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# SEQUENCING MODEL FOR A SEAT BELT MANUFACTURER

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**Keywords**

*Sequence and scheduling, assembly line, unfinished works, ERP (enterprise resource planning), APP (aggregate production planning)*

**Abstract**

*The study focuses on optimizing the production process of a Turkish family company specializing in seat belt manufacturing, boasting an annual capacity of 810,000 units and employing 150 individuals. Serving major clients such as Otokar, Ford Otosan, Bmc, Karsan, Anadolu Isuzu, Mercedes, Man, Temsa, and Türk Traktör, the company utilizes pressing, plastic injection, and assembly lines in its production. With a specific emphasis on the sequencing and scheduling of the assembly lines, a mathematical model was formulated and solved using GAMS software. Comparative analysis, incorporating scenario assessments, revealed that the proposed model significantly enhanced efficiency compared to various scenario outcomes.*

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**Anahtar Kelimeler**

*Sıra ve çizelgeleme, montaj hattı, tamamlanmamış işler, KKP (kurumsal kaynak planlama), APP (toplam üretim planlama)*

**Öz**

*Ticari araç sektörüne yönelik emniyet kemeri ve yedek parça üretimi gerçekleştiren, yılda 810.000 emniyet kemeri üretebilen aile şirketi, müşterileri arasında Otokar, Ford Otosan, Bmc, Anadolu Isuzu, Mercedes, Man, Temsa, Türk Traktör gibi önemli markaları bulundurmaktadır. Firmanın üretim kapasitesi, pres, plastik enjeksiyon ve montaj hatlarından oluşmaktadır. Şirketin üretimini geliştirmek amacıyla emniyet kemeri montaj hatlarının sıralanması ve programlanmasını ele almaktadır.*

*Şirketin 3 adet emniyet kemeri montaj hattı bulunmaktadır. Sıralama ve çizelgeleme sorununu çözmek için matematiksel bir model geliştirilmiş ve model GAMS yazılımı kullanılarak çözülmüştür. Çalışmanın sonuçları, GAMS modelindeki tamamlanmamış senaryo analizlerinin karşılaştırmasıdır. Önerilen modelin sonuçları, farklı senaryo analizlerine dayalı sonuçlarla kıyaslandığında, önerilen modelin daha etkili sonuçlar elde ettiğini göstermektedir.*

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## 1. Introduction

Seat belt is a valuable product in the automotive industry to protect the lives of passengers and vehicle users and to prevent accidents. Gustave Liebau is invented in 1903. In the 1930s, an American physician placed two-point seat belts in his car and insisted that car manufacturers put them on new models. Over time, seat belt technology, product features, and diversity have evolved. The automobile industry is a constantly evolving industry. Pedestrian and passenger safety in particular comes to the forefront for automobile manufacturers.

Seat Belt manufacturer Ark Pres, which is the subject of study, started production with the Static Seat Belts in 1973 and short time started to supply seat belts to one of the national automotive giants, Tofaş for the Kartal vehicle model and Dogan vehicle model. With that, it reached an important position in the sector in 1981. The company has various products such as 2-point, 3-point, 4-point, and 5-point, and sub-products of these products. The company within the developments in our age, the company can compete with its competitors in the sector with a minimum focus on the cost of production.

In production and operations management, dispatching rules are decision rules that specify the sequence in which jobs or tasks are completed in a manufacturing or service setting. These guidelines are essential for organizing and allocating work in a way that maximizes a system's overall effectiveness and performance. Often, the main goal of dispatching rules is to reduce performance indicators such as makespan and overall completion time (Salama, Kaihara, Fujii, & Kokuryo, 2023).

The Parallel Machines and Flow Workshop problem type is the focus of the study. To improve the company's production efficiency, APP (Total Production Planning) and MRP (Material Requirements Planning) studies were used in the SAS (Sorting and Scheduling) research. The investigation's goal is to locate incomplete work.

The work with the Smallest Processing Time (SPT) or Expected Processing Time is processed first out of all the tasks that are processed. Linear programming (LP) is used to give fresh evidence of the correctness of SPT. The LP formulation was one that Wolsey and Balas had first introduced and improved (Cheng, Tang, & Zhang, 2023). According to the work presented by Qi, the SPT schedule is optimal for the interstation problem; The main problem is to minimize the sum of all job times completed at a single station and apply the SPT rule to obtain an optimal schedule. That is, all jobs are listed in non-decreasing order. Inter-station operations and idle periods between these operations are not allowed (Qi, Bard, & Yu, 2006).

Total flow time, or the amount of time it takes for a work to go through the complete production process, may be reduced with the use of SPT. By finishing shorter work sooner and enabling a faster resource turnover, it often optimizes the use of available resources. The Shortest Processing Time (SPT) rule offers an optimal solution to the problem of scheduling jobs on the same parallel machines to reduce average work completion times, which is one of the first achievements in scheduling theory. SPT offers a predictable planning sequence that facilitates the planning and management of manufacturing operations (Kim & Jeong, 2007). In addition to this facilitation, it is necessary to mention its limitations.

Even while SPT is good at cutting down on processing times for certain projects, it can make jobs wait longer and even lengthen lead times overall. When it comes to lowering completion time or other planning criteria like total completion time, it can not necessarily produce the best overall performance (Cho, Shmoys, & Henderson, 2023).

The job with the most processing or the largest possible processing time is processed first. In parallel scheduling of stations, it cannot generally be assumed that all stations are present along the schedule. Some stations are linked to unfinished work from the previous planning period, some are scheduled for correction, and some may be linked to specific work that must be done. In detail, it analyzes how the worst-case performance of the longest runtime first algorithm (or LPT for short) is affected by varying degrees of station availability (Hwang, Lee, & Chang, 2005).

