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Value stream mapping and simulation for lean manufacturing: A case study in furniture industry

Yalın üretim için değer akış haritalandırma ve simülasyon: Mobilya sektöründe bir uygulama

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Abstract

Lean principles have been followed by many organizations in recent years due to the increase of tough competition in the market. These principles focus on improving the efficiency of operations by eliminating and reducing wastes. Different techniques and methods have been applied in order to become lean. One of them is the Value Stream Mapping (VSM) which can be easily applied in a variety of industries. However, VSM is a static tool which only shows the current state of the organization. To deal with this shortcoming, simulation is widely used as a complimentary technique in which the assessment of the impact of proposed improvements can be easily analyzed. This paper presents an industrial case example combining VSM and simulation in furniture industry in which there are a lot of wastes to deal with. Both current and future state maps for a particular product family are described by VSM following the suggestions for improvement. A simulation model is also developed to show the "before" and "after" scenarios in detail.

Keywords: Value stream mapping, Simulation, Furniture industry, Lean manufacturing

Öz

Pazarda yoğun rekabetin artması sonucu, yalın prensipler birçok işletme tarafından takip edilmektedir. Bu prensipler, israfları azaltarak ve yok ederek operasyonların etkinliğini artırmaya odaklanmaktadır. Yalın olabilmek için ise birçok değişik teknik ve yöntem uygulanmaktadır. Bu tekniklerden biri de kolaylıkla farklı sektörlere uygulanabilen Değer Akış Haritalandırmadır (DAH). Fakat, DAH sadece bir organizasyonun mevcut durumunu gösteren statik bir araçtır. Bu eksikliği giderebilmek adına, önerilen iyileştirmelerin değerlendirilmesini kolayca yapabilen simülasyon yardımcı teknik olarak yaygın olarak kullanılmaktadır. Bu çalışma, israfın çok olduğu mobilya sektörüne yönelik DAH ve simülasyonu birleştiren bir endüstriyel uygulama örneği sunmaktadır. Belirlenen bir ürün ailesine yönelik iyileştirme önerileri ile birlikte mevcut ve gelecek durum haritaları DAH kullanılarak açıklanmıştır. Bir simülasyon modeli oluşturularak "önce" ve "sonra" senaryoları detaylı olarak analiz edilmiştir.

Anahtar kelimeler: Değer akış haritalandırma, Simülasyon, Mobilya sektörü, Yalın üretim

1 Introduction

Increasing costs and competition in the global market has forced organizations become lean in recent years. Lean production (also called lean manufacturing, or lean thinking) [1] focuses on wastes which are called non-value added activities. It is originated in Toyota Motor Corporation and considered to be an alternative to the traditional method of mass production [2]. The reader can refer to Fujimoto [3], Hines et al. [4], Holweg [2] for comprehensive reviews on lean production. The objective is to eliminate wastes which increases costs. Wastes can be found at any time and in any place. It may be found hidden in policies, procedures, processes, product designs and operations. Waste consumes resources but does not add any value to the product [5].

In order to reduce waste, lean production uses many different tools such as one-piece flow, visual management, cellular manufacturing, inventory management, Poka yoke, standardized work, 5S and Value Stream Mapping (VSM). Among these, VSM has attracted the attention of the researchers in recent years. VSM has been proposed by Rother and Shook [6] and defined as an enterprise improvement technique to visualize an entire production process, representing information and material flow, to improve the production process by identifying waste and its resources [6]. The first step in VSM is to identify the product families and select one of them as the target for improvement. Based on the information, a current state map is developed. To map the future state is the third step. Lastly, an implementation plan is created to apply in the future. The literature focusing on VSM is quite rich. Although most of the literature focuses on applications of VSM in automotive industry [5],[7]-[9], there are also applications of VSM in different areas such as wood industry [10], aircraft manufacturing [11], process industry [12], knowledge work [13], healthcare systems [14],[15], supply chain management [16]-[18] hotel industry [19], electronics assembly systems [20], material handling [21]; product development process [22]. Different from conventional VSM, sustainable VSM has been proposed that incorporates metrics for sustainability in Brown et al. [23]. The reader can refer to Sundar et al. [24] and Singh et al. [25] for a literature review on VSM. Table 1 summarizes some of the applications of VSM in different areas.

