limitation was the layout, it was determined first.

Another issue has been determining the sub-assembly organization. Although the operations that are held each sub-assembly are known, which assembly stations they would feed in the new line were not known since the station setup was not yet determined. Therefore, having balanced the line according to the assembly station layout, the layout of the sub-assemblies and material flow from them is planned after the balancing operation.

The assembly and sub-assembly stations of the new pre-assembly line are shown in table 5.1.

Table 5.1 - Station setup of the new bus pre-assembly line

Pre-assembly Station	Definition	Sub-assembly Station	Definition
D01	Air conditioner and brake system preparation	D50	Door handle preparation
D02	Brake and electrical systems assembly	D51	Roof air conditioner pipes preparation
D03	Brake and heater pipes, and engine room isolation assembly	D52	Side plate preparation
D04	Brake pipes and electrical systems assembly	D53	Piston, mudguard support, light holders, mudflap preparation
D05	Electrical systems and switch board assembly	D57	Oil pipes and clutch pipes preaparation
D06	Floor board assembly and engine room preparation	D59	Heater pipes preparation
D07	Floor board assembly and engine room preparation	D60	Polyamide brake pipes preparation
D08	Axle preparation	D61	Isolation preparation
D09	Axle assembly	D62	Brake valves preparation
D10	Engine assembly	D63	Electrical systems preparation
D11	Papering preparation	D65	Wheel preparation
D12	Engine room pipes, air conditioner and WC assembly	D67	Axle preparation
D13	Engine room pipes and air conditioner gas pipes assembly	D70	Glass preparation
D14	Oil cloth preparation	D71	Oil cloth preparation
D15	Oil cloth assembly	D72	Engine preparation
D16	Oil cloth assembly	D73	Fuel tank and air conditioner compressor preparation
D17	Oil cloth welding and side profile assembly	D74	Radiator preparation
D18	Electrical components assembly	D75	Brake - steering hydraulic pipes preparation
D19	Electrical components assembly	D76	Steering wheel and pedal preparation
D20	Glass assembly	D77	Webasto preparation
D21	Glass assembly	D78	Piping preparation
D22	Vehicle start	D79	Baggage covers preparation

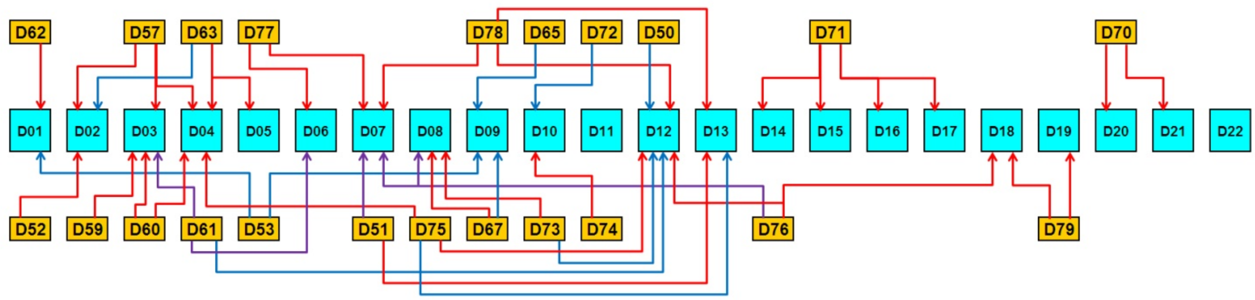


Figure 5.6 - Work flow at sub-assembly and assembly stations in the new pre-assembly line

Due to the variable operation times of different vehicle models, the operator demand of each model for stations also differs. Therefore, in order to prevent excess capacity at stations, number of required operators at each station is determined for the vehicle models of interest and the balancing algorithm is run for the minimum and maximum number of required operators at stations for the same distribution of operations. The aim of this action is to visualize the differences in idle times and takt overdue between the two cases. It should be noted that the new takt time is 65 minutes, however, the balancing is made for 60 minutes, creating a buffer of 5 minutes for conveyance.

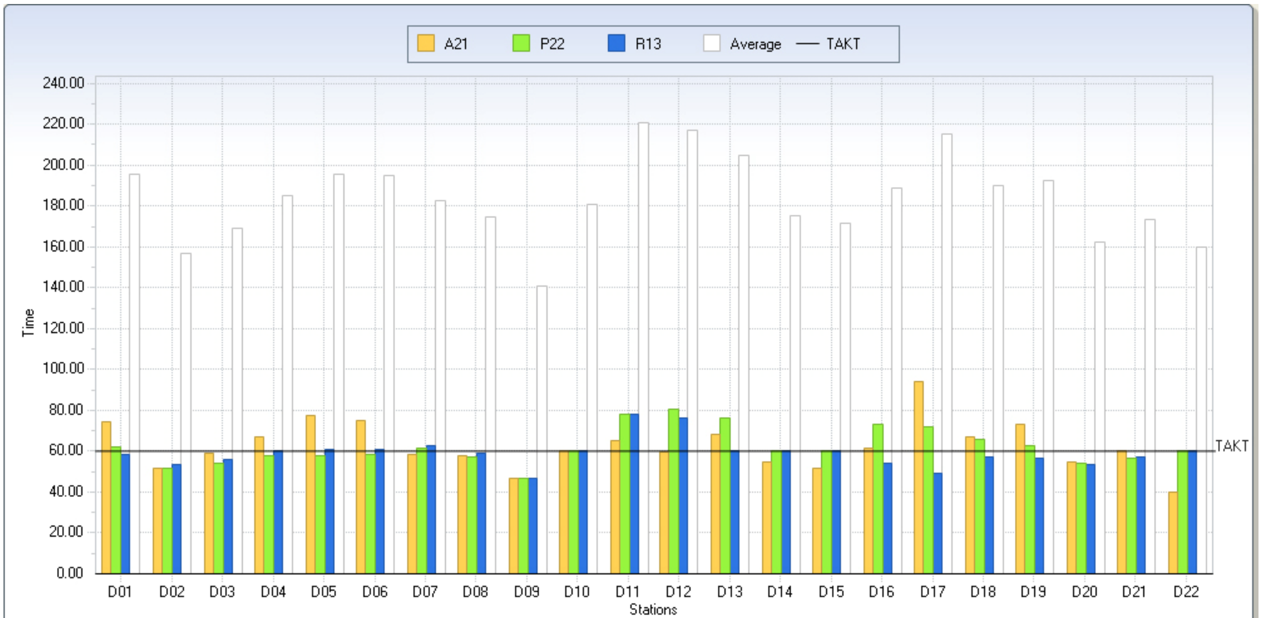
The distribution of operators to stations and balance graphs of the two cases of minimum and maximum number of operators are shown in table 5.9 and figures 5.7 and 5.8 respectively.

