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Research Article

A bottleneck analysis for an automotive company

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Abstract

The eminence of why firms should be more involved in improvement efforts has become clearer nowadays. Firms need to keep pace with changes in order to survive in competition with the other companies. One of the alternatives is the improvement in the manufacturing processes. Detecting the bottlenecks and having some measurements to cope with the problems in the manufacturing processes, methodologies enable us to improve overall outcomes. In this study, a bottleneck analysis study is implemented by using Solberg modeling methodology with real data for an automotive company that has difficulties in fulfilling the supply in response to increasing demand in the power steering department. It has been proved that this modeling methodology has some drawbacks at certain points and can also be improved to obtain accurate results by adding the lost time in the model as a contribution to the literature. Additionally, a solution has been developed to improve these stations and the current solution is shown by a simulation using MATLAB which proves the improvement of bottleneck stations in the production process.

Keywords: Bottleneck Analysis Modeling, Production Process Improvement, Lean Manufacturing, Simulation.

Bir otomotiv firması için darboğaz analizi

Öz

Firmaların neden iyileştirme çabalarına daha fazla dahil olmaları gerektiğinin önemi günümüzde daha net bir şekilde ortaya çıkmıştır. Firmaların diğer firmalarla rekabette ayakta kalabilmeleri için değişimlere ayak uydurmaları gerekmektedir. Alternatiflerden biri, üretim süreçlerindeki iyileştirmedir Darboğazları tespit etmek ve üretim süreçlerindeki sorunlarla başa çıkmak için bazı ölçümlere sahip olmak, metodolojiler genel sonuçları iyileştirmemizi sağlar. Bu çalışmada, hidrolik direksiyon bölümünde artan talebe karşılık tedariği karşılamakta zorlanan bir otomotiv firması için gerçek verilerle Solberg modelleme metodolojisi kullanılarak bir darboğaz analizi çalışması yapılmıştır. Bu modelleme metodolojisinin belirli noktalarda bazı eksiklikleri olduğu ve literatüre katkı olarak modeldeki kayıp zaman da eklenerek doğru sonuçlar elde edilecek şekilde geliştirilebileceği kanıtlanmıştır. Ayrıca bu istasyonların iyileştirilmesi için bir çözüm geliştirilmiş ve mevcut çözüm, üretim sürecindeki darboğaz istasyonlarının iyileştirilmesini gösteren simülasyon ile teyit edilmiştir.

Anahtar Kelimeler: Darboğaz Analizi Modellemesi, Üretim Süreci İyileştirme, Yalın Üretim, Benzetim.

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1. Introduction

Determining, defining, assigning an owner, and continuously monitoring the business processes of an organization is called Business Process Management (BPM). The outcome resulting from the improvement studies of the process management is called Business Process Improvement (BPI).

Improvement attempts first appeared in Japan after World War II. This is one of the pioneer situations in the emergence of KAIZEN. KAIZEN which is a continuous improvement effort has gradually spread worldwide and in Turkey. The process initially appears only as quality studies. Establishing a system according to the Total Quality Excellence method, which has come before us in recent years, is of vital importance for companies.

The redesign of the business process is called Business Process Reengineering (BPR). This process involves radical decisions. While sometimes it is enough to make changes within the established order, sometimes it may be more beneficial to change the method completely. This process is not a one-time event. It must be constantly renewed to keep up with the changes in business life and the factory sector. It should be carried out together with research to reduce the risks that may occur and to provide positive developments for the company. The first step is to analyze the current situation. It is decided whether the process should be designed from the beginning or modified according to the needs. This work is implemented by a committee made up of people familiar with the workflow. As a result of the study, the company management makes the final decision.

There are 3 possible general situations encountered as a result of process improvement: making changes in the steps of the process, creating the process from scratch, and applying of benchmark method. To decide this stage, first of all, the problem should be identified, and its source should be found. As a result of the situation, abstract experiments are made among the solution options. After deciding on one of the options, a pilot trial is conducted. The important point is that the improvement works are created using innovative and creative methods.

Bottlenecks are glitches or obstacles that slow down or cause a delay in a process. Ongbali et al. (2021) studies factors causing bottleneck problems in the manufacturing industry. A bottleneck limits the performance or capacity of the entire system to a single or limited number of components or resources. No matter how long the chain in your hand is, the weakness of one link is enough to pull all the other strengths to the bottom. Therefore, measuring rather than the arithmetic average of the performance of the elements, on the contrary measuring the power of the entire system with the performance of the weakest element will yield more realistic results. The systems need in both industry and daily life rarely appear as a single component. Therefore, each of these components needs to be sufficient in their task to create harmony and to keep the system working. Even if a single employee does his/her job in the fastest and most accurate way, the failure in the next or previous step causes the whole system to be disrupted. The situations we encounter with the bottleneck phenomenon are not limited to the industry but can be encountered in all systems consisting of multiple components.