It is generally not possible to assume that every machine will be accessible for use for the whole planning horizon in real-world parallel machine planning. A specific set of work that has to be done may partially occupy certain machines, some may be scheduled for repair or maintenance within a specific time frame, and some may be occupied by incomplete work from the previous planning period. It is scheduled at specific intervals because of a number of unavoidable factors. Given the restricted number of machines available, the scheduling problem's combinatorial character is undoubtedly made more difficult. Like all rules, the LPT rule has its limitations (Liao, Shyur, & Lin, 2005). Some studies contend that by minimizing the delay of individual jobs, LPT can result in longer flow times for the entire job group and potentially increase overall completion time. Lee contends that LPT can provide a program with an arbitrarily large runtime if all machines are shut down together for an arbitrarily long period of time (Zhao, Ji, & Tang, 2011). Furthermore, in terms of reducing other planning criteria like completion time or total completion time, LPT might not necessarily offer the greatest overall results.

In production and operations management, the Earliest Due Date (EDD) dispatching rule is used to schedule jobs or activities in a manufacturing or service setting. The idea of EDD is to arrange tasks according to their due dates. In particular, the earliest-due jobs are scheduled first (Bryant, Lakner, & Pinedo, 2022). By finishing the projects with earlier due dates first, EDD aims to reduce overall tardiness or lateness of jobs (Lushchakova, 2006). The due date is taken into account for each work, and the jobs are arranged in ascending order of their due dates. Jobs that have the earliest deadlines are booked ahead of those that have later deadlines. Even while the restrictions have their uses, they might not always result in the best overall performance when it comes to lowering other scheduling criteria like makespan or total completion time (Jiang, Lee, & Michael, 2021).

The order is made first as it is the milestone with the earliest delivery date in the project phase. To create a timed work queue in a three-station production area, this method must be considered to maximize total early work due to the same delivery day. Early completion of a job is a parameter defined as the total amount of work done before the time requested by the customer. This work mainly focuses on the unweighted model and proposes a dynamic programming approach that works in "O" time. This is studied by an approximation method where it has been shown that the Earliest Due Date (EDD) algorithm, best known in factory planning, can achieve only the most erroneous performance ratio for propagation optimal minimization problems. With the motivation to suggest better approximation algorithms. Finally, it is noted that the approximation results also work for the weighted model if a certain constraint is met (Chen, Miao, Lin, Sterna, & Blazewicz, 2022).

The first job to the station is done first. When the customer order reaches the seat belt assembly line, a production plan is taken according to the order of the order, and the "first come, first served" principle is kept in the foreground to manage the service requests in the name of equality. Most CSS studies do not directly model shared seat belt supply-demand interactions, especially when demand shortages arise. This work formulates the supply-demand dynamics of one-way CSS under different First Come First Serve (FCFS) mechanisms and puts them in the constrained rational dynamic user equilibrium (BR-DUE) problem. Two separate FCFS mechanisms have been proposed to improve the use of shared seat belts given the same CSS resources at the split time. To accurately capture CSS selection in space and time, a path-expansion strategy has been proposed to deal with different wait times under separate FCFS mechanisms. Numerical examples show that FCFS mechanisms have a significant impact on supply-demand dynamics and CSS selection (Wang & Liao, 2021).

One of the most basic scheduling principles is FCFS, which processes jobs in the order that they arrive. Reducing the lead time or waiting period for each task is the main objective. Jobs are booked according to the times of arrival. The first work that arrives gets handled first, and then the second task in the sequence of arrival. FCFS is simple to use and appropriate in situations where business priorities are not crucial or if arrival order is the only factor to be taken into account (Jia, Bard, Chacon, & Stuber, 2015).

One of its limitations is that FCFS might not be the best option for overall system performance. It doesn't account for work deadlines or processing times, which might result in wasteful use of resources or longer flow times (Winograd & Kumar, 1996).

While investigating APP and MRP concerns, it is determined that SAS issues are critical in production and assembly lines. Today, most of the goods we use to make our lives simpler are constructed. These things are sub-items that are sequentially merged to make the main product. The assembly line is the manufacturing mechanism utilized to create these items. This manufacturing system is made up of several workstations that are organized along with the material handling system. A series of jobs direct workers or robots to handle components at each workstation. Tasks are delegated to a predefined group of workstations depending on their priority relationship. To achieve acceptable productivity, the total cycle time per workstation and processing time of assemblies should not exceed. The ALB (assembly line balance) problem refers to the priority connections between activities. These challenges address the issue of distributing jobs to workstations to achieve a specified goal, such as decreasing cycle time for a given number of workstations or optimizing assembly line efficiency (Becker & Scholl, 2006). On the other hand, Abdelsalam et al. developed a mixed integer programming model. They solved it with GAMS by considering several scenarios to determine the current system's idle time and unused machine capacities. With the developed model, they mentioned that the proposed model maximizes the company's efficiency (Abdelsalam, et al., 2023).

A Gant Chart is created using assumptions such as the steps to be followed to solve the problem, arrival time, process time, and cycle time. A mathematical model is established, and a scenario analysis is made.

The rest of this study is structured as follows: Section 2 the proposed methodology of the problem is defined. In Section 3, the implementation and the numerical results are discussed. The conclusion of the proposed method is presented in Section 4.

GAMS and scenario analysis in the study. The Gantt Chart drawing shows the production cycle of the assembly line and the duration of the unfinished works, the estimation, and the estimation of the bottleneck situation for 3 assembly lines in the company. Transition times from all processed stations are observed at 174, 183, and 170 seconds. The most efficient method for line 1 in scenario analysis;

is time to completion: 6.5, Usage Capacity: 6.45%, average number of jobs completed in the system: 3.2, number of jobs delayed: 0.41, and FCFS method. The most efficient method in line 2; Completion time with EDD method: 12.5, Usage capacity: 38.67%, average number of completed jobs in the system: 2.58, number of delayed jobs: 4.5. on the 3rd line;

Average completion time: 16, Usage Capacity: 37.37, the average number of completed jobs: 2.67, and the number of delayed jobs: 7.5, the most efficient method is the SPT method.

