SEPTEMBER 2019 M.Sc. in Industrial Engineering HÜSEYİN KARATAŞ

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MULTIMANNED ASSEMBLY LINE BALANCING PROBLEM: A CASE STUDY IN BACKHOE LOADER MANUFACTURER

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Supervisor

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This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Hüseyin KARATAŞ

ABSTRACT

MULTIMANNED ASSEMBLY LINE BALANCING PROBLEM: A CASE STUDY IN BACKHOE LOADER MANUFACTURER

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M.Sc. in Industrial Engineering

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When large quantities are ordered for long periods for a final product, it is more economical and logical for firms to make a special layout for this product. Assembly lines are a special form of placement systems according to the product. In this system, tasks are the smallest and indivisible state of a job. In the formation of the system, the tasks are sequentially arranged in order according to the relationship of precedence between them. As a result, assembly lines are the system in which raw materials or semi-finished products leave the end of the line as final products. The main purpose of an assembly line is to meet the demands of large quantities of products in the most economical and fast manner. The assembly lines of high volume products such as buses, trucks, and helicopters differ from traditional lines examined in the literature. In the production processes of these products, there are long working times and a great number of tasks. Assembly lines with 1 worker (traditional assembly lines) or 2 workers (two-sided assembly lines) at each workstation are not suitable for this type of product. Multi-manned assembly lines allow workers to perform in more than one and varying numbers at each workstation. At this point, the assembly process can be performed with fewer workstations and lower cycle time. There is not much research on a multi-manned assembly line balancing problem. However, research on the multi-manned assembly lines has accelerated in the recent years. In this study, a mathematical model and heuristic algorithm were developed for balancing the multi-manned assembly line of a fabrication of assembly, which unlike traditional assembly line balancing. This study presents heuristic algorithm which is based on COMSOAL method to balance the assembly line. This model aims to minimize the workstation number. Thanks to this model, a reasonable workstation gain was achieved in the assembly line of the manufacturing factory. In order to meet the needs of the factory, the model was also run according to different production speeds.

Key Words: Assembly Line Balancing, Multi-manned Assembly Line, Mathematical Model, Heuristic Algorithm, COMSOAL

ÖZET

ÇOK ADAMLI MONTAJ HATTI DENGELEME PROBLEMİ: BEKO LODER ÜRETİM FABRİKASINDA BİR VAKA ÇALIŞMASI

KARATAŞ, Hüseyin

Yüksek Lisans Tezi, Endüstri Mühendisliği

Danışman: Doç. Dr. Eren ÖZCEYLAN

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69 sayfa

Nihai bir ürün için uzun dönemler boyunca büyük miktarlarda siparişler söz konusu olduğunda, bu ürüne özel bir yerleşim yapmak, çoğu durumda firmalar için daha ekonomik ve mantıklı olabilmektedir. Montaj hatları ürüne gore yerleşim sistemlerinin özel bir halidir. Bu sistemde görevler bir işin en küçük ve bölünemez halidir. Sistemin oluşumunda görevler, aralarındaki öncüllük ilişkilerine gore art arda sıralanır. Neticede montaj hatları, hammadde veya yarı mamülün hattın sonundan nihai ürün olarak çıktığı sistemdir. Bir montaj hattının temel amacı, ürüne olan büyük miktarlardaki taleplerin, en ekonomik ve hızlı şekilde karşılanmasıdır. Otobüs, kamyon ve helikopter gibi büyük ve geniş boyutlu ürünlerin montaj hatları, literatürde incelenen geleneksel hatlardan farklıdır. Bu ürünlerin üretim süreçlerinde, uzun iş süreleri ve çok fazla sayıda görev vardır. Her istasyonda 1 işçi (geleneksel düz montaj hatları) veya 2 işçi (çift taraflı montaj hatları) olan montaj hatları bu tip ürünler için uygun değildir. Çok adamlı montaj hatları her istasyonda birden fazla ve değişen sayılarda işçi çalışmasına izin veren hatlardır. Bu sayede, daha az sayıda istasyon ve daha düşük çevrim zamanı ile montaj işlemi gerçekleştirilebilmektedir. Çok adamlı montaj hattı dengeleme üzerine çok fazla çalışma bulunmayıp konu ile ilgili çalışmalar son dönemde hız kazanmıştır. Bu çalışmada, geleneksel montaj hattı dengelemeden farklı olarak, iş makinası üretimi yapan bir fabrikanın çok adamlı montaj hattı dengelemesi için matematiksel model ve COMSOAL sezgisel model geliştirilmiştir. Bu model sayesinde üretim yapan fabrikanın montaj hattında iyi bir istasyon kazanımı sağlanmıştır. Yapılan bu çalışmanın fabrikanın gereksinimini karşılaması için de farklı üretim hızlarına gore de model çalıştırılmıştır.

