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RESEARH ARTICLE

IMPROVING AN INEFFICIENT PRODUCTION LINE VIA AHP AND VALUE STREAM MAPPING

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ABSTRACT

Nowadays competition among companies is rapidly increasing with the progress of technology. In order to stand out in this competition environment, companies need to be renovated in their own fields. Many companies use lean manufacturing techniques to achieve this renewal.

This study was performed in a company operating in the automotive industry. In this study, the production line which will be improved is determined by using the Analytical Hierarchy Process method. Next, Value Stream Mapping has been applied to the determined product line. We revealed the current situation of the production line by drawing current state mapping. Second, the future state mapping is drawn up to solve the problems presented in the current state mapping, and an action plan was presented for improvements.

Keywords: *Analytic Hierarchy Process, Lean Manufacturing, Value Stream Mapping*

VERİMSİZ BİR ÜRETİM HATTININ AHP VE DEĞER AKIŞ HARİTALAMA İLE İYİLEŞTİRİLMESİ

ÖZ

Günümüzde şirketler arası rekabet teknolojinin ilerlemesiyle birlikte hızla artmaktadır. Bu rekabet ortamında pazarda öne çıkabilmek için şirketler kendi bünyesinde yenilenmeye ihtiyaç duymaktadır. Bu yenilenmeyi sağlayabilmek için birçok şirket yalın üretim tekniklerini kullanmaktadır.

Bu çalışma otomotiv sektöründe faaliyet gösteren bir firmada uygulanmıştır. Bu çalışmada, geliştirilecek üretim hattı Analitik Hiyerarşi Prosesi metodu kullanılarak belirlenmiştir. Sonrasında belirlenen hatta değer akışı haritalaması uygulanmıştır. İlk önce üretim hattının mevcut durumu mevcut durum haritası ile ortaya konmuştur. İkinci olarak mevcut durum değer akışında görülen problemlerin iyileştirilmesi için önerilen gelecek durum haritası çizilmiştir ve iyileştirmeler için aksiyon planı sunulmuştur.

Anahtar Kelimeler: *Analitik Hiyerarşi Yöntemi, Yalın Üretim, Değer Akışı Haritalama*

1. INTRODUCTION

In today's world, the price of the product is determined by the market. Therefore, companies can not increase the price of the product sold in order to make more profit. Firms choose to reduce the cost of the product instead of increasing the price in order to make more profit without losing its competitive power. To reduce the costs, improvements have to be made during the production phase. With this approach which employs lean production philosophy, many companies have increased their competitiveness levels.

Value is the critical starting point for lean philosophy and can only be identified by the end customer. The customer is now willing to pay for any operation that does not create a surplus value on the product he/she buys. These processes are defined as operations. To make the value concept meaningful, customer demands must be expressed in a product type that meets at a certain time and at a certain price [1].

Lean thinking is based on the removal of waste and refuse. It primarily begins with the Value Stream Mapping (VSM) method for detecting waste and refuse. By analyzing the current state with the VSM method, it is possible to determine the steps that are value added and non-value added in value stream.

In this study, we adopt the AHP (Analytical Hierarchy Process) methodology, one of the well-known multi criteria decision making methods to determine the product line for the VSM. Then, we apply the VSM method to the determined production line. The outline of this paper is as follows: In the second section, we present the related work on this topic. The third section deals with the VSM method used in the study and the fourth section presents the basics of the AHP methodology. In the fifth section, we discuss the details of our application. Finally, in the sixth section, we present the results and suggestions about our study.

2. LITERATURE REVIEW

In our literature review, we focus on a number of studies which incorporate VSM methodology in both the production and service sectors.

The first study on VSM was conducted by Rother and Shook in 1999. In the book "Learning to See" [2], Rother and Shook described the VSM in detail and provided a number of examples. In [3], Efe and Engin used the VSM method in the Numune Training and Research Hospital Emergency Service. They reduced the supply period obtained from the current state map from 132.5 minutes to 84 minutes. That is, they have achieved an improvement of 36.6%. In their study, it was observed that the VSM method provided significant improvements in the service sector.

In their study, Abdulmalek and Rajgopal [4] used the VSM method in a steel manufacturing company to identify opportunities for a variety of lean techniques. At the same time, they defined a simulation model to compare before and after performances. Seth and Gupta in [5] used VSM methodology to improve the supplier productivity of an automotive industry in their study. The current and future states of the supplier are discussed using the value stream concepts. In the study, per capita production volume was increased, and process time, flow time and finished product stock were reduced [5].