However, VSM is a static tool which only shows the current value stream of one product. Based on the current state, some suggestions for improvement can be proposed but benefits of these suggestions cannot be analyzed in a future state map.

For example, inventory levels, utilization of machines and operators cannot be predicted for future. In this case, a complementary technique with VSM is needed to analyze these benefits. An obvious technique is simulation, which is capable of generating resource requirements and performance statistics [12]. Standridge and Marvel [31] has also answered the question of "Why lean needs simulation" by giving industry-based case examples. Using simulation, different future state maps can be analyzed which help management to compare expected performances of different maps and give them a chance to decide. In this case, VSM provides the vision, simulation evaluates this vision. Therefore, to overcome the weakness of VSM, the integration of VSM and simulation has become popular in literature in recent years. One of the first studies in this group belongs to Disney et al. [25] in which a simulation model is used with VSM to improve the performance of British Telecommunications PLC. McDonald et al. [7] have utilized VSM in a manufacturing plant to solve problems. The future state map is then simulated in order to see the benefits gained. A novel approach consisting of VSM, rough set theory and simulation has been proposed in Huang and Liu [26] for a factory of Taiwan-funded enterprise in Mainland China. Another application of various lean manufacturing tools with simulation has been shown in Abdulmalek and Rajgopal [12] for continuous/process sector. VSM is the main tool in this study and used to identify the opportunities for various lean techniques such as cellular manufacturing, setup reduction, 5S, just-in-time, production leveling, total productive maintenance and visual systems. Moreover, a simulation model is developed to compare the current and future states. Lian and Van Landeghem [27] have presented an application of VSM-based simulation generator and illustrate through an example in a manufacturer of poultry and pig raising equipment. Al-Aomar [28] has described a simulation-based approach for developing a lean production system for three lean measures such as productivity, cycle time and work-in-process inventory. The approach utilizes Simulated Annealing, Simulation and VSM to optimize the production process. Another novel approach consisting of lean approaches and simulation has been proposed in Robinson et al. [15] in improving healthcare systems. For dealing with the energy assessment of manufacturing systems, Baysan et al. [30] have proposed a discrete event simulation based methodology. The authors define indirect and direct energy, an energy requirement calculation procedure and an energy reduction and performance improvement cycle. Another interesting application combining simulation and VSM [32] has been developed at Ericsson AB in Sweden for two different telecommunication products. Yang et al. [33] propose a lean production system design for a fishing net manufacturing system which is optimized by simulation.

Having motivated by the results of integrating VSM and simulation in production and service systems, we deal with the problem of a manufacturing plant producing furniture. The literature review (see Table 1) has stated that there is only one paper [34] focusing on eliminating wastes of a furniture plant via VSM. The authors have proposed some improvement suggestions for five production lines based on a current state map and constructed a future state map. However, the future state map has not been analyzed in detail. The main contribution of our study is to present an industrial case example by combining VSM and simulation in furniture industry. Similar to Bulut and Altunay [34], the current and future state maps of the production system have been constructed via VSM. Moreover, detailed experiments have been carried out using simulation to analyze the current state and assess the impact of the improvement suggestions in the future state. Up to our knowledge, this study is the first one in which these two techniques are used together in this industry.

The rest of the paper is organized as follows. First, current state map is drawn to identify sources of wastes with a simulation model showing the current state in detail. A future state map is then developed with recommendations for improvement. To analyze the benefits gained in the future state map, the simulation model is modified and findings of this study are presented in the last section.

Table 1: Applications of VSM.