The bottleneck is evaluated as short term or long term. The short-term bottleneck is a temporary situation, while the long-term bottleneck is permanent and needs some radical improvements. The key element that is not active at work can be an example of a short-term bottleneck. Disruption occurs until the employee returns to work, but then the problem disappears. An example of a long-term bottleneck may be the failure of hardware, and it may be necessary to replace the hardware to overcome it. Systematic improvement studies are needed to improve this phenomenon.

Lean production system, which is of great importance for companies, is a method of avoiding waste that will increase the satisfaction rate of both the company and the customer in the production and distribution in the long run. This method prevents the increase in costs, which will never be accepted by the customer, which is a big step to be taken for companies to strengthen their position in the competitive market. This waste concept that may occur on the company side can be caused by many reasons such as excessive inventory, excess production, loss in transportation costs. Since all these situations are tried to be prevented by the increase in the price of the product or the decrease in the profit rate that will bring to the company, the loss is substantial in both cases. It is not an acceptable situation to keep the customer waiting or to realize incomplete production.

Increasing customer satisfaction is very important in terms of strengthening the firm's position in the competitive environment. At this point, the lean production system should be carried out together with the bottleneck work. Being open to changes greatly affects the identification of the problem and the success of the method to be developed. In this context, the management style of the companies should move forward based on keeping up with changes and innovations.

Suffering a quality crisis in its products Japan has successfully implemented lean manufacturing, kaizen, Just-In-Time (JIT) production, Total Quality Management (TQM) methods. Because Japanese consumer goods once were considered poor quality and counterfeit, and therefore it was critical for improving the quality to eliminate that view (Öztürk, Arıkan, & Öztürk, 2011).

Each activity involves at most one server of limited capacity and availability in service environments. In production environments, activities and servers are replaced by jobs and machines (Karabulut, 2010). Varela et al. (2003) tried to solve the problem of bottlenecks caused by stoppages in a factory with the help of an algorithm. According to Arslan (2008), lean waste is beyond its known meaning, anything the customer will not accept to pay the extra money or anything that has no benefit to the user of the product or service. The aim of reducing costs through the elimination of all products or service creation phases (errors, overproduction, stocks, waits, unnecessary work, unnecessary moves, unnecessary transports) from design to shipment is to increase customer satisfaction, increase market climate flexibility, accelerate cash flow and increase profitability.

Total Productive Maintenance (TPM), which is another improvement approach, is a method of eliminating and improving losses by identifying losses and wastage (Karasu, 2019). In the airline industry, especially the area of baggage services, different systems and technologies can be used at each point (Demir, 2016). Liaw (2005) studied the factory's timetable to minimize the total time lag/downtime in production, developing an intuitive way to solve the problems that arise. Akın, 2010 studies the use of simulation for the determination of the factors and the bottlenecks affecting the performance of the lean manufacturing systems. Drobouchevitch ve Strusevich (2001) intend to solve problems arising from charting by using up-to-date charting methods, the bottleneck machines that consist of two and more countertops, and the resulting from stacking.

Bootleneck analysis can be done with many different techniques and methodologies. The bottleneck theory, which is developed by Goldratt (1990), is a management philosophy aimed at continuous improvement in all processes. The topic can both be studied with a deterministic or stochastic approach. Solberg (1981) developes a deterministic mathematical model. Velumani and Tang (2017) uses discrete event simulation for bottleneck analysis of a batch process manufacturing line. Kasemset&Kachitvichyanukul (2007) propose a simulation-based procedure to identify bottlenecks.

By taking nowadays' competitive conditions into consideration, businesses must be dynamic to maintain and continually improve their current situation (Tezcan, 2008). Wang, et al. (2005), gives an overview for bottlenecks in production networks. Appelqvist and Lehtonen (2005), have identified bottlenecks in the modeling they have created, based on the organization of a steel factory, the workshop, and the general constraints on the production line, and tried to improve the problem. Tang H. (2019) proposes a new method for bottleneck analysis in complex manufacturing systems.

In our study we first present the mathematical formulation for the problem in an automotive company using Solberg (1981) methodology. Then we give a simulation model. Next, we discuss our results and findings. Finally, we come up with our conclusions.

2. Mathematical Formulation

In the plant, the production line (Figure 1) refers to the operations of raw materials processed in the factory. Power steering benches entering the improvement work in the factory, are respectively OP-10 (CNC-Lathe station), OP-20 (Hole drilling station), OP-30 (Punching station), OP-40 (Milling station), OP-50 (Deburring station), OP-60 (CNC-Press station), OP-70 (Punching station), OP-80 (Deburring station), OP-90 (Hydraulic bending station), OP-100 (Fusing station), OP-110 (Chemical washing station). A total of 6 pieces of products (Control valve, Sector shaft, Worm gear, Hydraulic valve screw, Rack shaft, and Steering column) and 86 pieces of benches were handled in the line where this study will be carried out.