In [6], the authors used VSM methodology in a company that produces tractors. After the current state map is drawn, the proposed state is presented in the future state map. The authors stated that, the application of the proposed improvements would change the 21 days long manufacturing lead time to 3.5 days, hence the total inventory turnover would increase by 6 times.

[7] Considered improving the performance of aircraft maintenance services by using VSM. Considering the fact that customers expect a short delivery time from aircraft maintenance services, the authors analyzed service processes related to maintenance work to minimize the delivery time. Doing so, they revealed wastes and bottlenecks in the system. Next, with the help of the VSM methodology, they showed an improvement in the efficiency of the maintenance service.

3. VALUE STREAM MAPPING METHOD

The value is anything that the customer accepts to pay for the product. So first we have to understand what the customer wants. In a production system, operations that the customer is not willing to pay should be eliminated or minimized.

A value stream represents the sum of value-added and non-value added activities and works. In the value stream, the entire flow is examined and intended to improve the whole processes, instead of improving them individually [2].

VSM visually shows the value stream of the product using special figures and computations. This makes it easier for decision makers to understand the value stream. In the VSM, all material and information flow from the raw material to finished product is drawn with special symbols to the value flow. The map of the future is designed from this map drawn later [2].

In VSM, wastes become clearly visible and the links between the information flow and the material flow is displayed clearly. All operations from door to door in the VSM are drawn for the production of a single product group using a paper and pencil [2].

There are four basic steps in VSM: (1) The product family is selected, (2) The current state is drawn, (3) The future state is drawn, and (4) The business plan is prepared and applied. When the improvements designed in the future are completed, this future status map becomes the current status map. This is the logic of continuous improvement. Then a map of the state will be drawn again and so on [2].

When the current state is analyzed in the VSM, three kinds of operations are encountered;

1. The actions that add value to the product,

2. The actions that do not add value to the product,

3. The obligatory actions that do not add value to the product,

The processes that do not add value to the product are wasted and they should be destroyed. The obligatory processes that do not add value to the product should be minimized.

The VSM uses standard symbols for both the current state drawing and the future state drawing. These standard symbols form a common language in production. The symbols used are three kinds: material flow symbols, general symbols and information flow symbols. All of these symbols are shown in Figure 1 below [2].