Reference	Application area	Method
Seth and Gupta [5]	Automotive industry	VSM
Rother and Shook [6]	Manufacturing	VSM
McDonald et al.[7]	Automotive industry	VSM+Simulation
Rahani and Al-Ashraf [8]	Automotive industry	VSM
Belokar et al. [9]	Automotive industry	VSM
Shingo [10]	Wood industry	VSM
Halpin and Kueckmann [11]	Aircraft manufacturing	VSM
Abdulmalek and Rajgopal [12]	Manufacturing	VSM+Simulation
Staats et al. [13]	Knowledge work	VSM
Teichgräber and de Bucourt [14]	Healthcare systems	VSM
Robinson et al. [15]	Healthcare	VSM+Simulation
Villarreal et al. [16] Chen et al. [17] Rohac and Januska [18]	Supply chain management	VSM
Vlachos and Bogdanovic [19]	Hotel industry	VSM
Chong et al. [20]	Electronics assembly systems	VSM
Acharya [21]	Material handling	VSM
Tyagi et al. [22]	Product development process	VSM
Brown et al. [24]	Manufacturing	Sustainable VSM
Sundara et al. [24]	Manufacturing	VSM+Simulation
Disney et al. [26]	Telecommunication	VSM+Simulation
Huang and Liu [27]	Manufacturing	VSM+Simulation
Lian and Van Landeghem [28]	Poultry and pig rising equipment	VSM+Simulation
Al-Aomar [29]	Manufacturing	VSM+Simulation+ Simulated Annealing
Baysan et al. [30]	Manufacturing	VSM+Simulation
Bin Ali et al. [32]	Telecommunication	VSM+Simulation
Yang et al. [33]	Fishing net manufacturing	VSM+Simulation
Bulut and Altunay [34]	Furniture industry	VSM

2 Description of the case study

X is an organization founded in 1974 in Denizli which produces different kinds of furniture. It is one of the leading suppliers of furniture retailers in the world and biggest producer of massive products in Turkey. The total number of products is 197 most of which are oak massive. The annual capacity of the company is 70000 furniture with a 500 container of volume of export annually.

In this paper, we focus on the product mirror which is the most demanded item. The illustration of the product is shown in Figure 1. The product consists of four side parts (i.e. left, right, upper, base parts), a mirror and backboard. The weekly demand for this product is 100 units and the factory operates

5 days in a week. Therefore, it can be stated that the daily demand is 20 units.

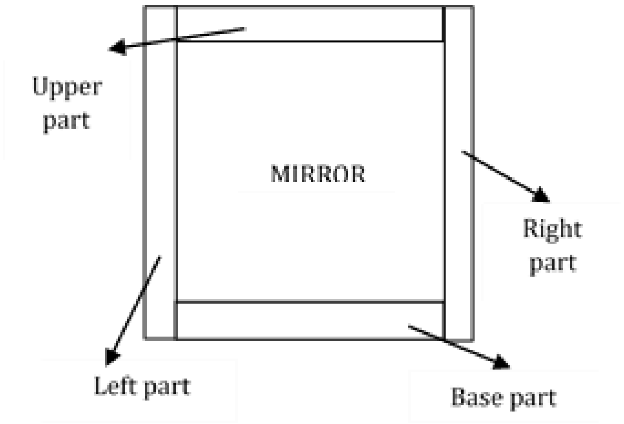

Figure 1: The illustration of the product considered in this study.

The raw materials of the side parts are ordered from the United States and the raw material of backboard comes from Malaysia by sea. Due to inventory levels and dynamic customer demands, the order time for raw materials should be minimum three months before the production. The supplier of the mirror is located in Denizli but the order time for mirrors is also approximately one month before starting production. So, in order to start the production of a final product, the company should place the order three months prior to production.

2.1 The current state map

After selecting the product, the next step is to understand the product flow and collect the necessary data for drawing the current state map. The production flow of this product can be seen in Figure 2. The production planning department sends production plan and daily follow-up forms to all departments weekly. These follow-up forms, having information about the operation sequence and the number of parts, move with the product together starting from the first department to the last one and help preventing the uncertainties in the production.

The production of this product starts from the Multi Slicing (MS) machine where the raw material is cut into four different side parts such as left part, right part, base part and upper part as shown in Figure 1. Then, these four parts go through the Longitude (L) machine where their lengths are adjusted according to customer requirements. The third operation is the Massive Weighing (MW) where the parts' surface roughness are removed. After MW, the left and right parts go to the Female Pin (FP) where the base and upper parts go to the Male Pin (MP). In these machines, necessary holes are opened in the parts in order to form the frame of the product. After FP and MP, these four parts are joined together in the Frame Press (FPR) where the frame of the product is formed. At the same time, the backboard of the product is produced in the Plate Cutting (PC) machine. Then the frame and backboard are transferred to the CNC machine, Critical Rubbing (CR) and Dying (D) departments, consecutively. In the assembly department (A), the frame, backboard and mirror are assembled to form the final product which is then sent to the quality control and repair (QC-R) departments. In this department, the defected products are repaired and controlled again. The products without defects are packed in the packaging (P) department and become ready for shipping.