## 2. Methodology

In this part of the study, methodology, data collection, analysis method, and flow chart of mathematical models are created. To overcome these challenges, are created a linear programming paradigm. SAS is a significant instrument in the management of production and operations. In everyday life, decision-makers are eager to discover an excellent strategy to properly manage resources to provide the most actual for the industrial and service industries. Scheduling is a timeline that comprises the start and finish timings of machine jobs, among other things. Machines are commonly used to refer to resources, whereas jobs or operations refer to tasks. The store is the setting for the scheduling problem. There are several sorts of shops utilized in scheduling difficulties, such as the job shop, mixed shop, flow shop, open shop, and so on. This paper describes the various methods to solve the SAS problem. Various works have been formulated to obtain the optimal solution in the field of scheduling problems. There are two different significant characteristics of other solution methods. The first characteristic is the quality of the solution, and the second characteristic is the computation time involved. This study classified these methods into the dispatching rules. Research and publication ethics were complied with in this study.

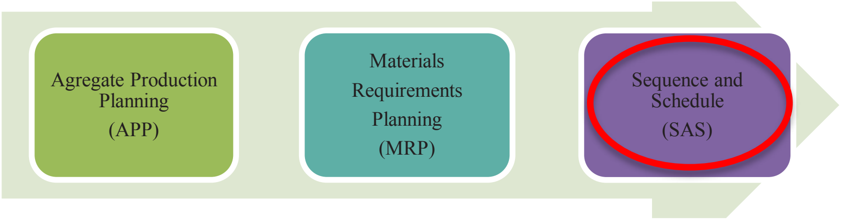



Figure 1. Production Planning and Control Relationship

In the Figure 1, orders from customers are gathered together by making an APP. All collected data is transferred to the relevant departments via MRP in order to prevent data loss and ensure correct information flow. The production, planning, supply, and related departments that receive this data initiate the necessary studies in order to realize production in a shorter and more efficient manner by making SAS.

### 2.1 Flow Chart of The Methodology

In Figure 2, a flow chart about the efficient capacity planning study process has been created. There is a need for some data about the Company in question.

These; machines used, machine capacities, production times and costs, setup time, customer order delivery date, order quantity, cycle process, transaction process, current stock, and other basic data. Thanks to the data obtained, past demands are analyzed, and production capacity is determined with ERP. An optimal result is obtained thanks to the linear mathematical model. In the SAS methods used, 4 different methods are used, and GAMS software is preferred for the solution of this model and the solution is collected from here. Optimum production planning according to the solution is realized as the lowest cost and maximum profit. These strategies and outcomes are discussed in order to expand the capability of the company.

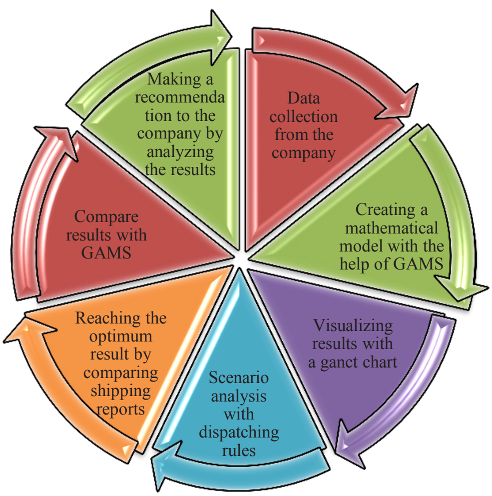



Figure 2. Proposed Methodology

In the Figure 2, the steps to be taken to achieve the optimal result are visually enriched. First, the data obtained from the company is collected. In order to attain the best possible outcome, a mixed integer programming model is constructed by sorting the workloads. After all the data are considered, a Gantt chart is created and at the end, a comparison is made by making a scenario analysis and a recommendation can be made to the company.

## 2.2 Data Collection and Analysis Methods

In this section, SAS analyses are made with the data taken from Ark Pres. First, the company's own planning method is observed. For example, in the weekly customer order, the production planning is determined according to the order dates. 4 strategies for this study are SPT, FCFS, EDD, and SLC. Details of the production process of the selected products are given below.

### 2.1.1 3 Point Seat Belt

This type of seat belt consists of 20 sub-products. There are 3 different types of this product in itself. The differences between these products are the variety of mechanisms. These products; Collector frame, Shaft, Rabbit, mainspring spring, Plastic cover, screw, Plastic gear, Angle element, plastic pin, triangle buckle, T-buckle, Bottom link bracket, Label, Sewing thread, plastic stopper, plastic cover with triangle buckle, Bolt, Isher, Belt, Plastic belt guide. It consists of 8 stations for the production of 3-point seat belts. Station 1 is 10 seconds, station 2 is 25 seconds, station 3 is 20 seconds, station 4 is 15 seconds, station 6 is 25 seconds, station 7 is 20 seconds, and station 8 is 22 seconds. In other words, a production process of around 2.50 is determined. A time loss of 6 seconds is determined between stations 1 and 2.

(a) (b) (c)

Figure 3. (a) 3Point AR3 Seat Belt (b) 3Point AR2 Seat Belt (c) 3Point All Age Seat Belt

In the Figure 3, different types of 3-point seat belts are added as a product image. The type (a) product mechanism has a newer and larger design, while the type (b) product has a smaller mechanism. Therefore, the belt wrapping feature of the (a) type product is higher than the (b) type product. Type (c) product is suitable for children's school bus/bus.