Anahtar Kelimeler: Montaj Hattı Dengeleme, Çok Adamlı Montaj Hattı, Matematiksel Model, Sezgisel model, COMSOAL

''To My Parents''

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LIST OF ABBREVIATIONS

AL	Assembly line
ALB	Assembly line balancing
ALBPs	Assembly line balancing problems
COMSOAL	Computer method of sequencing operations for assembly lines
JIT	Just in time
MAL	Multi-manned assembly line
MALBP	Multi-manned assembly line balancing problem
MIP	Mixed integer programming
TOPSIS	Technique for order preference by similarity to ideal solution
WIP	Working in process
WM	Workstation minimization
WWM	Workstation and worker minimization

CHAPTER I

INTRODUCTION

1.1 Assembly line description

The assembly line (AL) is a system consisting of a serial of workstation with a material handling system. The purpose of system is to assemble the components of a product and obtain the finished product (Özdemir et al., 2004). The assembly process consists of a sequence of tasks or workpieces. The installation of a workpiece must be made by looking at the predecence relation at the under given cycle time and workstation. When the line of the product to be assembled is designed, the problem of balancing the time differences between the operations of the product arises.

The one of the important objective in ALB is to minimize the number of workstations/cycle times with the same processing time on the line. The main purpose of ALB is to ensure an even distribution of the total workload in the assembly line. For this purpose, the workpieces are assigned to the workstations according to their predecence relationships with each other and their idle times. This problem is called the assembly line balancing problem(ALBP) in the literature (Kılınçcı, 2004).

In the production process, it is understood that the product to be produced will be divided into more than one workpiece and the processes of these workpieces can be made by different workers. By this way, faster and cheaper products can be made. As a result, the workpieces are started to be executed on a specific line with multiple workstations. Each of the components to be processed on this line is combined by taking into account constraints such as predecence relationships and cycle time, and consequently, workstations are formed (Kalender et al., 2008).

One of the main objectives of the assembly lines is to distribute the workload equal to each workstation. The difference in workload is a factor that reduces line efficiency. Lines can be arranged in different ways according to the features during the processing of the product.

The objectives that need to be achieved when installing an assembly line are:

- To ensure a regular flow of material
- To use labor and machine capacities at the highest level
- Completing transactions as soon as possible
- Minimization of the number of workstations on the assembly line
- Minimize idle times
- Uniform distribution of waste times between workstations to minimize production costs (Tanyaş and Baskak, 2003).

Production, which is a human activity, is the result of not meeting the human needs fully by nature; Although it is defined as creating benefits by economists. According to engineers, it is a process of making a change in a physical entity that increases its value or converting raw materials or semi-finished products into a usable one. Assembly lines (Figure1.1) are a special form of placement systems according to the product. In this system, tasks are the smallest and indivisible state of a job. In the formation of the system, the tasks are sequentially ranked according to the relationship of precedence between them. As a result, assembly lines are the system in which raw materials or semi-finished products leave the end of the line as final products. The main purpose of an assembly line is to meet the large demands on the product in the most economical and fastest way.

Multi-manned assembly lines allow workers to perform in more than one and varying numbers at each workstation. At this point, the assembly process can be performed with fewer workstations and lower cycle time. It is possible to mention the very important advantages of a multi-manned assembly line compared to the traditional assembly line (Figure 1.1a). Multi-manned assembly line allows simultaneous operation of more than one worker at the same workstation.So, the length of the multi-manned assembly line is significantly shortened. Meanwhile, the overall efficiency of the line, ie the production speed and the amount of idle time, remains at the same level as the traditional assembly lines (Roshani,2017).