Table 5.2 - Distribution of operations to stations and operator demand for A21, P22, R13 models

	A21		P22		R13	
Station	Station time	Number of operators	Station time	Number of operators	Station time	Number of operators
D01	696	11	689	12	764	13
D02	415	8	414	8	426	8
D03	530	9	485	9	505	9
D04	940	16	811	15	840	14
D05	618	11	461	8	485	9
D06	828	13	645	11	659	13
D07	641	11	679	12	691	12
D08	290	5	287	5	295	5
D09	235	6	235	5	235	5
D10	181	4	240	4	241	4
D11	325	5	390	6	389	6
D12	536	9	727	13	688	12
D13	409	7	458	8	362	6
D14	110	2	120	2	120	2
D15	155	3	180	3	180	3
D16	430	7	513	9	380	7
D17	565	10	432	8	296	6
D18	871	15	858	15	741	13
D19	734	13	625	12	565	10
D20	330	6	325	6	320	6
D21	300	5	283	5	285	5
D22	80	2	120	2	120	2
TOTAL	**10219**	**178**	**9977**	**178**	**9587**	**170**

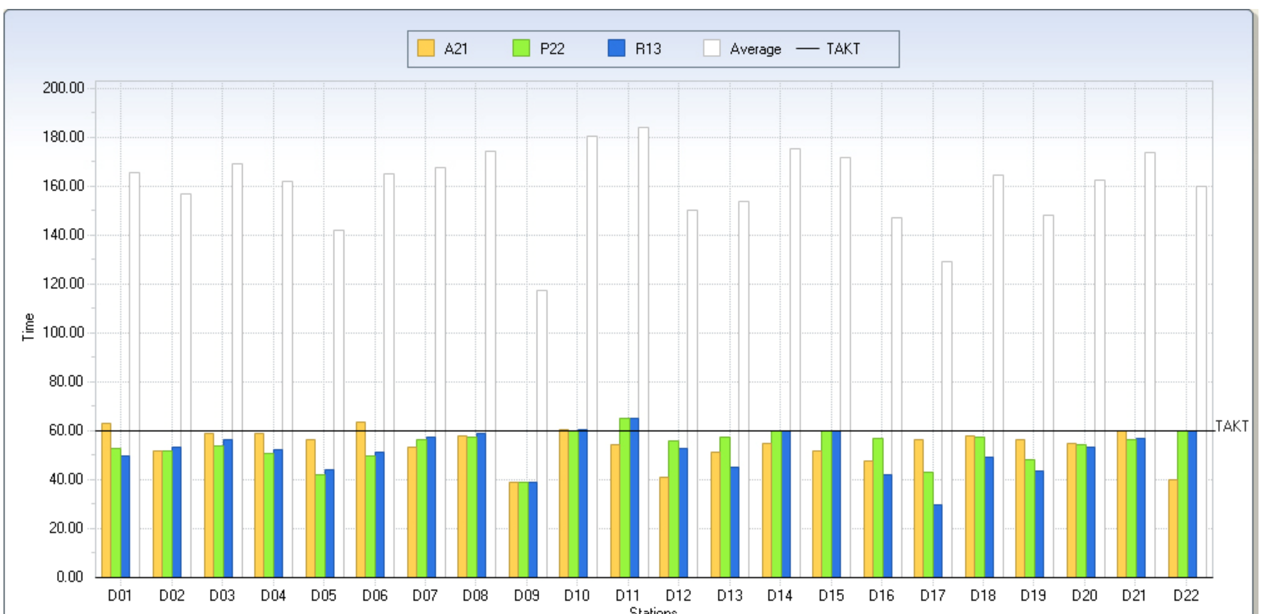
Time unit: minutes

Minimum required number of operators:	160
Maximum required number of operators:	189



	D01	D02	D03	D04	D05	D06	D07	D08	D09	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22
A21	74.55	51.88	58.89	67.14	77.25	75.27	58.27	58.00	47.00	60.25	65.00	59.56	68.17	55.00	51.67	61.43	94.17	67.00	73.40	55.00	60.00	40.00
P22	62.18	51.75	53.89	57.93	57.63	58.64	61.73	57.40	47.00	60.00	78.00	80.78	76.33	60.00	60.00	73.29	72.00	66.00	62.50	54.17	56.60	60.00
R13	58.64	53.25	56.11	60.00	60.63	60.82	62.82	59.00	47.00	60.25	77.80	76.44	60.33	60.00	60.00	54.29	49.33	57.00	56.50	53.33	57.00	60.00
Average	195.36	156.88	168.89	185.07	195.50	194.73	182.82	174.40	141.00	180.50	220.80	216.78	204.83	175.00	171.67	189.00	215.50	190.00	192.40	162.50	173.60	160.00