In order to draw the current map, all necessary data are collected according to Rother and Shook [6]. While collecting the data, inventory levels before each process, process cycle times and changeover times are recorded. Table 2 summarizes the data and Appendix 1 shows the current state map based on these data collected. Each process is represented by a small box and the number inside the box shows the number of workers at each process. Data box under each process shows the cycle time (CT), changeover time (CO) and available working time (WT) in a day.

Table 2: Current data.

	MS	L	MW	FP	MP	FPR	PC
CT (sec)	40	40	30	60	120	60	12
CO (min)	0	0	0	1	1	0	1
WT (sec)				50400			

	CNC	CR	D	A	QC-R	P
CT (sec)	210/30	75/18	120	300	250	240
CO (min)	5	0	10	0	0	0
WT (sec)			50400			

The timeline in the current map shows two components. The first one is the total flow time (in days), which is 40.8 days. The second one is the processing time, namely the value-added time, which is about 0.0172 days. The reason of this huge difference between total flow and process time is that the parts have to wait for a long time between machines in the departments. The factory does not transfer the processed parts from one machine to the next until all parts are finished. This waste, which is about 99.93% of the total time, should be eliminated in order to improve the total flow time. The total value added time is 0.07% of the total time which is time needed for other processes. It should be noted that assembly, quality control and packaging departments are linked together with a conveyor belt and the products are transferred among these departments through this system constantly. Therefore, no waiting occurs among these departments.

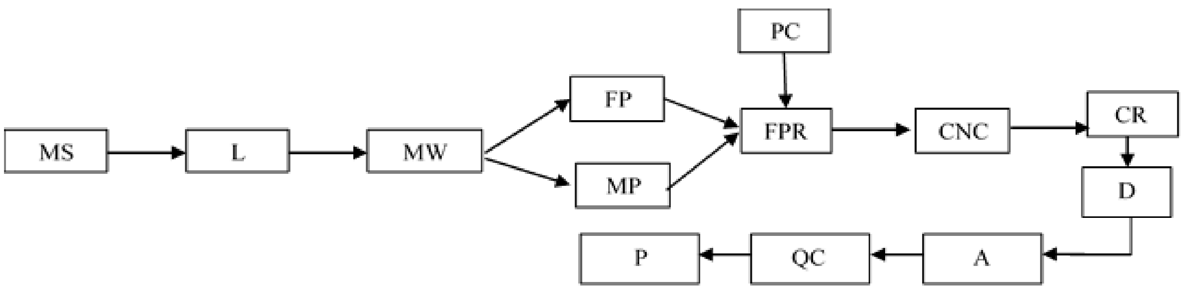

Figure 2: The production flow of the considered product.

After analyzing the current map, a simulation model of the system has been developed in Arena 14.0. The results of the simulation run have been verified and validated by the managers in the company comparing the actual production throughput. The warm-up period has been determined as the time needed to produce 10 products and defined in simulation runs. After verification and validation phases, the simulation has run for 100 final products and repeated 10 times (i.e. 10 replications). The detailed results are given in Table 3.

Table 3: The summary of the entities in the current state.

Entity (Part)	Value added time (second)	Waiting time in the system (second)	Transfer time (second)
Base part	230	69130	415
Upper part	230	69130	415
Left part	170	56950	415
Right part	170	56950	415
Backboard	180	17820	575
Frame (parts are joined)	447	68273	408
Final product (frame, backboard and mirror are joined)	790	33176	0

From Table 3, it can be seen that the waiting times, which are non-value added times, are very high. These high waiting times give us clues for where to make improvements. Therefore, we can state that multi slicing (MS) and frame press (FP) are the one of the critical processes in the production line.