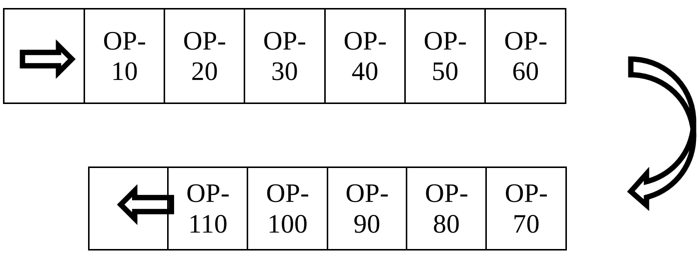

Figure 1: Production Line

In order to create a bottleneck model, first of all, the time that the products processed in the workbench for each workbench in the factory are calculated. These calculations are made daily and within a monthly plan. A member of the committee established for this study keep track of these durations and forms a table. Only the processing time of the machine during production is not enough to calculate the bottleneck. In every production department, there is lost time per machine. These may be due to the inexperience of the operator in general, the mistakes made during the part replacement, the old parts of the machine, or the machine software that is not being sufficient as before. When creating a bottleneck model, it is crucial to use these data in calculations.

Improvement studies are very important for all small and large-scale businesses; however, as these studies are implemented, when the time losses per machine are not taken into account, the most common solution offered is to increase the number of benches in the work area that appears to be a bottleneck. Thus, the loss of time per machine is included in the calculation to see the genuine bottleneck. As a result of this, improvement studies can be used as an intermediate step as they help to reach a more accurate result.

A bottleneck study is implemented using real data for an automotive company that has difficulties in fulfilling the supply in response to increasing demand in the power steering department. In this study, the Solberg bottleneck modeling is used for the solution of the problem. It has been proved that this modeling methodology has some drawbacks at certain points and cannot always reach the most accurate result. Thus, the solution can be progressed more by adding the time-lost definition that is required to be calculated.

In this study, there are 6 product types and there are 86 stations where these parts are processed. The processing time spent in the looms (monthly averaged data) where these parts are processed and the frequency is stated in Table 1. The average lost time per counter is calculated in the measurement of one-month processing time. While making this calculation, the time arising from the individual competence of the operator, the technological lag of the machine, the breakdown caused by the old/worn parts in the machine, and the repair of the defect is calculated as an average. Lost times vary according to the type of stations and the process.

The steps of our mathematical formulationis given as follows:

- the bottleneck stations are determined by Solberg methodology (Solberg, 1981)
- workload WL_i for each station is defined,
- Rp_i , the production rate of i^{th}station is calculated,
- Rp^*, the maximum production rate of the bottleneck station is calculated,
- Rp_j, the maximum quantitiy of parts that the system can produce is calculated,
- After calculation of U_i, the utilization rate, the average station occupancy for the entire system, $\overline{U}$ is determined.
- Additionally, m_{ijk}, the proportion of time lost by the operation performed is found.

The notation used in the process are described as:

Indices:

i: Station number,

j: Part code,

k: Transaction sequence used in the process

Parameters:

t_{ijk}: The time spent in process k of part j at station i.

P_j: Piece Mix Ratio that states the ratio of piece j in the total production quantity.

F_{ijk}: The operation frequency at which k operation is performed per piece for piece j at station i

We can define this bottleneck by using the model developed by Solberg mathematically. The mathematical formulation is given as follows:

To determine the bottleneck station, we calculate the workload WL_i for each station i :

$$WL_i = \sum_j \sum_k t_{ijk} F_{ijk} P_j \quad (1)$$

$$Rp_i = \frac{s_i}{WL_i} \quad (2)$$

where Rp_i in (2) is the production rate of i^{th}station and s_i in (2) is the number of servers/machines doing the same job for each station,

$$Rp^* = \frac{S^*}{WL^*} \quad (3)$$

where Rp^* is the maximum production rate of the bottleneck station,

$$Rp_j = P_j \frac{S^*}{WL^*} \quad (4)$$

where Rp_j is the maximum quantitiy of parts that the system can produce.