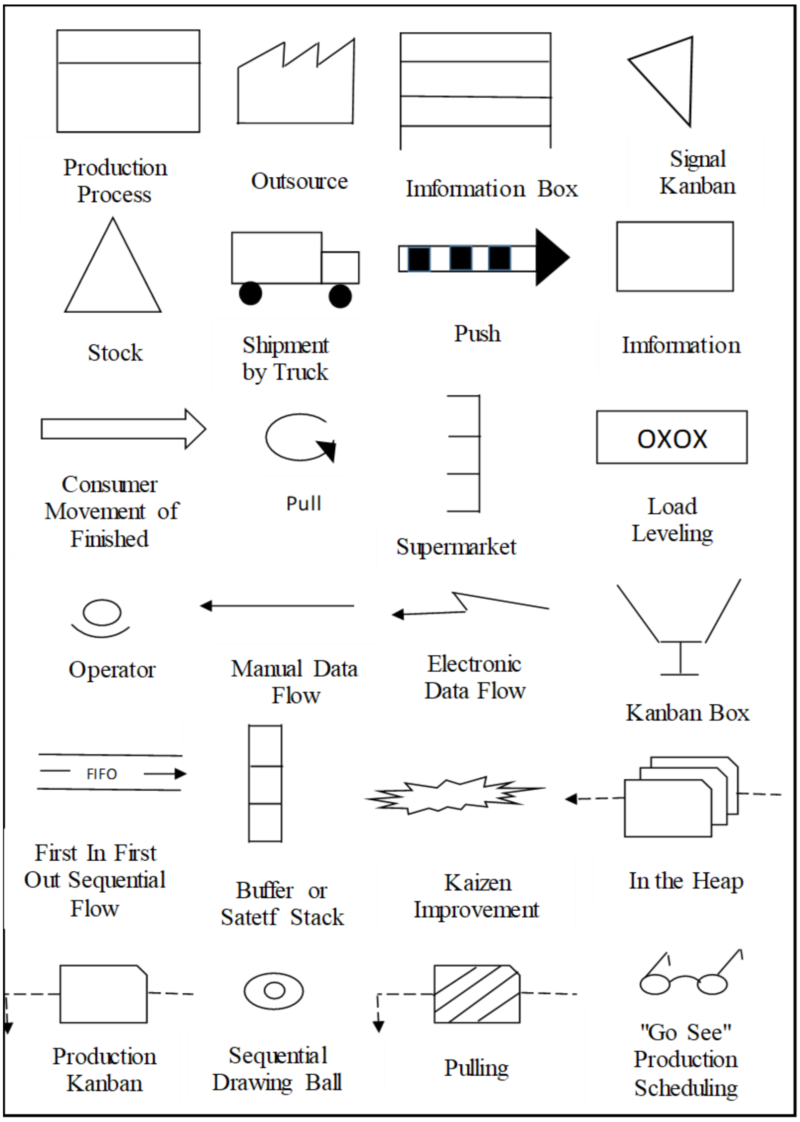

Figure 1. Symbols Used in Value Stream Mapping (from [2])

4. ANALYTIC HIERARCHY PROCESS

Decision making is very important in both daily and business lives. Making right decisions increases the competitive levels of companies. Decision theory provides guidance on the best alternative to take while aiming to maximize utility [8]. People can make their decisions by using their intuition or by taking advantage of their experience. In cases where multiple alternatives and assessment criteria exist, decision makers use Multi-Criteria Decision Making methods which aim to assist them by providing an analytic solution approach [9]. One of those methods is the Analytic Hierarchy Process (AHP), developed by Thomas L. SAATY in the 1970s with the intention of supporting decision makers during decision making [10].

The AHP is a method that allows a hierarchical model to include the objective, assessment criteria & sub criteria, and alternatives for the problem of interest. [11]. The AHP process decomposes the decision problem into a number of sub-problems, which are easier to evaluate and solve [12, 13]. There are 7 stages in the Analytic Hierarchy Process. These steps include creating hierarchical structure, determination of priorities, pairwise comparison matrix, creating priority vector, calculation of consistency ratio, determination of final sequence, and finally sensitivity analysis [10].

4.1. Creating Hierarchical Structure

First, the problem needs to be understood clearly. Then, the objectives (targets) and criteria should be determined by the experts [14]. Figure 2 shows a hierarchical structure consisting of targets, criteria and alternatives [15].

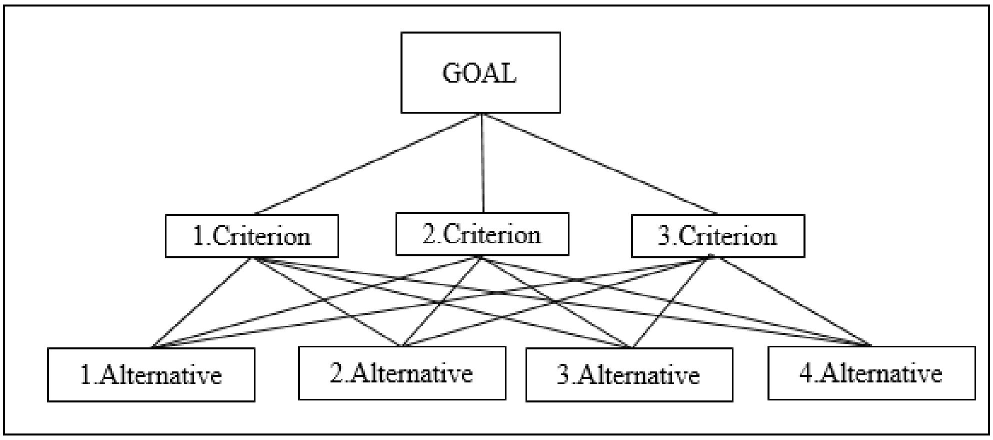

Figure 2. Example of a Decision Hierarchy (from [15])

4.2. Determination of Priorities

The elements forming the hierarchy are compared with each other and priorities are calculated relative to each other. In this comparison, "1-9 scale" is used to eliminate complexity in comments and minimize many errors [16]. Table 1 represents the "1-9 scale" [17].

4.3. Pairwise Comparison Matrix

The pairwise comparison matrix is the result of the decision maker's comparision of alternatives and criteria using the values in Table 1. This matrix is provided as a result of proportion of w_i to w_j which are weights or importance ratings according to the basic scale [18].