Table 4 shows the utilization rates of the resources in the production line. Based on the results, the highly utilized resource is the male pin with the rate of 19% and the least utilized resource is the plane cutting with the rate of 1%. This low utilization rate also explains the high waiting times of the frames. Looking at the current state map for X, the most important problem is the difference between the total flow time (40.8 days) and the value-added time (0.0172 days) which is under 5% of the total. This should be improved in the future state map.

Table 4. The utilization rate of the resources (machines) in the current state.

Resource (Machine)	Utilization Rate (%)	Resource (Machine)	Utilization Rate (%)
Multi Slicing	12	CNC	18
Longitude	12	Critical Rubbing	7
Weining	9	Dying	18
Female Pin	9	Assembly	7
Male Pin	19	Quality Control and Repair	6
Frame Press	4	Packaging	6

2.2 The future state map

Based on the current state map, the value and non-value added activities are determined. As explained before, the most important waste in the current state map is the time elapsed between machines and departments. To eliminate these wastes, lean principles and tools have been suggested for constructing the future state map. The following steps have been followed in order to draw the future state map.

- To calculate the takt time,
- To utilize continuous flow where possible,
- To use supermarkets where continuous flow is impossible,
- To build FIFO line where there are varieties of products.

2.2.1 To calculate the takt time

Takt time is an important reference point in manufacturing. It refers to the rate at which customers are buying products from the production line (Abdulmalek and Rajgopal, 2007). In order to satisfy customer requirements, the unit production rate should match the demand rate. Takt time is calculated by dividing the total available time per day by the daily customer demand. The daily customer demand for the final product is 20 units and factory operates 14 hours per day which translates to 50400 seconds, so that the takt time is approximately (50400/20)=2520 seconds. This means that the company needs to produce one final product in 2520 seconds in order to satisfy the customer demand. In our case, since the order size of the final product is small (i.e.100 units), it is not possible to exceed the takt time with the current processing times. Therefore, we do not propose any improvement changes in the changeover times or processing times.

2.2.2 To utilize the continuous flow where possible

After calculating the takt time, it is necessary to utilize the continuous flow where possible. The continuous flow can be described as producing one at a time and transferring it to the next station immediately. This is the most effective way of the production that will help us to eliminate the wastes in the production. The continuous flow is shown with a process box. Based on the insights from the current state map and our observations, we think that it is possible to build the continuous flow among multi slicing, longitude and massive weighing departments and also another continuous flow among assembly, quality control- repair and packaging departments (see Appendix 2). As stated in the current state map, the waiting times between these departments are very high. For example, parts have to wait for 5.1 days in order to be transferred from MS department to the next one. Forming a continuous flow among these departments eliminates the waste of 10.2 days.

2.2.3 To use supermarkets where continuous flow is impossible

Building supermarkets where continuous flow is impossible, is important in eliminating unnecessary inventory and waiting. The continuous flow can be impossible in the following situations.

- Some processes might be designed to work in very slow or very fast cycle times,
- Some processes might be far away from the production site, i.e. in supplier's site and it is not realistic to produce one at a time,
- Some processes might be too long to link to the other processes directly or they might not be reliable.

In these cases, supermarket based pull system can be formed in the production system. In our case, continuous flow cannot be constructed between PC and CNC departments and also between CR and D departments. Therefore, we think of utilizing two supermarkets at these departments (see Appendix 2).

- The first supermarket is constructed before the CNC department in order to eliminate unnecessary waiting times defined in the current state map. The CNC machine can process 5 units at the same time. When the machine has been set up and started production, five units are transferred to the other department. Therefore, a supermarket with a capacity of 10 units, is constructed. When 10 parts are withdrawn from the supermarket for production, other departments prior to supermarket have started producing for filling the supermarket. Thus, unnecessary waiting times are eliminated,
- The second one is built between CR and D departments. The capacity of the oven is 10 units therefore we think of using withdrawal and production kanbans here. As long as the oven empties, parts are withdrawn from supermarkets in order to sustain the production.