Figure 5.7 - Balance of the line for the minimum required number of operators



	D01	D02	D03	D04	D05	D06	D07	D08	D09	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22
A21	63.08	51.88	58.89	58.75	56.18	63.69	53.42	58.00	39.17	60.25	54.17	41.23	51.13	55.00	51.67	47.78	56.50	58.07	56.46	55.00	60.00	40.00
P22	52.62	51.75	53.89	50.69	41.91	49.62	56.58	57.40	39.17	60.00	65.00	55.92	57.25	60.00	60.00	57.00	43.20	57.20	48.08	54.17	56.60	60.00
R13	49.62	53.25	56.11	52.50	44.09	51.46	57.58	59.00	39.17	60.25	64.83	52.92	45.25	60.00	60.00	42.22	29.60	49.40	43.46	53.33	57.00	60.00
Average	165.31	156.88	168.89	161.94	142.18	164.77	167.58	174.40	117.50	180.50	184.00	150.08	153.63	175.00	171.67	147.00	129.30	164.67	148.00	162.50	173.60	160.00

Figure 5.8 - Balance of the line for the maximum required number of operators

Table 5.3 - Idle times and takt overdue for regular distribution of operators at stations

			Station																						
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	Total
Station time	A21	Idle time	X	8	1	1	4	X	2	2	21	15	X	0	2	5	8	X	3	2	4	5	0	20	103
		Takt overdue	3	X	X	X	X	4	X	X	X	X	5	0	X	X	X	1	X	X	X	X	0	X	13
	P22	Idle time	3	8	6	6	2	1	3	3	13	0	X	4	3	0	0	3	6	3	8	6	3	0	81
		Takt overdue	X	X	X	X	X	X	X	X	X	0	5	X	X	0	0	X	X	X	X	X	X	0	5
	R13	Idle time	1	7	4	0	6	9	2	1	13	0	X	3	0	0	0	6	11	3	3	7	3	0	79
		Takt overdue	X	X	X	0	X	X	X	X	X	0	5	X	0	0	0	X	X	X	X	X	X	0	5
	Average	Idle time	1	8	4	2	4	3	2	2	16	5	X	2	2	2	3	3	7	3	5	6	2	7	88
		Takt overdue	1	X	X	X	X	1	X	X	X	X	5	X	X	X	X	0	X	X	X	X	X	X	8

Takt time: 65
Time unit: minutes

Table 5.4 - Idle times and takt overdue for minimum required number of operators at stations

			Station																						
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	Total
Station time	A21	Idle time	X	8	1	X	X	X	2	2	13	15	X	0	X	5	8	X	X	X	X	6	3	0	63
		Takt overdue	3	X	X	7	17	15	X	X	X	X	5	0	8	X	X	1	34	7	13	X	X	0	110
	P22	Idle time	X	8	6	2	2	1	X	3	13	0	X	X	X	0	0	X	X	X	X	6	3	0	44
		Takt overdue	3	X	X	X	X	X	2	X	X	0	18	21	16	0	0	13	12	6	3	X	X	0	94
	R13	Idle time	X	7	4	0	X	0	X	1	13	0	X	X	0	0	0	6	11	3	3	7	3	0	58
		Takt overdue	9	X	X	0	1	0	3	X	X	0	18	16	0	0	0	X	X	X	X	X	X	0	47
	Average	Idle time	X	8	4	1	1	X	1	2	13	5	X	X	X	2	3	2	4	1	1	6	3	0	55
		Takt overdue	5	X	X	2	6	5	2	X	X	X	14	12	8	X	X	5	15	4	5	X	X	0	84

Takt time: 65
Time unit: minutes

Table 5.5 - Idle times and takt overdue for maximum required number of operators at stations

			Station																						
			D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	Total
Station time	A21	Idle time	6	8	1	1	4	X	7	2	21	15	6	19	9	5	8	12	3	2	4	5	0	20	158
		Takt overdue	X	X	X	X	X	4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	X	4
	P22	Idle time	7	8	6	9	18	10	3	3	21	0	X	4	3	0	0	3	17	3	12	6	3	0	136
		Takt overdue	X	X	X	X	X	X	X	X	X	0	5	X	X	0	0	X	X	X	X	X	X	0	5
	R13	Idle time	1	7	4	7	16	9	2	1	21	0	X	7	15	0	0	8	30	21	27	7	3	0	186
		Takt overdue	X	X	X	X	X	X	X	X	X	0	5	X	X	0	0	X	X	X	X	X	X	0	5
	Average	Idle time	5	8	4	6	13	6	4	2	21	5	2	10	9	2	3	8	17	9	14	6	2	7	160
		Takt overdue	X	X	X	X	X	1	X	X	X	X	3	X	X	X	X	X	X	X	X	X	X	X	5

Takt time: 65
Time unit: minutes

6 EVALUATION OF THE PROPOSED SYSTEM

This chapter evaluates the advantages of the proposed setup over the current system.

6.1.1 *Labor productivity*

The number of assembled vehicles at the pre-assembly line is not subject to change throughout this study. Therefore, due to the reduced number of operators at the pre-assembly line, the labor productivity will increase with the application of the proposed system. The rate of increase mainly depends on which scenario is to be applied and an improvement of up to 20 % in labor productivity is possible in the future system.

Table 6.1 - Comparison of labor productivity of current and proposed cases

	Current state	Proposed state	
Operators	193	189	160
Daily output (units)	8	8	8
Daily labor Producivity (units / operator)	0.0415	0.0423	0.05
Change (%)		2.1164	20.6250

6.1.2 *Efficiency*

One of the most important objectives of this project was to eliminate the excess capacity at the stations so that idle times and non-value-added work at the production system are minimized. Considering that the same number of output is produced by a smaller number of operators in the same duration, and the process times are reduced for the same products, it can be said that the efficiency of the pre-assembly line increased as a result of this study. Besides, reduced idle times at stations and new strategies developed for handling operations that cause takt overdue –which is the greatest waste in terms of efficiency- are other factors that improve the efficiency of the line. Different from the previous system, operations causing takt overdue will not be completed by rework. Instead, they will be completed by joker workers instantly at the corresponding station so that wastes caused by over-processing will be eliminated. With the new line balance and operator planning, the maximum balance delay time (total idle time) at the line can be reduced up to 80 %. Also, the maximum total takt overdue can be reduced 90 % with the same method.