C_1, C_2, ..., C_n are the elements at any stage of the decision hierarchy. The A matrix is the nxn matrix of pairwise comparisons of C_i and C_j. a_{ij} are the values of pairwise comparison matrix (i, j = 1,2, ..., n). Thus the matrix A consisting of pairwise comparisons is as follows [19].

$$A=\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ . & . & \dots & . \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}_{nxn} \tag{1}$$

Table 1. Significance Ratings and Explanations Used in Pairwise Comparisons (from [17])

Importance Level	Definition	Explanation
1	Equally Important	Both parties have the same importance
3	Slightly Important	A factor according to experience and judgement is more important than the other.
5	Strongly Important	One factor is more important than the other
7	Very Strong Important	One factor is strongly preferred at a higher level than the other.
9	Absolutely Important	One of the factors is very important at a higher rate than the other.
2,4,6,8	Represents intermediate values	When compromise is needed
Mutual Values	i is assigned a value (x) as compared with j; when j is compared with i, the value to be assigned (1 / x) will be.	

4.4. Creating Priority Vectors

In this phase, the correlation matrices are first normalized to determine the priority or weight vectors. A normalized matrix is formed by dividing the value of each column by the sum of the respective columns. Subsequently, weights or priority vectors of the criteria, sub criteria and alternatives are obtained by taking the average of the row values of the normalized matrix [10]. This priority vector is defined as *w* column matrix.

4.5. Calculation of Consistency Ratio

The consistency of the decision is tested by the consistency rate determined at this stage. This rate is calculated as follows (for details, see [20]):

1. The pairwise comparison matrix *A* is multiplied by *w* matrix and the weighted sum matrix A_w is obtained,

2. The A_w matrix is divided into *w* matrices,

3. Calculate the maximum $\lambda_{\max}$ by taking the arithmetic mean of the values in the matrix obtained from the second step,

4. Consistency index is found in the following formula:

$$CI = \frac{max - n}{n - \mathbf{1}} \tag{2}$$

5. Finally, the consistency rate is calculated using the following formula,

$$CR = \frac{CI}{RI} \tag{3}$$

RI (Random Index) is found in Table 2 for various *n*'s [21].

Table 2. Random Index Values (from [21])

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41
n	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
RI	1.45	1.49	1.51	1.48	1.56	1.57	1.59	

It means that the binary comparison matrix is consistent when the consistency rate is smaller than 0.10.

4.6. Determination of the Final Sequence

The priorities extracted from the pairwise comparison matrices are aggregated. Thus, result weights are found for alternatives in the lowest level. Decision makers can see the best alternative by ranking the alternatives with the results found [10].

4.7. Sensitivity Analysis

After the order of the alternatives is determined, the result should be checked. At this stage, it is discussed how the order of the alternatives and the determined decision are sensitive to the changes in the interpretations [10].

5. APPLICATION

The application was performed in a company operating in the machine manufacturing sector. The company seeks to improve its competitive power among other competitors performing in the sector. Therefore, the company intends to determine the wastes on the production line and to eliminate (or minimize) them. The VSM methodology is used for this purpose.

The company has multiple production lines. For this reason, it is desirable to identify the production line that will be improved by VSM. At this point we applied the AHP method to determine the line. In order to apply the AHP method, all possible alternatives and assessment criteria for selecting the most suitable line have been determined by the field experts.

In particular, there are six production lines in the company as alternatives. These are MT (Magnettopf), FT (Fitting), CP (Connecting Pieces), AP (Ankerplatte), RA (Rail) and Aktorfuss (AF). To assess the performances of these lines, six assessment criteria have been determined as: the distance traveled in the layout, stock amount, scrap rate, rate of turnover, shipment performance and proximity to Takt. These criteria are described below:

1. Distance travelled in layout represents the total distance of the route from the raw material to the final product.
2. Stock amount represents the area covered by the stock amount seen in the company's ERP (Enterprise Resource Planning) system. The system is checked at certain times.
3. Scrap rate represents an analysis of the last six months of determined scrap rates on a weekly basis.
4. Rate of turnover represents the shares of the products in total turnover.
5. Shipment performance is the rate of compliance with the prepared shipment plans by the production planning department.
6. Proximity to Takt; The takt time of the product is calculated by dividing the annual working time by the annual order. Subsequently, the cycle time information of all the process steps of the product was taken and the distance from the longest cycle time of the takt time is determined.

Figure 3 shows the AHP decision hierarchy to e select the production line according to the determined criteria.