2.2.4 To build FIFO line where there are varieties of products

To manage material and information flow, FIFO lines are built where there are varieties of products. From this point of view, a FIFO line is constructed after D department. 5 units of frame and backboard come to D department. After being processed at this department, they are transferred to the oven and then a total of 10 units are transferred to A department. At the A department, these parts are joined together with mirrors in order to form the last product. However, the duration of the assembly operation is too long therefore, some space is needed to collect the parts which come from D department. Therefore, we think of building a FIFO line here to provide the parts coming from D department to transfer A department based on first-in-first our rule. The maximum number of units that can wait in the line is also limited to 10 units. Doing this gives us a 4.6 day improvement.

Looking at the future state map given in Appendix 2, it can be seen that the total flow time decreases to 16.8 days which means that we have 41% improvement. After drawing the future state map, the simulation model is also modified to capture the proposed improvement suggestions. Based on the results, the simulation model has run again for producing 100 products and the detailed results are given in Table 5.

The improvement suggestions help to decrease the waiting and transfer times since the times in Table 5 are smaller than the waiting times given in Table 3. On the other hand, the utilization rates of the resources have also increased (see Table 5).

The detailed comparison between current and future states is presented in Table 7. The suggestions improve the non-value added time and help to decrease to 16.8 days. Since we combine and form continuous flow among the departments Multi Slicing, Longitude and Weining, the non-value added time among these departments is eliminated. Building supermarkets before CNC machine decreases the waiting time in front of this machine. Forming another continuous flow among assembly, quality-control and repair and packaging helps to gain 90% improvement in the wasted time. With the FIFO line, we gain a reduction of 4.6 days in the non-value added time before the dying process.

Table 5: The summary of the entities in the future state.

Entity (Part)	Value added time (second)	Waiting time in the system (second)	Transfer time (second)
Base part	230	32520	345
Upper part	230	32520	345
Left part	170	12180	345
Right part	170	12180	345
Backboard	180	19756	515
Frame (parts are joined)	455	68329	416
Final product (frame, backboard and mirror are joined)	790	12886	0

Table 6: The utilization rate of the resources (machines) in the future state.

Resource (Machine)	Utilization Rate (%)	Resource (Machine)	Utilization Rate (%)
Multi Slicing	19	CNC	29
Longitude	19	Critical Rubbing	11
Weining	14	Dying	29
Female Pin	14	Assembly	12
Male Pin	29	Quality Control and Repair	10
Frame Press	7	Packaging	9

Next, we conducted the Wilcoxon signed-rank test in SPSS 16.0 at the 0.05 significance level to check whether the differences observed between the current and future state maps are statistically significant in terms of total flow time. p-value of two-sided Wilcoxon signed-rank test has been found as 0.002 which shows that there is a statistically significant improvement. In terms of total waiting time, observed difference between the current and future states is found to be statistically significant. It might be stated that using lean principles have caused a significant improvement in total waiting time of this production system.

3 Conclusion

Due to the increase in the competitive pressures, many manufacturing firms have become lean by using various techniques and tools. The most widely used is the VSM which pictures the current state of an organization. With the picture presented, organization can identify the value and non-value added activities and try to eliminate wastes.

In this paper, we focus on the VSM of a furniture plant which is one of the leading suppliers in its industry. The main contribution of the paper is that it presents an industrial case in which there are a lot of wastes to deal with. First, the current state of the company is given and a simulation model is developed to analyze the production system in detail.

Then, based on the results of simulation and current state map, a future state map is constructed with improvement suggestions. The simulation model is modified and improvement suggestions are implemented to see the effects. With the suggested recommendations, the total flow time has been improved and non-value-added time has been decreased.

Table 7. Comparison between current and future states (based on 10 replications)

	Multi Slicing	Longitude (day)	Weining (day)	Female and Male Pin (day)	Frame Press (day)	Plate Cutting	CNC (day)
Current	-	5.1	5.1	5.1	5.1	-	5.1
Future	-	-	-	5.1	5.1	-	0.5
Improvement (%)	-	100	100	-	-	-	90

	Critical Rubbing (day)	Dying (day)	Assembly (day)	Quality Control-Repair	Packaging	Total Flow Time (day)	Total cycle time (sec)
Current	5.1	5.1	5.1	-	-	40.8	1485
Future	5.1	0.5	0.5	-	-	16.8	1485
Improvement (%)	-	90	90	-	-	41	-

This manufacturing case study has shown that simulation is a useful technique when used with VSM. Since VSM is a static tool, it only shows the current state and based on the current state further recommendations can be made. However, with simulation different scenarios can be tested and the results can be obtained easily.