Table 1. Processing times and processing frequency of product types in stations

Product Type	Stations	Average Processing Time (min)	Frequency
Control Valve	OP10	12,5	1
	OP20	12,8	1
	OP30	7,2	1
	OP50	26,4	1
	OP70	1,5	1
	OP90	17,2	1
Sector Mile	OP20	16,4	1
	OP30	3,6	1
	OP40	26	1
	OP60	34,7	1
	OP80	5,3	1
	OP100	27	1
	OP110	25,1	1
Worm Gear	OP10	33,2	1
	OP40	19,4	1
	OP50	19,7	1
	OP60	21,6	1
	OP70	1,5	1
	OP90	19	1
	OP100	32,1	1
Hydraulic Valve Screw	OP10	44	1
	OP20	19,9	1
	OP30	4,5	1
	OP90	13,9	1
	OP110	24,6	1
Rack Shaft	OP10	24,6	1
	OP30	4,9	1
	OP40	10,5	1
	OP50	16,2	1
	OP60	13,8	1
	OP80	4,9	1
Steering Column	OP10	21	1
	OP20	14,7	1
	OP30	5,3	1
	OP40	12,1	1
	OP60	28,1	1
	OP70	1,5	1
	OP110	25,7	1

$$U_i = \frac{WL_i}{S_i}(Rp^*) \quad (5)$$

where U_i is the utilization rate

The average station occupancy for the entire system:

$$\bar{U} = \frac{\sum_{i=1}^{n} U_i}{n} \quad (6)$$

Lost time, which was not included in the Solberg modeling, is defined as s in this study.

m_{ijk} is the proportion of time lost by the operation performed

$$m_{ijk} = \frac{g}{t_{ijk}} \quad (7)$$

where g= time lost within machines between operations.

Table 2: Product Data

	Station										
Product Type	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Control valve	1	1	1		1		1		1		
Sector mile		1	1	1		1		1		1	1
Worm gear	1			1	1	1	1		1	1	
Hydraulic valve screw	1	1	1						1		1
Rack shaft	1		1	1	1	1		1			
Steering column	1	1	1	1		1	1				1

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110	Monthly Production Amount	P_j
Product Type	Number of operand in station	4	14	10	4	12	18	5	4	6	5	4		
Control valve		12,5	12,8	7,2		26,4		1,5		17,2			468	0,1690
Sector mile			16,4	3,6	26		34,7		5,3		27	25,1	978	0,3532
Worm gear	Processing	33,2			19,4	19,7	21,6	1,5		19	32,1		1154	0,4168
Hydraulic valve screw		44	19,9	4,5						13,9		24,6	68	0,0246
Rack shaft		24,6		4,9	10,5	16,2	13,8		4,9				60	0,0217
Steering column		21	14,7	5,3	12,1		28,1	1,5				25,7	41	0,0148
Waste of time per		3,50	2,8	2,1	4,12	4,1	2,2	2,9	2	3	1	4	**2769**	**1,0000**

Table 3: WL and $\frac{WL^*}{S^*}$ Calculations without Lost Times

Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
WL	17,87353	8,6622	2,7836	17,6749	13,0231	21,9730	0,9009	1,9781	11,1668	22,9142	9,8499
WL/S	4,46838	0,6187	0,2784	4,4187	1,0853	1,2207	0,1802	0,4945	1,8611	4,5828 *	2,4625

Miscalculated bottleneck Station	**OP100**

Table 4: Results Including m_{ijk}values

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Product Type	Number of operand in	4	14	10	4	12	18	5	4	6	5	4
Control valve		0,28	0,21875	0,2916667		0,155303		1,93333		0,17442		
Sector mile			0,17073	0,5833333	0,04307692		0,0634		0,37736		0,03704	0,15936
Worm gear	m_{ijk}	0,1054217			0,05773196	0,2081218	0,10185	1,93333		0,15789	0,03115	
Hydraulic valve screw		0,0795455	0,1407	0,4666667						0,21583		0,1626
Rack shaft		0,1422764		0,4285714	0,10666667	0,2530864	0,15942		0,40816			
Steering column		0,1666667	0,19048	0,3962264	0,09256198		0,07829	1,93333				0,15564

The final form of formula when we integrate m_{ijk} into the model is:

$$WL = \sum_j \left[\sum_{ijk} F_{ijk} P_j + \sum_k m_{ijk} P_j\right] \quad (8)$$

In other words, the m_{ijk} value in (8) will serve as an efficiency criterion, making the real work production skills of the machines visible and allowing us to follow their effectiveness (Table 2).

The WL and $\frac{WL^*}{S^*}$ results, when the lost time is not included in the calculations, are shown in Table 3.

Although the bottleneck station looks like the OP100 counter in this table, it has been observed that this is wrong when we include the m_{ijk}values in Table 4 into the calculation, and it is shown in Table 4 that the real bottleneck station is in another area.

At this point, incorrect results resulting from the missing time is not included in the calculation are blurred by focusing on the wrong counterbore. Improvements to the OP100 counter are insufficient to eliminate bottlenecks. However, the improvements in OP40, the actual bottleneck station shown by including the m_{ijk} values in the calculation will help achieve clearer results in the study. Although the number of worktops being considered first among the improvements that can be made is increased, this solution may not always be possible. This might include high costs for worktops, lack of space, lack of adequate equipment, and a number of operators. As an alternative, focusing on the reasons for wasting time and trying to minimize it can be faster and more cost-effective for the business. The fill rate, the production rate of the bottleneck station, and the estimated annual production values of other stations are given in Table 5.