The total physical area,, which takes place with the multi-manned assembly line, emerges as a new parameter in the objective function in large assembly lines in practice. Especially in the case of new line installations, if the physical space constraint is the subject, physical space optimization is included the main objectives. In addition, in a shorter assembly line, the product output period and the number of semi-finished products (WIP) processed at workstations are decreasing. the cost of material handling is minimized in multi-manned assembly lines. This also minimizes the hand tools, parts and product requirements of the workers. The common use of tools such as hand tools, airlines, and power outlets by the same workstation worker also saves material and time. Considering these advantages, it seems to be reason enough to benefit from the multi-manned assembly lines (Figure 1.5).

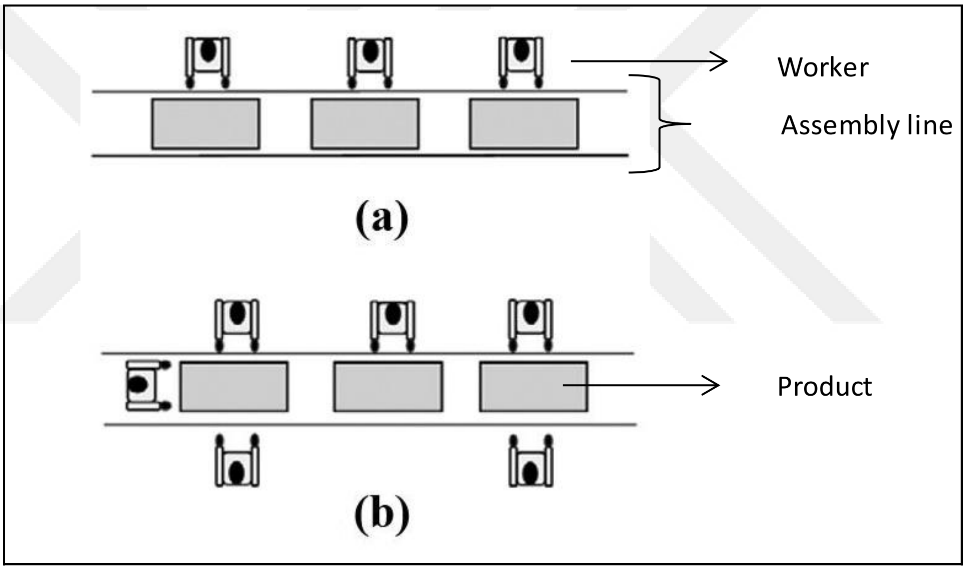

Figure 1.1 (a) Traditional assembly line and (b) Multi-manned assembly line

There is enough study in the literature on traditional assembly line balancing problems. However, the number of researchers who have addressed MALs is limited. To our best knowledge, the design and balancing of MALs were first studied by Dimitriadis (2006). He developed a two-level heuristic based on the algorithm of Hoffmann (1963) for the problem and applied it to solve various experimental problems and after this study, studies on MALBP has accelerated in recent years.

In this study, a mathematical model was developed for balancing the multi-manned assembly line of a fabrication of assembly, which unlike traditional assembly line balancing. This study gives a mixed-integer programming model to balance the assembly line. The proposed model aims to minimize the workstation number. In this way, both the productivity of the assembly line will be increased and the cost will be minimized. The validity of the model has been tested by solving a small sample problem. Thereafter in this study, unlike traditional assembly line balancing, COMSOAL heuristic algorithm has been presented for multi-manned assembly line balancing of a factory producing machine.

In this thesis we are dealing with a factory with it's 42,000 m^2indoor facilities, with the state of the art technology, in Gaziantep, produces Backhoe loader, Telescopic Forklift(Telehandler), Mini Excavator and Maxi Excavator and add value to our national industry. Assembly line layout of backhoe loader is given below (Figure 1.1).

In this factory, the backhoe loader has a high production speed. In this thesis, we are dealing with MALBP of the backhoe loader assembly line (Figure1.2). In AL, there are subassembly lines which are shown in Figure 1.3, Figure 1.4 and Figure 1.5.