Further application of this study might be analyzing other products or production lines in the factory using VSM and simulation. This might also help to improve the overall efficiency of the production system.

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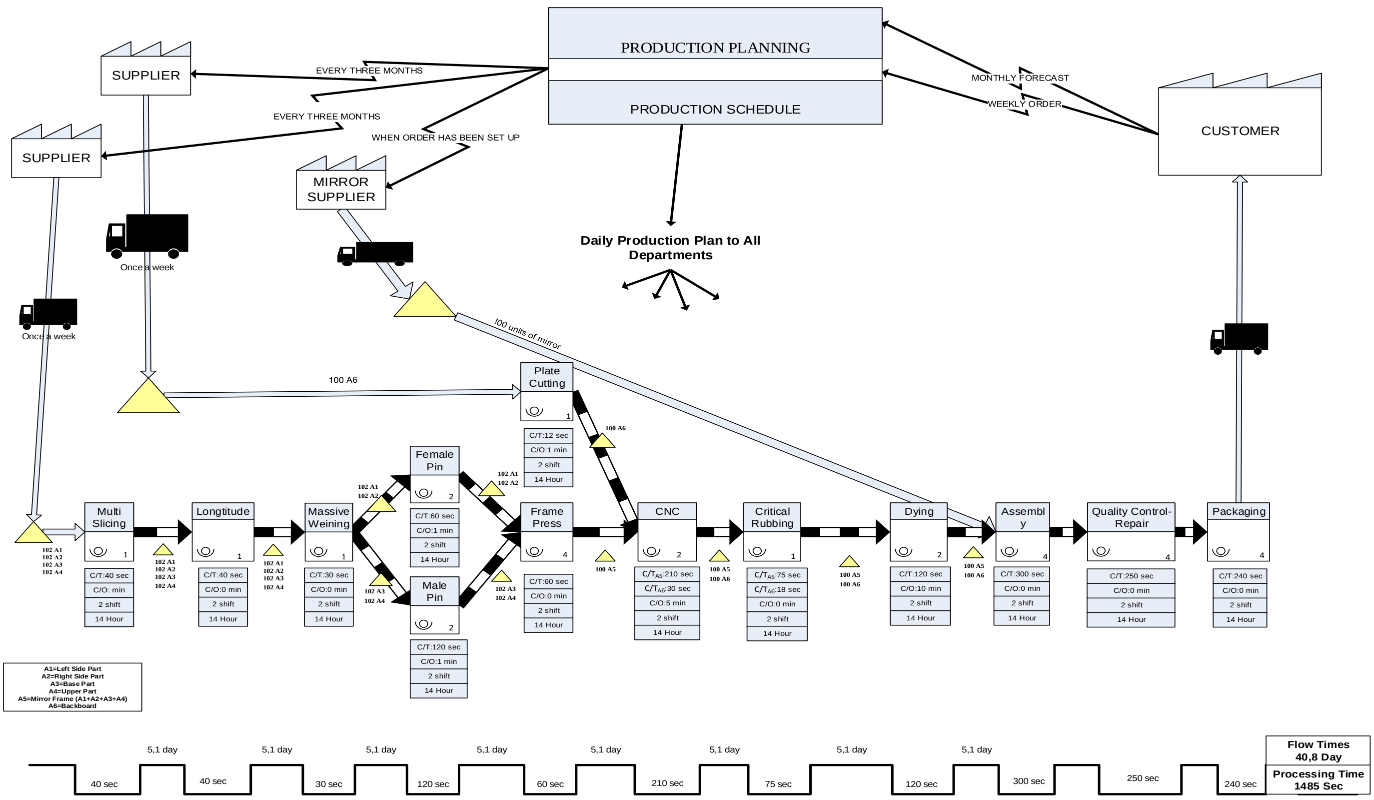
Appendix A. The current state map



Appendix B. The future state map