Table 6.2 - Comparison of idle times and takt overdue between current and new states

			Total idle time	Total takt overdue
Current state		A21	315	1091
		P22	168	1091
		R13	246	1006
New State	For minimum required number of operators	A21	63	110
		P22	44	94
		R13	58	47
	For maximum required number of operators	A21	158	4
		P22	136	5
		R13	186	5

Time unit: minutes

6.1.3 *Layout*

The layout of the new pre-assembly line is planned in a way that will preserve the station setup of the previous pre-assembly line in order to reduce reorganization cost. It was also considered to minimize the distance between the main assembly and sub-assembly stations at the production site. Therefore, the key notion of layout planning was generating the largest possible area for sub-assembly stations as close to the main assembly stations as possible without increasing station setup costs.

Unlike the current layout where most stations were positioned outside the U-shaped pre-assembly line, the new plan suggests sub-assembly stations to be located right in the middle of the U-shaped assembly line, reducing the distance between them and their main assembly stations dramatically and improving material flow.

6.1.4 *Reorganization cost*

Proposing solutions that will minimize the reorganization cost has been the primary objective of this study, which had the greatest effect on layout and station planning. Considering the factors that increase reorganization cost, i.e., removing and re-installing large station equipment such as cabins or platforms, digging ground canals, setting up pneumatic systems, etc., and short transition time, the strategy of keeping these equipment at their current positions is applied. Besides, it is tried to be avoided to define new locations as stations that were not stations before, since it would require infrastructural investment to convert those areas to assembly stations.

Items that make up the reorganization cost can be listed as,

- lining the ground to indicate assembly station areas for new stations D6 and D7,
- removing station equipment from the emptied assembly line,
- restructuring ground rails on which vehicle carrying fixtures move.

It can be said that avoiding radical solutions and preserving the current setup as much as possible helped the reorganization cost to be kept at relatively low levels considering the scale of the change. In contrast, elimination of one of the production lines will reduce air, electricity and cleaning costs.

6.1.5 *Material handling*

At the core of this study laid elimination of non-value-added operations at stations that are caused by high material handling requirements of operations, which is the greatest waste in the current production system. Although bus production requires manual assembly up to a large extent, this does not necessarily mean that operators are obliged to do additional labor at the assembly stations such as unpacking, or making adjustments on the parts to be assembled. In order to get rid of these operations and create an assembly line where operators perform “grab and assemble” operations only, it was an important part of the project to determine the tasks that could be removed from the pre-assembly stations to sub-assembly stations. In addition, logistics department is briefed on issues regarding how parts are supposed to be supplied to the stations for minimizing handling losses. 95% of the reduced operation time for vehicles is a result of re-addressing of required operations to sub-assemblies and elimination of material handling requirements at stations caused by inappropriately supplied parts.

6.1.6 *Material flow*

The new layout provides significant improvement on material flow to pre-assembly stations. Unlike the current line, where the short distance between parallel lines makes it difficult for fork-lifts to enter, the new line overcomes that problem with large free area around the stations. In addition, the distances between the new pre-assembly stations and the associated sub-assembly stations are much shorter than they are in the current system, which reduces wastes caused by transportation and walking.

Table 6.3 - Comparison of distance from sub to main assembly stations for current and proposed systems

	Total distance between sub-assembly to main assembly stations
Current	~ 1065
New	~ 860
Change (%)	~ 20

Distance unit: meters

6.1.7 *Process times*

The improvements on the current production system focused on eliminating noticeable wastes in and removing operations that are not appropriate for the pre-assembly line. By planning the required changes for readdressing those operations and removing them from the pre-assembly line, a substantial reduction of line operation time of about 29% is achieved.

Table 6.4 - Comparison of vehicle operation times for current and proposed systems

	Process times		
	A21	P22	R13
Current	14204	14274	13544
New	10219	9977	9587
Change (%)	-28	-30	-29

Time unit: minutes

6.1.8 *Number of assembly operators*

Assigning assembly operators to the assembly stations has a crucial effect on the efficiency of the line. Variant losses are mainly caused by the fixed number of operators at the stations; at an assembly line that is balanced for the most complex model, the operators at stations remain idle for a less complex model, which is a capacity loss for the line. The number of operators required to complete the operations at the pre-assembly line differs for different products, and this should be taken into account during balancing the line for eliminating capacity losses.

Table 6.5 - Comparison of number of operators for current and proposed systems

		Number of operators
Current		193
New	minimum	160
	maximum	189

On one hand, for eliminating idle times at stations, number of operators should be the minimum of that is required at that station. On the other hand, this would cause takt overdue for more complex assemblies, which can be solved by having the maximum number of operators required at that station. In this sense, having the minimum number of operators fixed at stations is a better approach in terms of efficiency of the line, because extra labor requirement can be handled by on-demand operators such as joker workers, while idle losses are intolerable and complete loss of capacity for the line.

6.1.9 *Joker worker organization and compatibility*

For the assembly system of interest at which product variance is very high, using joker workers will provide the best solution for optimizing line capacity and eliminating variance losses. Considering the minimum and maximum operator requirements at the stations, a joker worker organization of maximum 29 operators would fulfill the requirements of the assemblies on the line for the whole product range.

29 operators, however, is considerably a great number for a line of 160 operators. Planning the schedule of the joker workers is an important task since the cost of an idle joker worker is no different from an idle assembly operator. Therefore, joker worker schedules should be planned parallel to production so that there will be no problems with the line flow due to additional labor demands. When the joker workers are not assigned to any operations at stations, they can take part in Kaizen activities as well as doing rework.

Although the concept of using joker workers at the pre-assembly line is new, such organization would be compatible with the structure of the company since continuous improvement philosophy is a part of the company culture and is managed by an independent department, which can organize and direct the joker worker activities together with the production management.