Table 5: The fill rate, the production rate of the bottleneck station, and the estimated annual production values.

Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
WL (included waste)	20,1373	10,2346	4,0084	20,9973	15,5136	23,7471	2,6425	2,7278	12,9978	23,6841	11,4201
WL/S	5,0343	0,7310	0,4008	5,2493 *	1,2928	1,3193	0,5285	0,6820	2,1663	4,7368	2,8550

Bottleneck Station	**OP40**

The utilization rate, the production rate of the bottleneck station, and the estimated annual production values of other stations are given in Table 6.

Table 6: The utilization rate, the production rate of the bottleneck station, and the estimated annual production values.

	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Utilization Rate:	95,9042	13,9263	7,6360	100,0000	24,6279	25,1324	10,0681	12,9914	41,2679	90,2367	54,3884

Rp*	0,1905002	piece/ minute
	11,430014	piece/ hour

Production Pace	Product/ hour	Annual Production* (piece)
Rp Control valve*	1,93183	4636,40013
Rp Sector mile*	4,03704	9688,88745
Rp Worm gear*	4,76354	11432,49092
Rp Hydraulic valve	0,28069	673,66498
Rp Rack shaft*	0,24767	594,41027
Rp Steering column*	0,16924	406,18035
		27432,03410

* We assume 8 hours for a day and

As a result of the improvements to the OP40 countertop, the wasted time on this counter is reduced by 72,8%, which means that the countertop is no longer a bottleneck station and the bottleneck recovery study is 2nd phase. The detection of the bottleneck encountered in step 2 continues with the improved values as shown in Table 7.

Table 7: Improved Bottleneck values in step 2

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110	Production	P_j
Product Type	Number of operand in	4	14	10	4	12	18	5	4	6	5	4		
Control valve		12,5	12,8	7,2		26,4		1,5		17,2			468	0,1690
Sector mile			16,4	3,6	26		34,7		5,3		27	25,1	978	0,3532
Worm gear	Processing	33,2			19,4	19,7	21,6	1,5		19	32,1		1154	0,4168
Hydraulic valve screw		44	19,9	4,5						13,9		24,6	68	0,0246
Rack shaft		24,6		4,9	10,5	16,2	13,8		4,9				60	0,0217
Steering column		21	14,7	5,3	12,1		28,1	1,5				25,7	41	0,0148
Waste of time per		3,50	2,8	2,1	1,12	4,1	2,2	2,9	2	3	1	4	**2769**	**1,0000**

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Product Type	Number of operand in	4	14	10	4	12	18	5	4	6	5	4
Control valve		0,28	0,21875	0,2916667		0,155303		1,93333		0,17442		
Sector mile			0,17073	0,5833333	0,04307692		0,0634		0,37736		0,03704	0,15936
Worm gear	m_{ijk}	0,1054217			0,05773196	0,2081218	0,10185	1,93333		0,15789	0,03115	
Hydraulic valve screw		0,0795455	0,1407	0,4666667						0,21583		0,1626
Rack shaft		0,1422764		0,4285714	0,10666667	0,2530864	0,15942		0,40816			
Steering column		0,1666667	0,19048	0,3962264	0,09256198		0,07829	1,93333				0,15564

When the WL and $\frac{WL^*}{S^*}$ values in step 2 are examined, the bottleneck station is OP10 as shown in Table 8.

Table 8: The WL and $\frac{WL^*}{S^*}$ values in step 2.

Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
WL (included waste)	**20,1373**	10,2346	4,0084	18,5781	15,5136	23,7471	2,6425	2,7278	12,9978	23,6841	11,4201
WL/S	5,0343	0,7310	0,4008	4,6445	1,2928	1,3193	0,5285	0,6820	2,1663	4,7368	2,8550

Bottleneck Station	**OP10**

The annual production rate in this situation is proven to be increased by 4% and the work improvement are shown in Table 9.

Following the improvements to the OP10 workbench, the waste time on this station is reduced by 85,7% (Table 10).

When WL and $\frac{WL^*}{S^*}$ calculations are done to determine the next bottleneck station as Step 3, the new bottleneck station is an OP100 station (Table 11).

As a result of a 2-step improvement study, the annual production capacity will be 9,76% higher than the beginning as in Table 12.

As a summary we can say that there is a considerable reduction in the waste of times of the work benches.

The relatively short amount of time wasted in the OP100 station bottleneck indicates that the problem at this point requires a different solution. Therefore, this operation can be stopped at this point.

Table 9: Improved values in production.