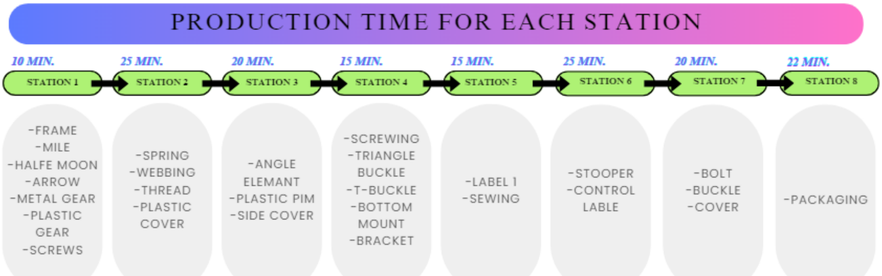


Figure 4. 3 Point Seat Belt Production Line

In the Figure 4 for visual to shows that the assembly line of the 3-point seat belt consists of 8 stations. There is a detailed explanation of the processing time of each station and the sub-product group assembled at this station. For a seat belt to become a product, it must complete these processes.

2.2.2 2 Point Seat Belt

This type of seat belt consists of 15 sub-products. There are 3 different types of this product in itself. The differences between these products are the variety of mechanisms. These products are collector frame, shaft, half-moon, mainspring, metal gear, plastic cover, screw, plastic gear, angle bracket, spring, label, plastic belt guide, bottom link bracket, plastic stopper, and belt. The construction of the 2-point seat belt consists of 7 stations. Station 1 lasts in 15 seconds, station 2 in 25 seconds, station 3 in 25 seconds, station 4 in 17 seconds, station 5 in 15 seconds, station 6 in 25 seconds, and station 7 in 14 seconds.

(a) (b) (c)

Figure 5. (a) 2Point ELR Seat Belt (b) 2Point Static Seat Belt (c) 2Point ALR Seat Belt

In the Figure 5 different types of 2-point seat belts are added as a product image. The technical feature of the (d) type product has a 3-point seat belt feature. Since it has a 2-point fastening feature, it is referred to as a 2-point seat belt. (e) type product does not have a mechanism. The fixation provision of this belt is also seen in the image. The product mechanism in the image (f) is different from all other seat belt mechanisms. The belt does not have a rewind mechanism feature.

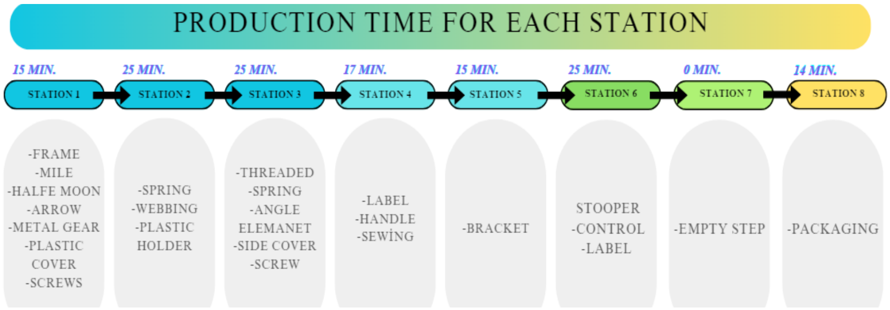



Figure 6. 2 Point Seat Belt Production Line

In the Figure 6 depicts the production process for the 2-point seat belt, which has 7 stations. In the image above, station 7 is an empty step, that is, a station that is not used in the 2-point seat belt assembly process. There is a detailed explanation of the processing time of each station and the sub-product group assembled at this station. For a seat belt to become a product, it must complete these processes.

### 2.3 Mathematical Modelling Approach

In this part of the study, there are the formulas of the constraints created from the sequence and scheduling perspective in order to calculate the objective function.

$$Min\ Z = \sum_{i=1}^{6} \sum_{i=1}^{6} U_{ij} \qquad \forall_{,j} \tag{1}$$

Equation 1 represents the objective function to minimize the time of unfinished work.

$$S_{ij} - A_{ij} \geq 0 \qquad \forall_{,j} \tag{2}$$

Equation 2 presents the processing of a model cannot start before the model arrives at the station.

$$S_{ij} - T_{ij} \geq -M * (2 - x(i,k) - x(1,k-1)) \qquad \forall_{,j} \tag{3}$$

Equation 3 symbolizes the starting time of a model art a station cannot be less than the finishing time of the model before itself.

$$T_{ij} - A_{ij} \geq c_{ij} \qquad \forall_{,j} \tag{4}$$

Equation 4 imitates a job must be finished at the station in a cycle time after its arrival.

$$T_{ij} \geq S_{ij} + P_{ij} \qquad \forall_{,j} \tag{5}$$

Equation 5 exemplifies the finishing time of a job is less than or equal to the sum of its starting time and its processing time.

$$U_{ij} \geq S_{ij} + P_{ij} - T_{ij} \qquad \forall_{,j} \tag{6}$$

Equation 6 represents the equation of unfinished jobs.

$$\sum_{i=1}^{6} X_{i,k} = 1 \qquad \forall_{,j} \tag{7}$$

Equation 7 describes every model should be assigned to a slot.

$$\sum_{k=1}^{6} X_{i,k} = 1 \qquad \forall_{,j} \tag{8}$$

Equation 8 presents a model that should be assigned to every slot.

This problem has been solved using the MIP model. Demand for production for use for products, available capacity per resource, worker-hour, machine-hour, raw material, production, inventory cost, and setup time data are used as parameters.

Data collecting is one of the basic elements of maintaining an effective, productive operation, as most industrial organizations will confirm. Having the capacity to analyze and manage production data may have a big influence on a company's ability to function and expand in a particular sector, and it can be the difference between flourishing and going out of business.