6.1.10 *Flexibility upon request*

The new single line is flexible for product variance; its new setup and operator organization allows a new type to be easily integrated to the current product range with minimal capacity loss. However, with its current setup and balance, the new line is not flexible for increasing production capacity. Also, like any other single line production system, the new line has become vulnerable to problems such as missing parts or other technical problems, which may cause the whole pre-assembly line to stop until solved.

6.1.11 *Compatibility to merging pre-assembly and assembly lines at U1 building*

The idea of merging pre-assembly and assembly lines and constructing a single assembly line relies on the production strategy of achieving a continuous production line where the work pieces do not leave a building and taken to another during the assembly process. There are two critical determinants of this merging action that are to be fulfilled for this operation;

1. the properties of the two lines have to be the same with each other,
2. the physical area of the building that will host the merged line has to be large enough to provide enough space for the assembly and sub-assembly stations as well as the logistics activities.

With the proposed changes at the pre-assembly line, its structure became compatible with the rest of the assembly lines in the whole production line. That is, the takt time of 130 minutes is reduced to 65 minutes, and the parallel two-line production is switched to single line production, which enables the pre-assembly and assembly lines to operate as a single line if merged. Also, the physical area of the U1 building is enough to cover the pre-assembly and assembly lines and their sub-assembly stations if the area occupied by the warehouses is emptied.

6.1.12 *Competence*

Cleveland et al., ([6] p.657) defines production competence as *"the preparedness, skill, or capability that enables manufacturers to prosecute a product-market specific business strategy"* and argue that the nine skills or capabilities of manufacturers are adaptive manufacturing, cost effectiveness of labor, delivery performance, logistics, production economies of scale, process technology, quality performance, throughput and lead time, and vertical integration.

The competition in the commercial vehicle market and the decreased demand due to ongoing economic crisis forces the companies to reduce costs for maintaining their competitiveness. The planned changes at MAN Türkiye is also aiming to improve the competence of the company in the market by cutting production costs without changing productivity.

The proposed changes have affects on the reduction of costs that cannot be omitted. The primary gain is achieved in the inventory costs by switching from two parallel lines to single line production, which reduces the number of pre-assembly stations from 39 to 22. The reduction of 17 stations from the production line reduces the working process inventory of the pre-assembly line more than 40%. The reduction in the station costs such as air, electricity, cleaning and material costs is a plus to the inventory costs.

Besides the inventory costs, reduced number of operators at the pre-assembly line means a reduction in the labor costs of about 17%. With the new takt time of 65 minutes, the learning time of the operators at stations will decrease, which will improve the operating skills of operators and reduce the quality flaws of the end-products.

7 DISCUSSION

This aim of this chapter is to approach the achievements of the conducted study from a critical point of view. It presents the discussion of how the theory and applied methods affected the generated results and whether these results fulfill the expectations of the company. The prerequisites of taking the proposed system into service and recommendations on further improvement of the project are also put forward.

7.1 Theory and applied methods

Although the primary objective of this study is assembly line balancing, as the balance losses at the current system are investigated it is figured out that the problems were originated from various dynamics of the production process, which required consideration of assembly concepts mentioned in Chapter 3 throughout the project. However, it is not possible to eliminate all problems at such a complex assembly system in such a short time with such a small budget and would also not be a reasonable objective. What this study aimed, though, was highlighting the problems observed during the assembly line balancing process so that it develops a guide for future studies.

Scholl's capacity oriented and cost oriented goals for balancing an assembly line are adapted as the major criteria that shaped the course of the project. Switching to single line assembly and halving the takt time resulted in a significant reduction in inventory costs and flow time. For reducing the wage costs, operator planning has been made by balancing the line for the most standard configuration of products and handling the remaining work by joker workers, which would minimize the required number of operators at the stations. This also helped the idle times and takt overdue to be eliminated, helping the idle and incompletion costs to drop.

Product - Process Matrix has been the initial guide for comprehending the problems with the existing system. It is observed that the production system at MAN Türkiye was off the diagonal on the Product-Process Matrix, which indicated a wrong process decision for the product. Besides, it was also noticed that the emphasized advantages of flow line systems were not effective on the current system; throughput times were high and capacity utilization was low, in process inventory was high, material handling needs were high due to the lack of mechanical conveyance and required shop floor and storage space was high. For some parts of the assembly line, it was also not possible to use less skilled operators since most operations required specialization. Thinking about the reasons of this discrepancy and its reasons, it is finally comprehended that the main reasons of this situation are the size and complex structure of the products; buses are big and heavy, and they are made up of thousands of components that are manually assembled. Low production volumes, high level of product variation and manual processing requirements did not enable automation in the production process, which results in not being able to take advantages of flow line assembly. Therefore, it is concluded that, since it is not possible to change the product process pattern of the factory, necessary actions should be taken to bring the position of system as close to the diagonal as possible. Switching to single line assembly with a lower takt time had significant effects on reducing the in process inventory and shop floor space needs at the assembly line as well as improving the operator learning time, which enables less skilled operators to be used at the line. Other actions included improving capacity utilization and reducing material handling needs at the pre-assembly line.