	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Occupancy Rate:	100,0000	14,5211	7,9621	92,2568	25,6797	26,2057	10,4981	13,5462	43,0304	94,0905	56,7111

Rp*	0,1986359	piece/ minute
	11,918157	piece/hour

Production Pace	Product/ hour	Annual Production*(piece)
Rp Control valve*	2,01434	4834,40728
Rp Sector mile*	4,20945	10102,67161
Rp Worm gear*	4,96697	11920,73931
Rp Hydraulic valve	0,29268	702,43525
Rp Rack shaft*	0,25825	619,79580
Rp Steering column*	0,17647	423,52713
		28603,57638

* We assume 8 hours for a day and

,

Table 10: The improvements on the workbenches

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110	Production	P_j
Product Type	Number of operand	4	14	10	4	12	18	5	4	6	5	4		
Control valve		12,5	12,8	7,2		26,4		1,5		17,2			468	0,1690
Sector mile			16,4	3,6	26		34,7		5,3		27	25,1	978	0,3532
Worm gear	Processing	33,2			19,4	19,7	21,6	1,5		19	32,1		1154	0,4168
Hydraulic valve screw		44	19,9	4,5						13,9		24,6	68	0,0246
Rack shaft		24,6		4,9	10,5	16,2	13,8		4,9				60	0,0217
Steering column		21	14,7	5,3	12,1		28,1	1,5				25,7	41	0,0148
Waste of time per operation		0,50	2,8	2,1	1,12	4,1	2,2	2,9	2	3	1	4	**2769**	**1,0000**

	Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Product Type	Number of operand	4	14	10	4	12	18	5	4	6	5	4
Control valve		0,04	0,21875	0,2916667		0,155303		1,93333		0,17442		
Sector mile			0,17073	0,5833333	0,0430769		0,0634		0,37736		0,03704	0,15936
Worm gear	m_{ijk}	0,01506024			0,057732	0,2081218	0,10185	1,93333		0,15789	0,03115	
Hydraulic valve screw		0,01136364	0,1407	0,4666667						0,21583		0,1626
Rack shaft		0,0203252		0,4285714	0,1066667	0,2530864	0,15942		0,40816			
Steering column		0,02380952	0,19048	0,3962264	0,092562		0,07829	1,93333				0,15564

Table 11: WL and $\frac{WL^*}{S^*}$ values.

Station	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
WL (included waste)	18,1969	10,2346	4,0084	18,5781	15,5136	23,7471	2,6425	2,7278	12,9978	23,6841	11,4201
WL/S	4,5492	0,7310	0,4008	4,6445	1,2928	1,3193	0,5285	0,6820	2,1663	4,7368	2,8550

Bottleneck Station	**OP100**

Table 12: Improved values.

	OP10	OP20	OP30	OP40	OP50	OP60	OP70	OP80	OP90	OP100	OP110
Occupancy Rate:	96,0396	15,4331	8,4622	98,0512	27,2925	27,8516	11,1574	14,3970	45,7330	100,0000	60,2730

Rp*	0,2111117	piece/ minute
	12,666701	piece/hour

Production Pace	Product/ hour	Annual Production*(piece)
Rp Control valve*	2,14085	5138,04219
Rp Sector mile*	4,47383	10737,19073
Rp Worm gear*	5,27894	12669,44591
Rp Hydraulic valve	0,31106	746,55314
Rp Rack shaft*	0,27447	658,72336
Rp Steering column*	0,18755	450,12763
		30400,08295

* We Assume 8 hours for a day and

3. Simulation Model

A simulation is an artificial creation of the procedures of a real process or system over time. The simulation can be described as imitating the operation of a system or layout. The simulation can indicate the behavior of a system and the processes. Changes in the simulated state can be easily integrated into the system, inputs may be applied repeatedly and the results can be reviewed in detail. Reasons such as easy integration of the change in strategy, easy observation of its impact on the results, and taking measures to suit input changes that can occur after the model are developed have increased the usage of simulation. The biggest convenience that simulation gives us is that we can try and evaluate new decisions or new options without making any changes to the existing system.

It is important to reflect the changes on the model to the outcome and to improve alternatives by asking "What if?" questions, which is useful to offer alternatives for the managers (Çörekçi, 2014). In today's more common machine-intensive construction projects, by accurately estimating the efficiency of each building machine, the cost of the machine can be pre-determined (Bayhan, 2016). According to Ustundag & Cevikcan, 2018, simulation and other analytical applications can be both cost-effective and solution-accessible.

By using the data provided by the automotive company, bottleneck stations are determined by identifying the points that are obtained during the production and missed points by the bottleneck analysis. A solution has been developed to improve these stations using simulation. The simulation results show us the improved change in bottleneck stations in production. A solution is obtained that maximizes the production of the company and minimizes the time lost as a result of the study. First, the bottleneck stations of the production system are detected and then the results obtained from the previous stage are used in the second stage by using simulation. It is necessary to input the data of the products/product groups to develop the simulation model. These data include the time losses and part processing time. Additionally, other data such as the processing times, monthly production quantities, production weight ratios are also some of the inputs used in the simulation model. The accuracy of the data in the inputs is important for the simulation to produce usable results. Thus, the data that is used in the MATLAB simulation is the real data obtained from the automotive company in concern.