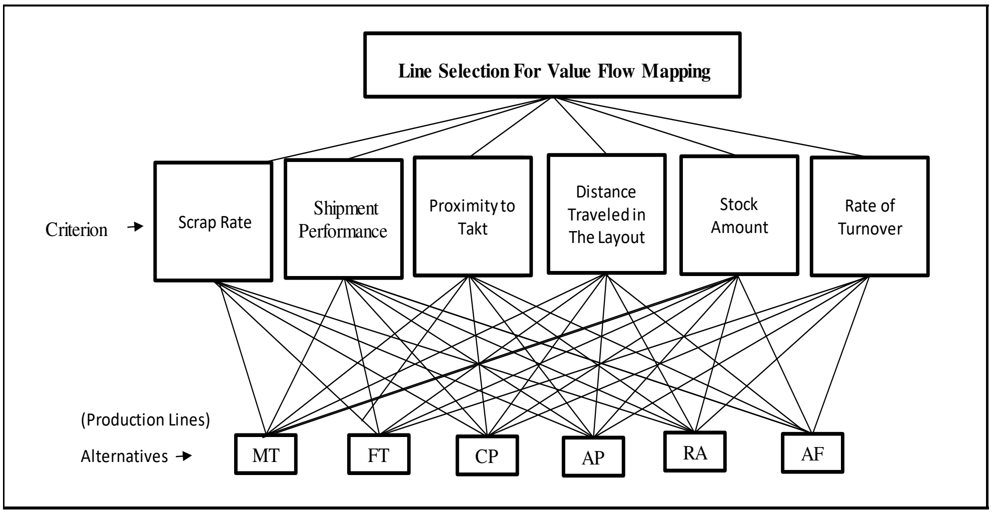

Figure 3. Decision Hierarchy

There are six alternatives in the AHP hierarchy in Figure 3. The pairwise comparisons for these alternatives are shown in the matrices in Table 3-Table 9. It is seen that the CR value of all pairwise comparison matrices is smaller than 0.10. So the comparisons are consistent.

Table 3. Pairwise Comparison Table for Criteria

	Scrap Rate	Shipment Performance	Proximity to Takt	Distance Traveled in The Layout	Stock Amount	Rate of Turnover
Scrap Rate	1	2	4	0.50	4	0.25
Shipment Performance	0.50	1	2	0.25	4	0.20
Proximity to Takt	0.25	0.50	1	0.20	2	0.14
Distance Traveled in The Layout	2	4	5	1	7	0.50
Stock Amount	0.25	0.25	0.50	0.14	1	0.11
Rate of Turnover	4	5	7	2	9	1
						CR= 0.02

Table 4. Pairwise Comparison of Alternatives for Scrap Rate Criteria

Scrap Rate						
	MT	FT	CP	AP	RA	AF
MT	1	0.13	0.33	2	2	0.20
FT	8	1	7	9	9	6
CP	3	0.14	1	4	4	0.50
AP	0.50	0.11	0.25	1	0.50	0.20
RA	0.50	0.11	0.25	2	1	0.25
AF	5	0.17	2	5	4	1
						CR=0.06

Table 5. Pairwise Comparison of Alternatives for Shipment Performance Criteria

Shipment Performance						
	MT	FT	CP	AP	RA	AF
MT	1	0.20	1	0.25	3	0.50
FT	5	1	5	2	5	4
CP	1	0.20	1	0.25	2	0.50
AP	4	1	4	1	5	3
RA	0.33	0.20	0.50	0.20	1	0.25
AF	2	0.25	2	0.33	4	1
						CR= 0.03

Table 6. Pairwise Comparison of Alternatives for Proximity to Takt Criteria

Proximity to Takt						
	MT	FT	CP	AP	RA	AF
MT	1	1	0.33	1	0.11	5
FT	1	1	0.33	1	0.11	4
CP	3	3	1	3	0.13	6
AP	1	1	0.33	1	0.11	4
RA	9	9	8	9	1	9
AF	0.20	0.25	0.17	0.25	0.11	1
						CR= 0.07

Table 7. Pairwise Comparison of Alternatives for Distance Traveled in Layout Criteria

Distance Traveled in Layout						
	MT	FT	CP	AP	RA	AF
MT	1	0.25	0.11	0.14	0.13	0.11
FT	4	1	0.11	0.20	0.17	0.13
CP	9	9	1	5	3	2
AP	7	5	0.20	1	0.50	0.25
RA	8	6	0.33	2	1	0.50
AF	9	8	1	4	2	1
						CR= 0.07