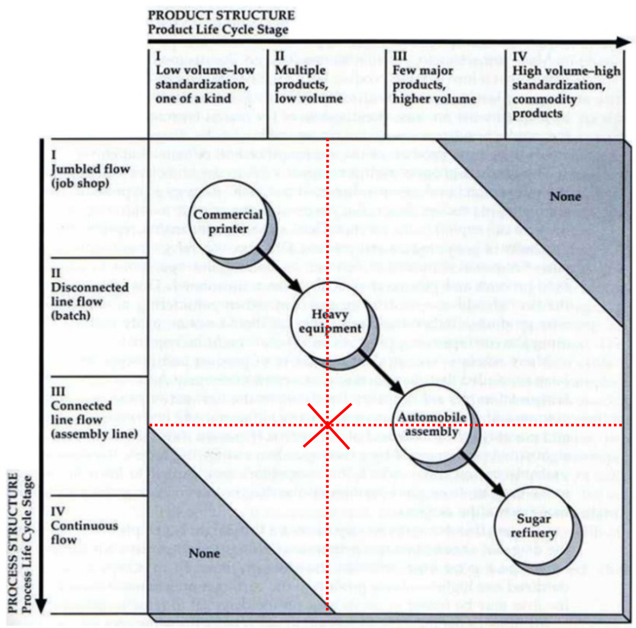


Figure 7.1 - Current position of the company on the Product-Process Matrix

Capacity utilization can be explained as aiming to reach the maximum potential productivity level of the facility for a given time with its current resources. Efficient use of operators is a key figure in capacity utilization, which can be summarized as determination of the correct number of operators at an assembly line and maximizing their performance.

Calculation of number of operators required at the pre-assembly line has been completed in two steps. In the first step, the theoretical calculation method is applied for figuring out the maximum number of operators required for each vehicle model by simply dividing the total operation time of each vehicle to the takt time. This number gave an idea about the number of operators needed at each station for running the balancing operation at ProBalance®. Having run the balancing algorithm on the software and manually manipulating the addressing of operations to stations, the distribution of operations to stations is determined, which is followed by the final operator assignment to stations explained in Chapter 3.

Application of joker workers has been a new approach at the pre-assembly line, but it offered considerable advantages in reducing capacity losses due to variation of products. However, variant losses are not the only sources of idle times and takt overdue at stations; the KSW operations with low frequency also caused the same results as the variants at the stations. In order to eliminate the losses caused by KSWs, operations with frequencies lower than 50% are removed from the main operations list before being distributed to stations so that the balance of the line is made for the most standard operations.

Operator job design was another concept that was considered while improving operator performance parameters. All operation times were increased by 15% and the line is balanced for the operation times with this distribution ratio, which was stated to improve operator productivity. Besides, in order to prevent two operators to work at the same region of the vehicle simultaneously, all operations are labeled according to their corresponding vehicle regions, which were taken as constraints during line balancing. In addition, for minimizing material handling requirements at stations, the problematic deliveries are reported to the logistics department so that actions like unpacking or sequencing of parts are made prior to their delivery to stations.

Acquiring a complete operations list and to verify the list by cross-checking with other references has been the initial step of the project. The company uses a complex production management system that controls whole operations by numbers instead of operations lists. Lists are prepared by management groups to follow the operations at the line for their own use. Assuming the frequent change of product features and thus operations, it would not be rational to accept the existing list at the Work Preparation Group as the master list since it could be outdated. Cross-checking, therefore, has taken more time than re-arranging the assembly line. Having achieved the master list, the master precedence graph of operations is prepared by observations at the stations and interviews.

Interviewing has been a very useful tool for gathering information during the project. The operators and team leaders were quite cooperative and had numerous ideas that come with experience. In order not to make it like an interrogation, questions were asked as if they were out of curiosity and the subjects were allowed to tell whatever they wanted about the topic; the sought information was highlighted as they explained.

Lean is a production culture that should be adopted and applied by all units within a company. The objective of this project was not applying lean fundamentals to the production system; this would be irrational and also there is a department whose specialization is applying lean to the factory. Rather, lean has been a tool for determining significant wastes that should be focused on and, if possible, eliminated throughout the balancing process.

Considering the 7 wastes in a lean production system, it has been much easier to identify the problems at the pre-assembly line. Observation of long walks to the sub-assembly stations caused the layout plan to be shaped in a way to reduce the distance between the sub-assembly and assembly stations. Over-processing was another problem noticed at stations; operators used to spend long times making sub-assemblies of parts or making adjustments on the assembled parts. This is eliminated by re-addressing such operations to sub-assembly stations. Transportation of materials at the pre-assembly line has been optimized by positioning the sub-assemblies as close to the main assembly stations as possible. Elimination of waiting times and rework requirements has been the greatest gain achieved through this study by line balancing and optimization of operations. Regarding the perspective it provided, lean has been a valuable tool for this study.

Simplified systematic approach has proved to be a reliable guide in the layout planning procedure, but due to the limitations of the project it could only be applied up to an extent. The main reasons for that method not to be able to shape the whole planning procedure are time and cost limitations declared by the project managers; setting up the ideal line by replacing the monumental station equipment required more reconstruction time and higher investment. Still, determination of the positioning of sub-assembly stations with respect to the corresponding pre-assembly stations is handled by applying this method, which resulted in a significant reduction of transportation distance. The gain would be higher if the whole line could be rearranged.

The applied method can be regarded as a company-adopted theoretical method for assembly line balancing. Although the theoretical approach to the given task is evident, it was not possible to apply the theory to a functioning system directly; it was also compulsory to take advantage of the own dynamics of that system and blend it within the ongoing restructuring process. Observing that the existing operation culture would not easily adopt to a top-down decision, it became clear to join the operators to the process via the team leaders. The target of this approach has been, as the ones who literally do the operations, to integrate their ideas and experience while shaping the new system. This has been done by the help of interviews and the workshops. On the other hand, it would not be reasonable to totally rely on the information given by the operators since it would reflect subjective opinion to protect their own interest. Therefore, to perform the given task, a task-specific heuristic method is generated and integrated with the theoretical method.

Considering the nature of this study of maintaining the efficient usage of resources and reduction of wastes, it can be said that this study has positive effects on economic sustainability. Overall, the primary objective has been optimization of materials used in production, which leads to reduction in used raw materials and wastes. In addition to the positive effect of resource utilization on economic sustainability, closing of 16 stations has a significant reduction in the usage of energy sources such as electricity and pneumatics as well as human resources, which can be regarded as improvements in environmental and social pillars of sustainability.