The data used in the input analysis of this simulation contain the following data that are obtained from the real processes from the automotive company: wasted time in the system, processing time values (t_{ijk}), monthly production quantities, operation frequencies (F_{ijk}), Number of stations. The outputs of the simulation model are: m_{ijk}, $(\, t_{ijk} + m_{ijk})$, p_j, WL, ${WL}/{S}$. t_{ijk} is the input data processing time. The second step is adding the wasted time p into the simulation model to calculate the m_{ijk}. Thus, the p values are added to the input section. The model does not yet have the data required to calculate the WL value. This requires the addition of monthly production amount data in the input section. Additionally, the model is ready to calculate WL values with t_{ijk} values that are added to the computational. The model calculates the WL values in the output 4 section. It is ready to display the ${WL}/{S}$ value by adding the station numbers to the input 5 section of the model. This results in a risk bottleneck that occurs between stations based on the data added. If an improvement is get for the bottleneck station, the model can be routed to change the data. These orientation results start the simulation from the beginning by adding new waste of time (input 2) values. When the final results are sufficient, the simulation is terminated, and the solution process begins.

4. Results and Discussion

Data are included in the model in the first stage of the simulation. When the data are processed and calculations are made, the table presented by the simulation determines the bottleneck station. The initial values of the ${WL}/{S}$ are stated in Figure 2. The next step determines whether the simulation ends or not. As the improvements continue, it is appropriate to enter new data. The improved data gives the second result when added to the model, which gives the bottleneck station in the second stage (Figure 3). If the improvements are not satisfactory, the simulation may continue by using the updated data that is applied to the simulation similar to the previous phase. In this case, the result is the new bottleneck station (Figure 4).

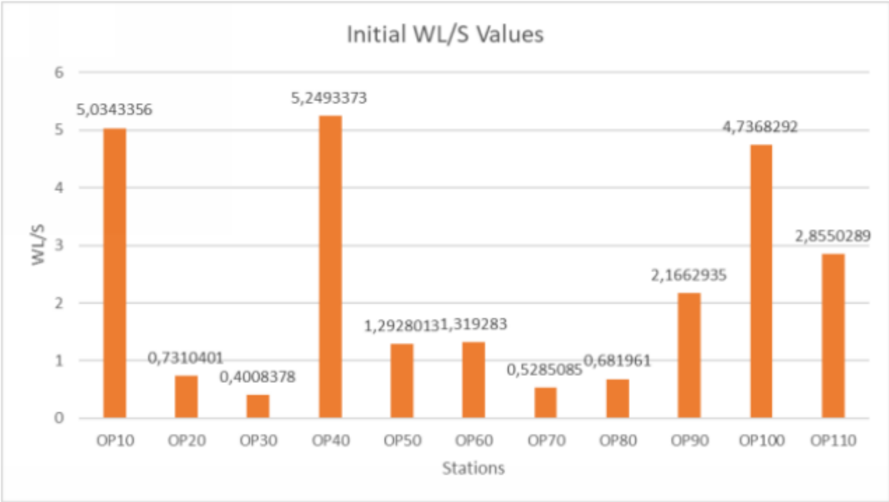

Figure 2: Initial ${WL}/{S}$ values

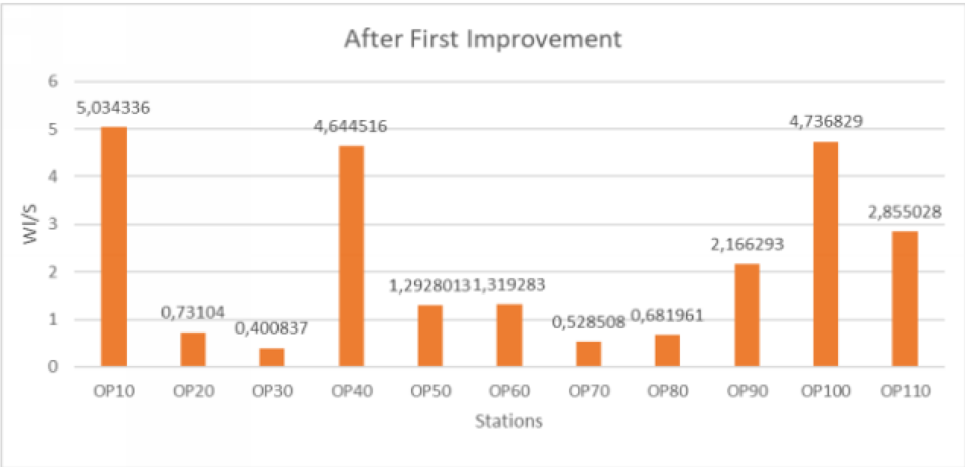

Figure 3: ${WL}/{S}$ values after the first improvement.