Cycle time is among the most important production KPIs. ERP and MES systems employ cycle time to schedule, buy, and budget manufacturing. While there are a plethora of metrics and KPIs to follow, Cycle Time is one of the most regularly evaluated in discrete manufacturing plants. Cycle time is the time it takes from the moment a produced Seat Belt gets started to the time it takes to get in the hands of our customers.

Cycle Time is the time a team works through the process before delivering the product. It is the amount of time required to execute a single job. This covers both the time spent making the item and the time spent waiting between active labor periods.

When calculating OEE (Overall Equipment Effectiveness), cycle time is also included. As a result, cycle time is the first to have a good full understanding of what a production activity is.

Scheduling and shipping rules are created to deal with uncertainty in the task process while monitoring the intended production in the mix. The facility's throughput is forecasted online, and the sequencing strategy is constantly altered as a result of the scheduling and dispatching rules.

In this study, it is tried to reach the optimal result by using the SAS method. In order to find the optimal order of the machines, a Gantt chart is created and commented on using GAMS software. In order to access this data, arrival time, process time, finishing time, and cycle time should be used. Therefore, the place of the cycle time here is very important.

### 2.4 Dispatching Rules

A dispatch rule is a rule that prioritizes all phases waiting to be processed on a station. The posting rule analyzes the jobs to be done and selects the job with the highest priority when the station is released.

Dispatching rules are called priority rules, scheduling rules, decision rules, or sequencing rules. These are the classical methods to solve scheduling problems based on the priority of jobs. Priority of jobs is defined as a function of shop characteristics, machine parameters, or job parameters. Generally, dispatching rules are applied without a proficient system. Therefore, for most scheduling problems, these rules do not have the guarantee to provide the optimum solution and are used as an initial sequence for improvement heuristics and metaheuristics methods.

Priority dispatching rules are the most often used scheduling strategy in job shops. The primary concept is to plan a work operation as quickly as feasible; if many productions waiting to be processed by the same station, schedule the one with the highest priority. A timetable and a Gantt Chart are simple to create. At the end of the day, this study aims to achieve the optimal timing by maintaining customer performance at its best level through shipment performance, average lead time, maximum lead time, average delay, maximum delay, number of delayed tasks, total and average preparation time performance data.

$$\text{Average Completion Time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} \tag{9}$$

$$\text{Utilization Metric} = \frac{\text{Total job work(processing)}\mathit{time}}{\text{Sum of total flow time}} \tag{10}$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work time}} \tag{11}$$

$$\text{Average Job Lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} \tag{12}$$

To calculate the average product assembly time in Equation (9), the total product flow time is divided by the number of stages. To calculate the current capacity utilization rate in Equation (10), the process time of the total jobs is divided by the total flow time. To calculate the average number of workflows on the assembly line in Equation (11), the total run time is divided by the total business process time. When calculating the average late work in Equation (12), the total number of days not completed is divided by the total number of jobs done.

Model Parameters Indicate

- i = 2PointAR3, 2PointALR, 2PointELR, 3PointH57, 3PointAR2, 3PointALLAGE
- j = Line 1, Line 2, Line 3
- k = Slot index 1, 2, 3, 4, 5, 6
- c = Cycle time
- at = Arrival time
- p = Process time

Model Variables

- z obj = minimizing the time of unfinished works
- $X_{ik}$ = Arrival time of two consecutive models at a station
- $A_{ij}$ = The arrival time of a pattern between two successive stations should be equal to the cycle time.
- $S_{ij}$ = Processing of a model cannot begin until the model arrives at the station.
- $T_{ij}$ = At a model station, the start time depends on the finish time of the previous jo

- $U_{ij}$ = Cycle time in arrival

## 3. Implementation and Results

The GAMS output, cycle time, SPT, LPT, EDD, FCFS calculations, the numerical results, the comparison of performance measures, and a summary of rules are discussed. After the applied methods, the results obtained from GAMS are compared.

Table 1. GAMS Production Plan

| Sequencing / Product | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 2PointAR3 | | | | | | |
| 2PointALR | | | | | | |
| 2PointELR | | | | | | |
| 3PointH57 | | | | | | |
| 3PointALLAGE | | | | | | |
| 3PointAR2 | | | | | | |

The analysis made in GAMS shows that; In order to produce 6 seat belts (models), the machines (assembly line) are assigned to the GAMS Production Plan in the Table 1.

Table 2. Cycle Time

| Product Name | Line1 | Line2 | Line3 |
|---|---|---|---|
| 3PointALLAGE | 26 | 38 | 34 |
| 3PointH57 | 32 | 30 | 28 |
| 2PointELR | 31 | 29 | 33 |
| 2PointAR3 | 28 | 25 | 30 |
| 2PointALR | 29 | 25 | 27 |
| 3PointAR2 | 28 | 23 | 31 |
| Total Time | 174 | 170 | 183 |

In the Table 2, there are cycle time details of 6 different seat belts for each assembly line.

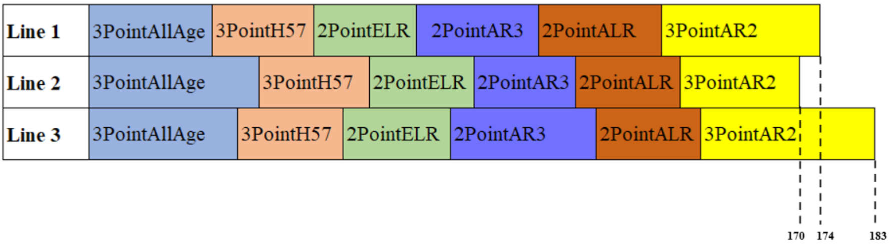



Figure 7. Gantt Chart From GAMS

Gantt chart assignments in the Figure 7 are made with GAMS software. According to the result of GAMS analysis, Line 2 makes the shortest and most efficient production.