7.2 Results

Throughout this study, the existing bus pre-assembly line at MAN Türkiye A.Ş. is re-structured by changing the production system from two-parallel lines to single line while halving the takt time of 130 minutes and balancing the new line, with the primary constraints being minimum transition cost and time.

At the beginning of this study no estimation has been made about the outcomes of the project; it was known that there were inappropriate operations that should not be handled at an assembly line and the line balance was not optimal, but no prediction was made about the gain that could be achieved at the end of the project in terms of operation times or operator numbers at the line.

Also, the ProBalance® software that was going to be used for balancing the line was new to the company and nobody had an idea about how reliable the generated results will be. The resulting outcomes of this project, though, were beyond what could be estimated in advance.

It can be said that the balancing procedure has been planned according to the demands of the software; the course of the project is determined for gathering the information that is required to run the software. It was a risky decision since any problem with the software would reset the whole effort that was put into the work. However, the test runs with the software were promising, which resulted in the work to be continued as planned. Although the final result was not the best that could be achieved, the final lining is configured through manual manipulation on the software.

A comparison between the current and the proposed system shows that the application of the proposed system creates a more advantageous situation for the competence of the company with its reduced costs and improved line efficiency. The proposed changes are feasible in terms of reorganization costs and transition time, and the pay-off of the proposed line is higher. The achieved results suggest that the objectives of the company with this project are obtained, and the requirements of the project are fulfilled.

7.3 Implementation of the proposed system

In order to take the proposed assembly system into service without having complications, it is mandatory to perform some changes at the operational and the organizational level within the production system. The required re-organization for the new assembly line has been planned by considering the resulting station setup and the assembly operations in detail so that the transition is managed with minimum complexity. The detailed action plan includes items about all stations and operations at these stations that are to be considered. In terms of reflecting the orientation of the planned steps, rather than listing the actions, it will be appropriate to highlight the major topics under which the necessary actions are determined.

The changes that should be organized at the operational level include,

- briefing the logistics department about the new organization of the assembly line and about the assembly operations that will henceforth be handled at sub-assembly stations so that material flow is reorganized,
- verifying if the assumptions about breaking down operations to multiple stations or conjoining operations of different assembly groups at the same stations are practically applicable,
- verification of the qualification matrices of operators at the line and making the new operation assignment to operators regarding their skills.

There are also actions that should be taken to prepare the production site for the new assembly line, which can be summarized as,

- reconstruction of the ground rails according to the new line flow such that the vehicles are going to be taken to the line from the side
- preparation of the stations for the new operation distribution for fulfilling the requirements of the operations addressed to those stations as well as maintaining operator safety. This includes dismantling of the monumental resources at the stations such as cabins, lifts or platforms, and making the infrastructural preparations, i.e., ground surveys, pneumatic systems etc., for their replacement to their new locations as well as setting up safety belts to the corresponding stations.
- removal of all infrastructural and operational equipment such as ground rails, pneumatics, lifts, cranes, etc. and covering of ground canals at the closed pre-assembly line so that the corresponding sector of the production site is no longer related to main assembly, but can be used within the sub-assembly station organization.

7.4 Further recommendations

Due to the limited time of this project it was not possible to analyze all operations at the pre-assembly line in detail, but only the most critical. A detailed analysis of every operation at the line can provide a deeper understanding of the non-value-added parts of those operations and make it easier to determine the wastes that should be eliminated. Considering the improvement that was achieved through eliminating the most evident wastes at the production line, performing an in-depth analysis of the operations in a solution-oriented approach will improve the gain significantly.

ProBalance® is proven to be a very useful tool for organizing station and operation data at a detailed level and maintaining assembly line balance with this information in a matter of seconds. It provides great flexibility for modifying or re-addressing operations as well as operator planning at stations. Integrating this or a similar tool for organizing assembly line setup can be of great advantage for the company at the long run for visualizing the balance changes, planning future actions like adding new products to the range or modification of operations at the pre-assembly line, and analyzing the changes instantly. The only challenge with adapting this software to an already running production system is that the software requires the operation data to be input in every detail, which would take some time to analyze the operations and form the initial structure of the production system in the software. However, once this is completed, no matter how complex the assembly line is, any change on the assembly line can be demonstrated and planned in a few minutes, reducing the time required to apply changes at the assembly line in a conventional system.

The layout of the current pre-assembly line is a limiting factor on the performance of the line in terms of material and line flow. Due to the limited area that is allocated to the pre-assembly line, the layout of the line cannot be optimized for the requirements of the production system, which also affects the balance of the line. If the pre-assembly and assembly lines are to be merged at U1 building, this action should follow a detailed layout planning where low-cost re-organization is not the priority.

Moving the work-pieces to the next station at the pre-assembly line takes about 2-3 minutes, and this operation cannot be started at all stations at the same time due to safety issues. That is, the operators of the last station start pulling the bus from the previous, and when they are at about half way, the operators of the previous station start pulling the previous bus to their station. At the current line of 19 stations, completion of line flow takes up to 10 minutes. Besides the negative effect of manual conveyance of buses on the motivation of the operators, with the new line of 22 stations and new takt time of 65 minutes, the conveyance time can become a serious problem. Although the line is balanced for 60 minutes with 5 minutes of tolerance, this time may not be sufficient for a complete line flow. Thus, a system for automating the conveyance at the line should be designed to eliminate the risk of delay at the line caused by conveyance.

8 CONCLUSION

This study shows that an unbalanced assembly line may generate significant capacity loss in a cumulative pattern, which requires a continuous waste elimination and balancing approach in production. With conventional methods it is very difficult to handle such a task at an assembly line with the number of operations reaching a few hundreds and frequently changing product properties. From this perspective ProBalance® is a very useful tool that can organize and accelerate the process of continuous control and manipulation of an assembly line. Although it requires a lot of time, attention and effort to integrate it to a running assembly system of high complexity, it saves much more than what is invested in the following optimization activities.