Table 8. Pairwise Comparison of Alternatives for Stock Amount Criteria

Stock Amount						
	MT	FT	CP	AP	RA	AF
MT	1	1	0.20	3	0.20	5
FT	1	1	0.20	3	0.20	5
CP	5	5	1	7	1	8
AP	0.33	0.33	0.14	1	0.14	3
RA	5	5	1	7	1	9
AF	0.20	0.20	0.13	0.33	0.11	1
						CR= 0.04

Table 9. Pairwise Comparison of Alternatives for Rate of Turnover Criteria

Rate of Turnover						
	MT	FT	CP	AP	RA	AF
MT	1	6	4	5	7	9
FT	0.17	1	0.33	0.50	2	4
CP	0.25	3	1	2	5	7
AP	0.20	2	0,50	1	3	7
RA	0.14	0.50	0.20	0.33	1	5
AF	0.11	0.25	0.14	0.14	0.20	1
						CR= 0.06

Each cell in each matrix is divided by the sum of the values in the cells in its column. Thus new values of the matrix are formed. Then the row average of each row is taken. A new matrix was created by combining the row averages obtained from the matrices consisting of Pairwise comparisons of alternatives for all criteria. This matrix and the row averages of the matrix obtained by comparing the criteria with each other are multiplied. The resulting sequence is shown in table 10.

As seen in Table 10, the CP has received the first rank. MT is located in the second rank. However, the two products have very similar ranking results. At this point, the VSM method has been applied for CP as a result of expert evaluation. It was decided by the experts to implement an implementation for MT later. At the end of the sorting, AF alternatives are seen.

Table 10. Ranking of Production Lines

Production Lines	Priorities	Percent	Ranking
MT	0.2313	23.1%	2
FT	0.1684	16.8%	3
CP	0.2334	23.3%	1
AP	0.1221	12.2%	5
RA	0.1236	12.4%	4
AF	0.1211	12.1%	6

The VSM method was applied for the CP line in the first rank. The stock values in the current situation map and the future situation map are shared by multiplying by a certain coefficient. Because, the company has privacy principles.

The raw material of CP is steel. The company announces the steel supplier details of the annual order with the annual forecast plan. In addition to, actual orders are weekly shared with the supplier. The supplier supplies steel twice a week. The CP's customer is a company that is working for the automotive main industry. The customer shares the details of the annual orders with the annual forecast plan. The customer gives actual orders once a week. According to given orders, the production planning department gives daily production knowledge (daily shipment schedule) to the production department.

Figure 4 shows the current state map for the CP line. As seen in the current state map, the CP line lead time is set at 25.5 days. The main reasons for the long lead time are;

1. At the end of the value stream, there is an eye control operation performed on the outsource. In the outsource, discarded products are sent back to the company. Because the company checks the scrap again. Approximately half of these parts are accepted pieces. So discarded parts need to be checked again in the company, but an operator is needed for it. Sometimes, if there are no extra operators, returning parts from outsource can not be checked again. This is why

there are excess stocks. This is the first reason why the lead time is long.

2. There is excess inventory after the first operation. It is seen that the machine in the second operation does not work efficiently. Moreover, although the two machines in the second operation are the same machine, the cycle times are different.
3. The flow in the production line flows in the form of pushing and it creates unnecessary stock.

On the CP line, the above mentioned problems have been encountered as a result of the studies for the drawing of the current state map. For the solution of the related problems, the future state map shown in Figure 5 is proposed. The details of the suggestions are following;

1. It is necessary to reduce the scrap rate in the outsource. So, the causes of discard must be analyzed. Pareto analysis should be performed and the most important causes should be identified. The discard rate should be reduced by making improvements on causes. Thus, there will be fewer scraps on the outsource and the outsource will send back less scraps to the company.
2. It is necessary to improve the efficiency of the two machines used for milling. Therefore, machine productivity needs to be regularly monitored. To determine the cause of machines inefficiency; operators should be given a form in which they can write daily production numbers and reasons for stopping. Subsequently, this form should be analyzed and calculated daily with three multiplications as productivity performance, employee performance and quality performance. The calculated performance values should be visualized. And it should be put in front of the relevant process. Efficiency values should be evaluated in front of these panels by the relevant persons on a daily basis and necessary actions should be taken.