According to the results of the improvements, the simulation should be ended or reviewed. The simulation shows the change in annual production amount against improved data. In this example, the results of the integrated data used in the mathematical modeling section into the model are shown in graphs. It is clear from Figure 5 that the annual production quantities have increased as a result of improvements.

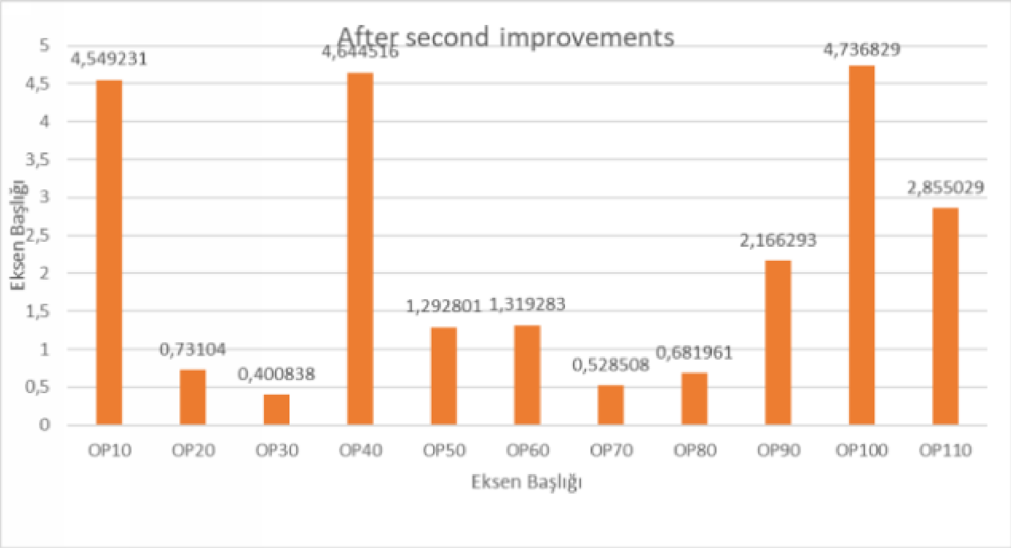

Figure 4: $WL/_S$ values after the second improvement.

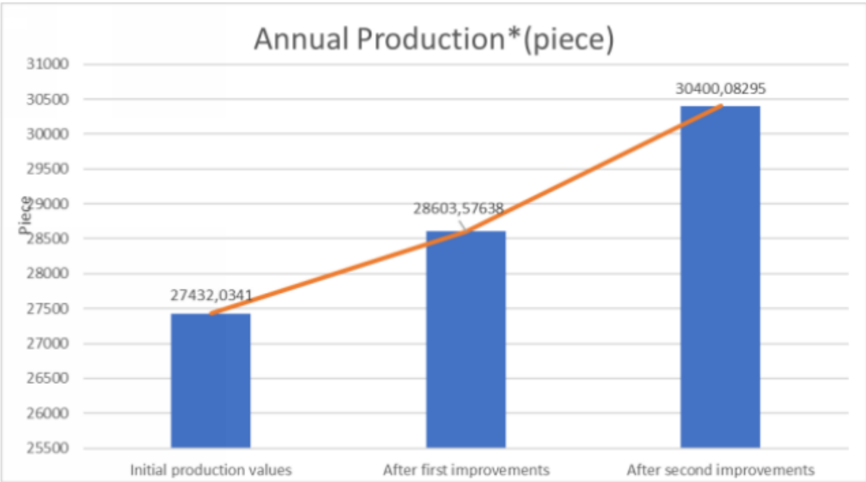

Figure 5: Annual production quantities

5. Conclusions

The analysis of the bottleneck at a power-assisted steering plant is conducted and an improvement procedure is applied by using simulation until no improvement is obtained. For this purpose, first, a bottleneck analysis is implemented by using Solberg method for the determination of the bottleneck station then, the mathematical model is improved via simulation since the result of adding a new workbench is not always effective. In this context, the lost time is integrated into the formula that led to the change of the apparent bottleneck station and paved the way for alternative solutions. The possible causes of the bottleneck station are found as a result of the Solberg calculations that identified the lost time in the production process and the improvements in the bottleneck station are reduced by eliminating these causes. We see that before making costly investments in the new machines, it is better to improve the lost time by using bottleneck analysis. It is advised to buy a new bench after we obtain the effect of the improvement on lost time. Simulation is a useful methodology to test different solution alternatives in order to see their effect by analyzing through different performance measurements. This study contributes to the literature by showing a powerful use of Solberg methodology and simulation together for the bottleneck analysis and the improvement of the bottleneck components of a production system respectively. The decision-makers can use these methodologies to make the operations in their organizations more cost effective.

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