The generated results throughout this study suggest that, with the desired single line structure of 22 stations and 65 minutes of takt time, in order to achieve maximum gain over the current system in terms of reduced operational costs and resource utilization, the new pre-assembly line should be organized such that,

- *operations that are concluded to be inappropriate for the pre-assembly line and re-addressed to the sub-assembly stations should be removed from the pre-assembly line,*
- *the line should be balanced for the minimum number of required operators at stations and on-demand work force should be provided by joker operators,*
- *sub-assembly stations should be relocated in order to meet the requirements of the new line layout,*
- *factory logistics should be informed about supplying the required parts in the desired sequence.*

Concurrent application of these changes at the existing pre-assembly line will result in,

- *a single line of 22 stations and 65 minutes of takt time,*
- *40% reduction in working process inventory costs,*
- *29% reduction in total operation time of produced vehicles,*
- *17% reduction in number of pre-assembly station operators,*
- *80% reduction in total idle time at stations,*
- *90% reduction in total takt overdue,*
- *about 20% reduction in the distance between sub-assembly and main assembly stations,*
- *20% improvement in labor productivity,*
- *improved learning time for operators at the line due to reduced takt time which leads to improved assembly quality.*

In addition, with the new structure of the pre-assembly line, all segments of the bus production line will acquire a uniform structure, which provides the groundwork of a possible integration of these segments in the future.

9 REFERENCES

9.1 Written sources

[1] Adams, W.M. (2006). *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*. Report of the IUCN Renowned Thinkers Meeting, 29–31 January, 2006. Retrieved on: 2009-02-16

[2] Askin, R. G., Goldberg, J. B. (2002) *Design and Analysis of Lean Production Systems*. John Wiley & Sons, Inc., New York, ISBN 0-471-11593-2

[3] Baudin, M. (2002) *Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow*. Productivity Press, New York, ISBN 1-56327-263-6

[4] Boothroyd, G., Dewhurst, P., Knight, W. (1994) *Product Design for Manufacture and Assembly*. Marcel Dekker, Inc., New York, ISBN 0-8247-9176-2

[5] Bunting, S. (2005) *The Interviewer's Handbook: Successful Interviewing Techniques for the Workplace*. Kogan Page Limited, London, ISBN 9780749442934

[6] Cleveland, G., Schroeder, R.G., Anderson, J.C. (1989) *A Theory of Production Competence*. Decision Sciences 20 (4), 655–668.

[7] Dresner, S. (2002) *The principles of Sustainability*. Earthscan Publications Limited, London, ISBN: 978-1-84407-706-9

[8] Glassey, W. C. (1966) *The Theory and Practice of Time Study*. Cox & Wyman Limited, London

[9] IVF Industrial Research and Development Corporation (2004) *Lean Production Presentation as part of the MG2205 Operations Management Course*, Royal Institute of Technology, Stockholm

[10] Kolisch, R. (2001) *Make-to-Order Assembly Management*. Springer- Verlag, Berlin, ISBN 3-540-41098-8

[11] Lung, Y., Chanaron, J. J., Fujimoto, T., Raff, D. (1999) *Coping with Variety: Flexible Poductive Systems for Product Variety in the Auto Industry*. Ashgate Publishing Company, Vermont, ISBN 0-7546-1115-9

[12] McGilvray, D. (2008) *Executing Data Quality Projects: Ten Steps to Quality Data and Trusted Information*. Morgan Kaufmann Publishers, San Francisco, ISBN 0-1237-4369-9

[13] Muther, R., Wheeler, J. D. (1994) *Simplified Systematic Layout Planning*. 3rd Edition, Management and Industrial Research Publications, Georgia, ISBN 0-9336-8409-6

[14] Occupational Safety and Health Organization (2002) *Materials Handling and Storing*. U.S. Department of Labor, 2236, Washington

[15] Ortiz, C. A. (2006) *Kaizen Assembly: Designing, Constructing and Managing a Lean Assembly Line*. Taylor and Francis Group, Boca Raton, ISBN 0-8493-7187-2

[16] Porritt, J. (2006). *Capitalism as if the world mattered*. Earthscan Publications Limited, London, ISBN 9781844071937

[17] Render, B., Heizer, J. (1997) *Principles of Operations Management with Tutorials*. 2nd Edition. Prentice-Hall, Inc., New Jersey, ISBN 0-13-840430-5

[18] Sawik, T. (1999) *Production Planning and Scheduling in Flexible Assembly Systems*. Springer-Verlag, Berlin, ISBN 3-540-64998-0

[19] Scholl, A. (1999) *Balancing and Sequencing of Assembly Lines*. 2nd Edition, Physica-Verlag, Heidelberg, ISBN 3-7908-1180-7

[20] Schroeder, R. G. (2007) *Operations Management: Contemporary Concepts and Cases*. 3rd Edition, Mc Graw Hill/Irwin, Singapore, ISBN 007-125436-6

[21] Slack, N., Chambers, S., Jonhston, R. (2007) *Operations Management*. 5th Edition, Pearson Education Limited, Essex, ISBN 978-0-273-70847-6

[22] Sule, D. R. (1994) *Manufacturing Facilities: Location, Planning and Design*. PWS Publishing Company, Boston, ISBN 0-5349-3435-8

[23] Suri, R. (1998) *Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times*. Productivity Press, Portland, ISBN 1-56327-201-6

[24] Wagner, B., Enzler, S. (2006) *Material Flow Management: Improving Cost Efficiency and Environmental Performance*. Physica-Verlag, Heidelberg, ISBN 3-7908-1591-8

[25] Womack, J. P., Jones, D. T. (2003) *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon & Schuster UK Ltd, London, ISBN 0-7432-3164-3

9.2 Interviews

Abdulkadir İçin, *Operator Team Leader, Pre-assembly Stations 12-13*, MAN Türkiye A.Ş.

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