Table 3. Gams Results For Unfinished Works

| Product | Line 1 | Line 2 | Line 3 |
|---|---|---|---|
| 2PointAR3 | 109 | 104 | 111 |
| 2PointALR | 100 | 96 | 99 |
| 2PointELR | 112 | 109 | 107 |
| 3PointH57 | 139 | 136 | 131 |
| 3PointAR2 | 128 | 130 | 126 |
| 3PointALLAGE | 125 | 123 | 125 |

A mathematical model is developed in GAMS using the processing time, arrival time, cycle time, and due date data obtained from the company. Unfinished works, which is the purpose of this study, are clearly expressed in the Table 3 above with the results from GAMS.

### 3.1 Numerical Result of Proposed Method

Results obtained by the proposed methodology are depicted Tables 5, 6, 7, 8, 9, 10, 11, and 12.

3.1.1 Numerical Result of SPT

The SPT sequencing rule is that the job is completed first in the shortest time to process. The SPT Rule is the method of ordering the assembly process time of the product from the shortest to the longest. The product process calculation solved by this method is as in Table 4 below.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Line 1** | 2PointAR3 | 3PointALLAGE | 2PointELR | 2PointALR | 3PointAR2 | 3PointH57 |
| **Line 2** | 3PointALLAGE | 3PointH57 | 2PointELR | 3PointAR2 | 2PointALR | 2PointAR3 |
| **Line 3** | 3PointH57 | 2PointAR3 | 2PointALR | 2PointELR | 3PointALLAGE | 3PointAR2 |

Figure 8. SPT Gant Chart

The diagram in the Figure 8 is product sequences listing the shortest processing and cycle times of the SPT method for Line 1, Line 2, and Line.

Table 4. SPT Calculation Table

| | Line1 | Line2 | Line3 |
|---|---|---|---|
| Average Comletition Time = | 6,50 | 12,50 | 16,50 |
| Utilization Metric = | %45 | %39 | %37 |
| Average Number of in the System= | 2,23 | 2,59 | 2,68 |
| Average Job Lateness = | 0,42 | 4,67 | 7,50 |

For Line 1, Line 2, Equation (9), (10), (11), (12). The results in the Table 4 are calculated. The job completion time is the shortest on Line 1 and the longest on Line 3. In general, In the Table 4 minimized results are obtained in Line 1.

### 3.1.2 Numerical Result of LPT

LPT assignment is a rule in timed duration theory that prioritizes timed assignment jobs (or tasks) over non-increasing processing times.

| | | | | | | |
|---|---|---|---|---|---|---|
| Line 1 | 2PointAR3 | 3PointAL-LAGE | 2PointALR | 2PointELR | 3PointAR2 | 3Po-intH57 |
| Line 2 | 3PointAL-LAGE | 3PointH57 | 3PointAR2 | 2PointELR | 2PointALR | 2Poin-tAR3 |
| Line 3 | 3PointH57 | 2PointAR3 | 2PointALR | 2PointELR | 3PointAL-LAGE | 3Poin-tAR2 |

Figure 9. LPT Gant Chart

The diagram in the Figure 9 is product lines listing the longest processing and cycle times of the LPT method for Line 1, Line 2, and Line 3.

Table 5. LPT Calculation Table

| | Line1 | Line2 | Line3 |
|---|---|---|---|
| Average Comletition Time = | 13,92 | 16,33 | 26,67 |
| Utilization Metric = | %20 | %30 | %23 |
| Average Number of in the System= | 5,06 | 9,80 | 4,32 |
| Average Job Lateness = | 6,42 | 8,00 | 18,17 |

In the Table 5, the LPT schedule is calculated using Equation (9), (10), (11) and (12). According to the results, Line 1 gives the most optimal results compared to Line 2 and Line 3. Line 2 and Line 3, on the other hand, give more optimal results than Line 2 and Line 3 when compared to each other.

### 3.1.3 Numerical Result of EDD

The EDD assignment rule is: "Jobs are processed according to the due date, earliest due date first." Table 8 shows the Job, Processing time, Due Date, Flow Time, and Job Lateness.

| | | | | | | |
|---|---|---|---|---|---|---|
| Line 1 | 2PointAR3 | 3PointAL-LAGE | 2PointALR | 2PointELR | 3PointAR2 | 3Po-intH57 |
| Line 2 | 3PointAL-LAGE | 3PointH57 | 3PointAR2 | 2PointELR | 2PointALR | 2Poin-tAR3 |
| Line 3 | 3PointH57 | 2PointAR3 | 2PointALR | 2PointELR | 3PointAL-LAGE | 3Poin-tAR2 |

Figure 10. EDD Gant Chart

Based on the diagram in Figure 10 customer demand date (due date) for Line 1, Line 2, and Line 3, the incoming orders are distributed to 3 lines, and the production flow is determined.

Table 6. EDD Calculation Table

| | Line1 | Line2 | Line3 |
|---|---|---|---|
| Average Comletition Time = | 6,58 | 12,50 | 16,50 |
| Utilization Metric = | %44 | %39 | %37 |
| Average Number of in the System= | 2,26 | 2,59 | 2,68 |
| Average Job Lateness = | 0,42 | 4,50 | 7,50 |

The EDD chart in the Table 6 is calculated using Equations (9), (10), (11) and (12). When the results are examined, Line 1 usage rate is more beneficial than

Line 2 and Line 3. The job completion time is observed in the most optimal Line 1.