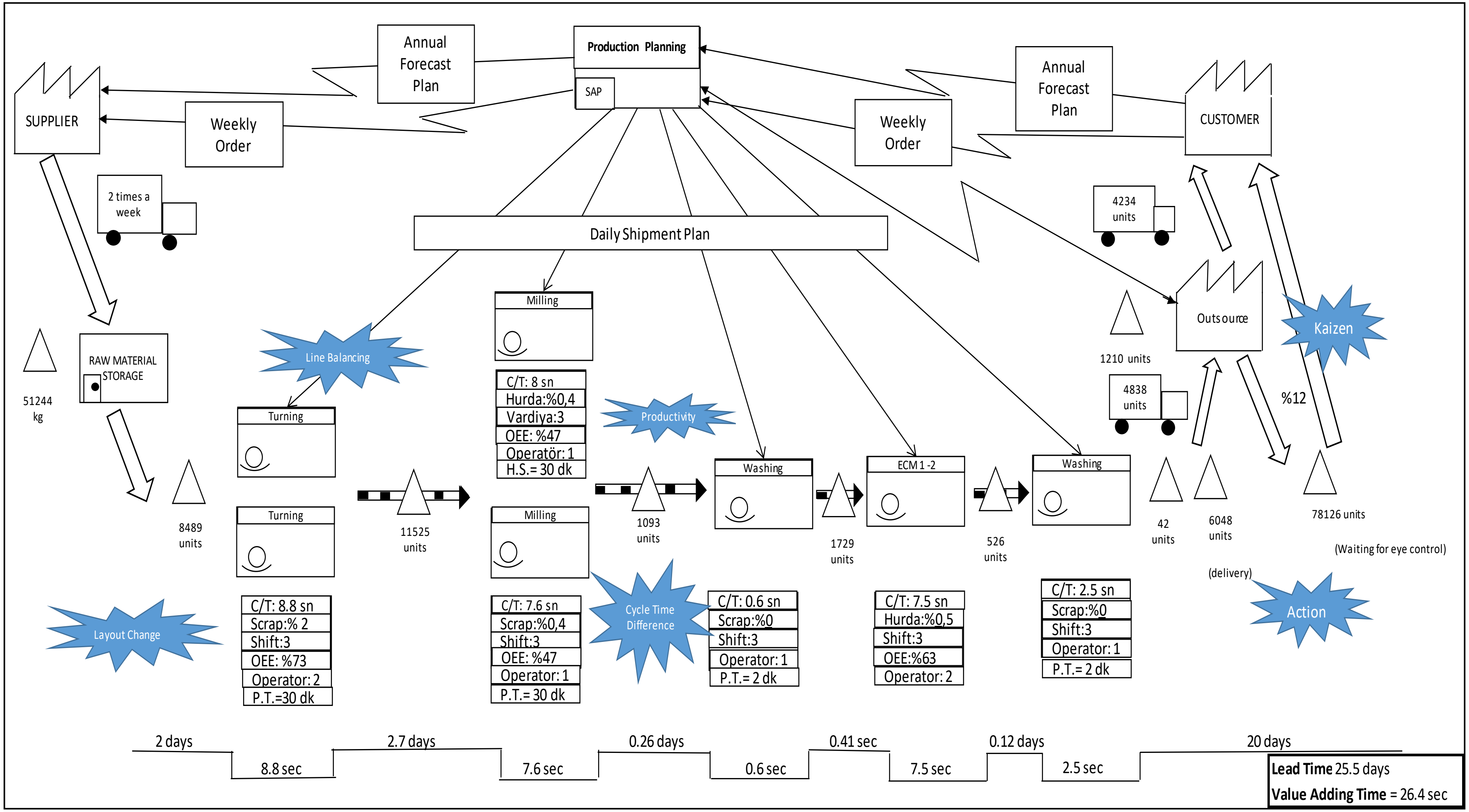

Figure 4. Current State Map

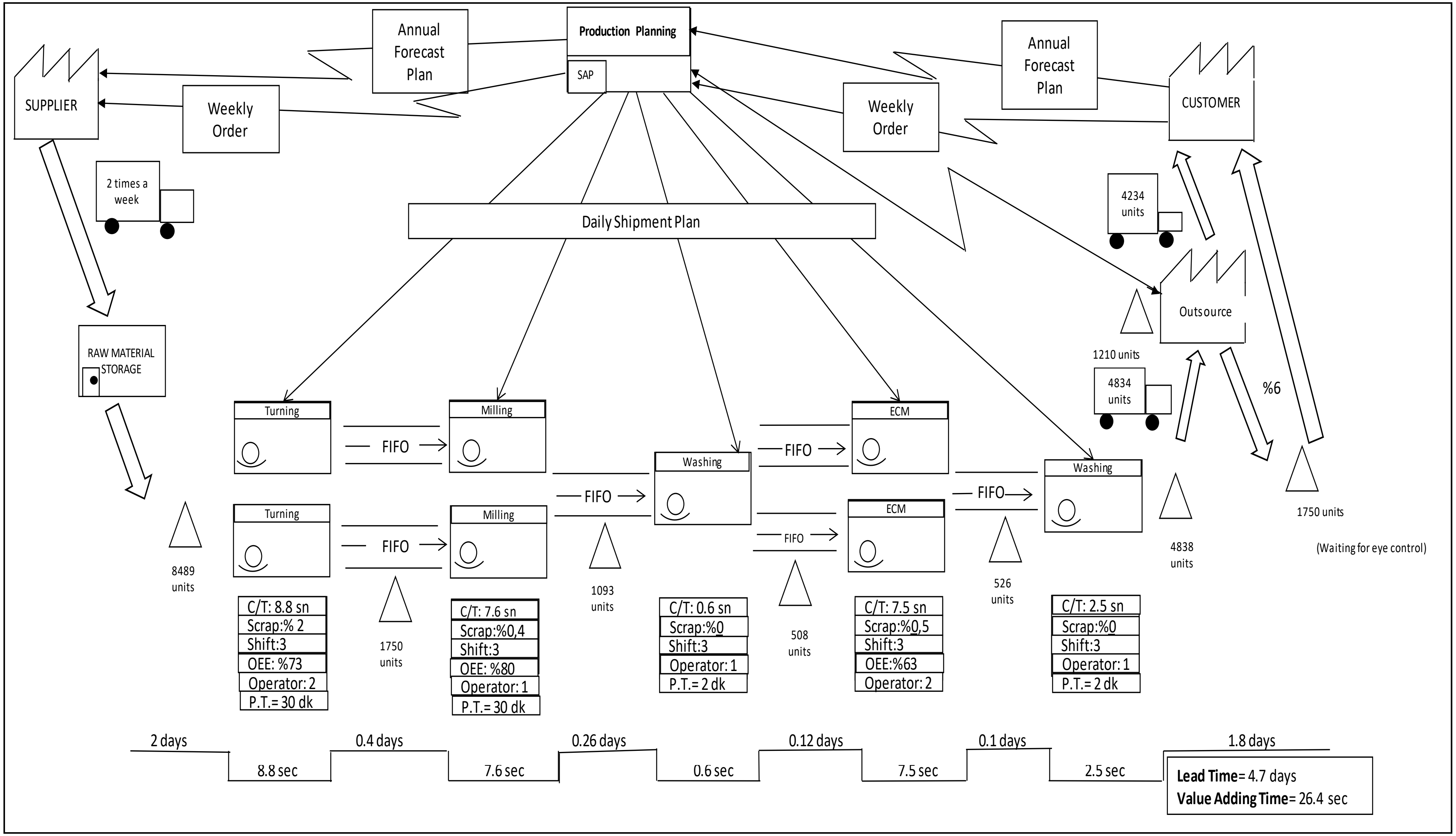

Figure 5. Future State Map

3. The reason why the cycle times of two machines in the milling operation are different should be investigated. If possible, the cycle times should be fixed by making the necessary adjustments.
4. The flow in the production line must flow with the principle of pulling with FIFO, not with pushing. It should flow with FIFO principle and take as much parts as necessary when necessary.

With the improvements described above, it can be seen that the flow period of 25.5 days in the current state map in Figure 4 is reduced to 4.7 days in the future state map in Figure 5.

6. RESULT AND RECOMMENDATIONS

In this study, our main objective was to apply the VSM methodology - the first step in lean production- in a company operating in the automotive sector. Since there are multiple production lines in the company, it was necessary to determine the line that needs most the VSM for an efficient use of time. For this purpose we implemented the AHP technique -one of the commonly used multi criteria-based decision making methods- and determined the CP line as the most suitable line.

Next, we prepared the current state map for the determined CP line and accordingly designed the future state map, and suggested a number of issues to improve the line. In the designed future state map, the lead time was reduced from 25.5 days to 4.7 days, resulting in an improvement by 81.57%.

We can summarize our contribution in two folds. First, we applied the VSM method to a real-world problem and improved the performance of a line in a company. Next, we applied the AHP methodology for selecting the appropriate line before employing the VSM. As a future work, we suggest implementing the VSM methodology to different production lines and to problems observed in different sectors.

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