### 3.1.4 Numerical Result of FCFS

The FCFS assignment rule is processing jobs in the order they arrive at a machine or job center. Job, working time, Deadline, Flow Time, and Job Delay are shown in Table 7.

| | | | | | | |
|---|---|---|---|---|---|---|
| Line 1 | 2PointALR | 2PointAR3 | 2PointELR | 3PointH57 | 3PointAR2 | 3PointALLAGE |
| Line 2 | 2PointALR | 2PointAR3 | 2PointELR | 3PointH57 | 3PointAR2 | 3PointALLAGE |
| Line 3 | 2PointALR | 2PointAR3 | 2PointELR | 3PointH57 | 3PointAR2 | 3PointALLAGE |

Figure 11. FCFS Gant Chart

While creating the production order in Figure 11 the demands from the customer are distributed to Line 1, Line 2, and Line 3 lines according to the demand receipt date and flows are created. Production is planned by dividing the demands of the customer into 3 assembly lines.

Table 7. FCFS Calculation Table

| | Line1 | Line2 | Line3 |
|---|---|---|---|
| Average Comletition Time = | 9,33 | 15,67 | 18,67 |
| Utilization Metric = | %31 | %30 | %33 |
| Average Number of in the System= | 3,20 | 3,36 | 3,03 |
| Average Job Lateness = | 2,83 | 7,33 | 9,83 |

The FCFS chart in Table 7 is calculated using Equations (9), (10), (11) and (12). Calculations in this table are prioritized and calculated according to the order of work from the customer. Line 1 gives the best results, while Line 2 and Line 3 are close together.

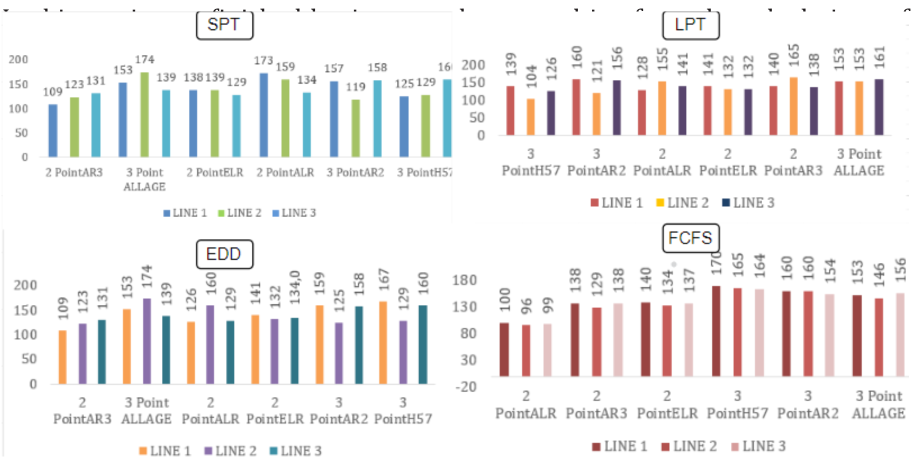
### 3.2 Summary of Dispatching Rules

As requested, a comparison is made in Table 8 First to order, first served Between the existing assignment rule using FCFS basis and the other two SPT, earliest end date EDD, and LPT program operation rules. The focus of the comparison is the determination of the best sequencing rule for the manufacture of The company Seat belts. The following are the findings.

Table 8. Average Detail Calculation

| Rule | Average Completion Time (days) | Utilization (%) | Average number of jobs in system | Average lateness (days) |
|---|---|---|---|---|
| FCFS | 16.17 | 29.29% | 3.49 | 8.06 |
| SPT | 11.83 | 40.30% | 2.50 | 4.19 |
| EDD | 11.86 | 40.11% | 2.51 | 4.14 |
| LPT | 18.97 | 24.56% | 6.30 | 10.86 |

### 3.3 Comparison of Performance Measures




In the Table 9, unfinished works according to SPT, LPT, EDD, and FCFS rules in scenario analyzes are shown in detail. When the analyses are compared, the average of the incomplete works is the LPT ranking. The highest is the SPT method.

Table 10. Dispatching Rules Compares

| | | FCFS | SPT | EDD | LPT |
|---|---|---|---|---|---|
| Line1 | Average Comletition Time | 9,33 | 6,50 | 6,58 | 13,92 |
| | Utilization Metric | 0,31 | 0,45 | 0,44 | 0,20 |
| | Average Number of in the System | 3,20 | 2,23 | 2,26 | 5,06 |
| | Average Job Lateness | 2,83 | 0,42 | 0,42 | 6,42 |
| Line2 | Average Comletition Time | 20,50 | 12,50 | 12,50 | 16,33 |
| | Utilization Metric | 0,24 | 0,39 | 0,39 | 0,30 |
| | Average Number of in the System | 4,24 | 2,59 | 2,59 | 9,80 |
| | Average Job Lateness | 11,50 | 4,67 | 4,50 | 8,00 |
| Line3 | Average Comletition Time | 18,67 | 16,50 | 16,50 | 26,67 |
| | Utilization Metric | 0,33 | 0,37 | 0,37 | 0,23 |
| | Average Number of in the System | 3,03 | 2,68 | 2,68 | 4,32 |
| | Average Job Lateness | 9,83 | 7,50 | 7,50 | 18,17 |

In Table 10, the average completed time, station usage rate, average work time in the system, and average delayed work are calculated. Looking at the data obtained, Line1 provides a clear advantage over Line2 and Line3 in calculating the average delayed work in the FCFS Method. It has also been determined that Line 1 is approximately 30% more efficient than Line 2 and Line 3 in terms of the time completed in the FCFS Method.

Table 11. Compares Of Scenario Analysis and GAMS For Unfinished Works

| EDD | | GAMS | EDD | | GAMS | EDD | | GAMS |
|---|---|---|---|---|---|---|---|---|
| LINE 1 | | | LINE 2 | | | LINE 3 | | |
| 2 PointAR3 | 109 | 109 | 3 Point ALLAGE | 123 | 123 | 3 PointH57 | 131 | 131 |
| 3 Point ALLAGE | 153 | 125 | 3 PointH57 | 174 | 136 | 2 PointAR3 | 139 | 111 |
| 2 PointALR | 126 | 100 | 3 PointAR2 | 160 | 130 | 2 PointALR | 129 | 99 |
| 2 PointELR | 141 | 112 | 2 PointELR | 132 | 109 | 2 PointELR | 134 | 107 |
| 3 PointAR2 | 159 | 128 | 2 PointALR | 125 | 96 | 3 Point ALLAGE | 158 | 125 |
| 3 PointH57 | 167 | 139 | 2 PointAR3 | 129 | 104 | 3 PointAR2 | 160 | 126 |
| SPT | | GAMS | SPT | | GAMS | SPT | | GAMS |
| LINE 1 | | | LINE 2 | | | LINE 3 | | |
| 2 PointAR3 | 109 | 109 | 3 Point ALLAGE | 123 | 123 | 3PointH57 | 131 | 131 |
| 3 Point ALLAGE | 153 | 125 | 3 PointH57 | 174 | 136 | 2PointAR3 | 139 | 111 |
| 2 PointELR | 138 | 112 | 2 PointELR | 139 | 109 | 2PointALR | 129 | 99 |
| 2 PointALR | 173 | 100 | 3 PointAR2 | 159 | 130 | 2PointELR | 134 | 107 |
| 3 PointAR2 | 157 | 128 | 2 PointALR | 119 | 96 | 3PointALLAGE | 158 | 125 |
| 3 PointH57 | 125 | 139 | 2 PointAR3 | 129 | 104 | 3PointAR2 | 160 | 126 |
| LPT | | GAMS | LPT | | GAMS | LPT | | GAMS |
| LINE 1 | | | LINE 2 | | | LINE 3 | | |
| 3 PointH57 | 139 | 139 | 2 PointAR3 | 104 | 104 | 3 PointAR2 | 126 | 126 |
| 3 PointAR2 | 160 | 128 | 2 PointALR | 121 | 96 | 3 Point ALLAGE | 156 | 125 |
| 2 PointALR | 128 | 100 | 3 PointAR2 | 155 | 130 | 2 PointELR | 141 | 107 |
| 2 PointELR | 141 | 112 | 2 PointELR | 132 | 109 | 2 PointALR | 132 | 99 |
| 2 PointAR3 | 140 | 109 | 3 PointH57 | 165 | 136 | 2 PointAR3 | 138 | 111 |
| 3 Point ALLAGE | 153 | 125 | 3 Point ALLAGE | 153 | 123 | 3 PointH57 | 161 | 131 |
| FCFS | | GAMS | FCFS | | GAMS | FCFS | | GAMS |
| LINE 1 | | | LINE 2 | | | LINE 3 | | |
| 2 PointALR | 100 | 100 | 2 PointALR | 96 | 96 | 2 PointALR | 99 | 96 |
| 2 PointAR3 | 109 | 100 | 2 PointAR3 | 129 | 104 | 2 PointAR3 | 138 | 104 |
| 2 PointELR | 140 | 112 | 2 PointELR | 134 | 109 | 2 PointELR | 137 | 109 |
| 3 PointH57 | 170 | 139 | 3 PointH57 | 165 | 136 | 3 PointH57 | 164 | 136 |
| 3 PointAR2 | 160 | 128 | 3 PointAR2 | 160 | 130 | 3 PointAR2 | 154 | 130 |
| 3 Point ALLAGE | 153 | 125 | 3 Point ALLAGE | 146 | 123 | 3 Point ALLAGE | 156 | 123 |

Scenario analysis is calculated in Table 15 and applied according to the data obtained; Among the FCFS, SPT, EDD, and LPT methods, the most efficient is determined as the SPT Method for Line 1, EDD Method for Line 2, and SPT for Line

3. The data in this table represent unfinished works. When Table 14 and Table 15 are compared, it is observed that GAMS results are much more efficient than scenario analysis.

## 4. Conclusion

Maximum efficiency is tried to be obtained from the assembly line by using the GAMS program and FCFS, SPT, EDD, and LPT methods in the assembly line of Ark Pres company. There are 3 stations in the assembly line in the company. 7 workers for 2-point seat belts and 8 workers for 3-point seat belts work at these stations. As a result of the analysis, unfinished works and bottlenecks on the stations are determined. Necessary information is obtained from the company to find solutions to these problems. This information; cycle time, input time, manpower, customer demand, and production process at stations. First, is determined the cycle time of the products, the time of the entry of the products to the station, the installation time, and the unfinished works in the GAMS program. Then, the bottleneck rate in the company is determined by creating the Gantt chart diagram. In this way, the product order has been updated again to minimize the bottleneck in the stations. Incomplete works from the GAMS program are analyzed. The analyses made and the scenario analysis is made are compared. Scenario analysis is made according to the results of FCFS, SPT, EDD, and LPT methods. Methods are calculated according to customer demand. In the scenario analysis, it is observed that different methods are efficient in 3 stations. It has been analyzed that the SPT method is more efficient than other methods in terms of capacity utilization and completion time at Line 1 station. The minimum time loss in terms of the average delayed job in Line 2 is determined in the EDD method. In Line 3, the SPT and EDD methods are found to be the same and it is observed that these two methods are more efficient than FCFS and LPT methods in terms of average delayed work, capacity utilization, completed work, and average number of works in the system. The values found in the GAMS are compared with the values found in the methods. It has been observed that the values found in the GAMS of the average incomplete work process of the stations are better than the values found in the scenario analysis. As a result, in the study, a solution proposal is presented for the product ordering of the company's station use and the bottleneck problem resulting from this.

## 5. Conflict of Interest

No conflict of interest is declared by the authors.

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