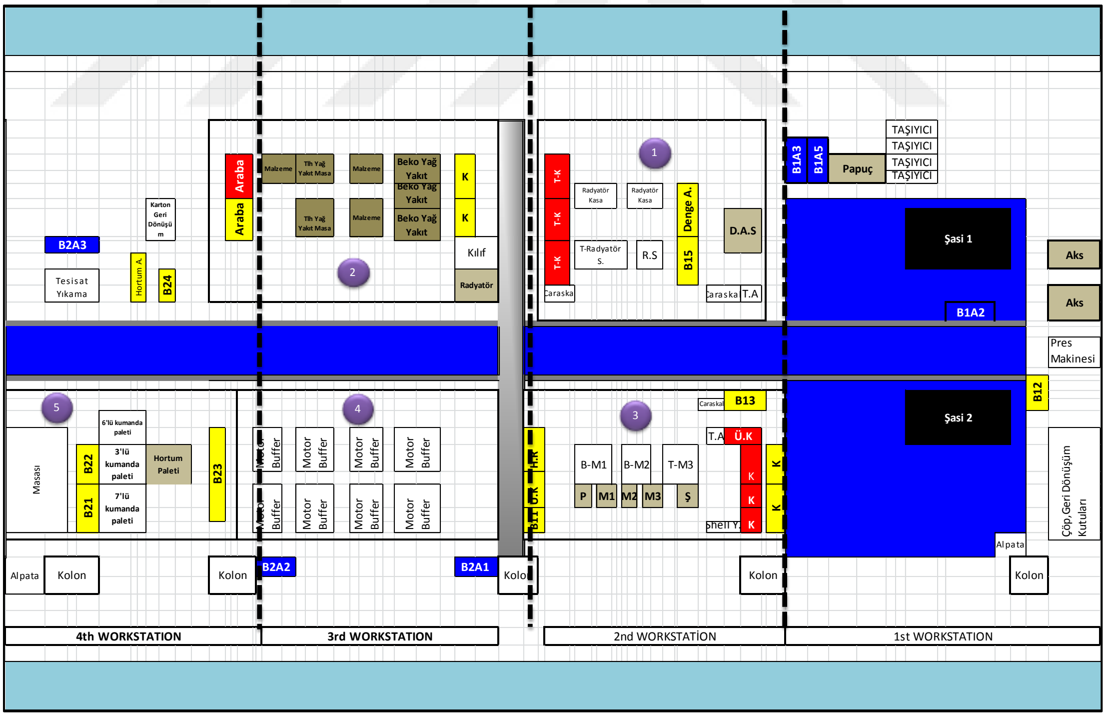

Figure 1.2 Assembly line layout of Backhoe Loader

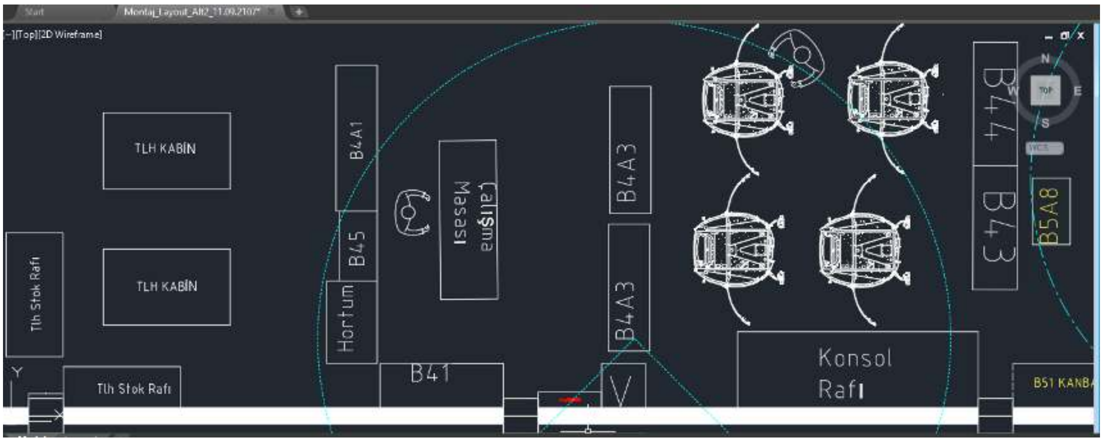

Figure 1.3 Cabin subassembly line layout of Backhoe Loader

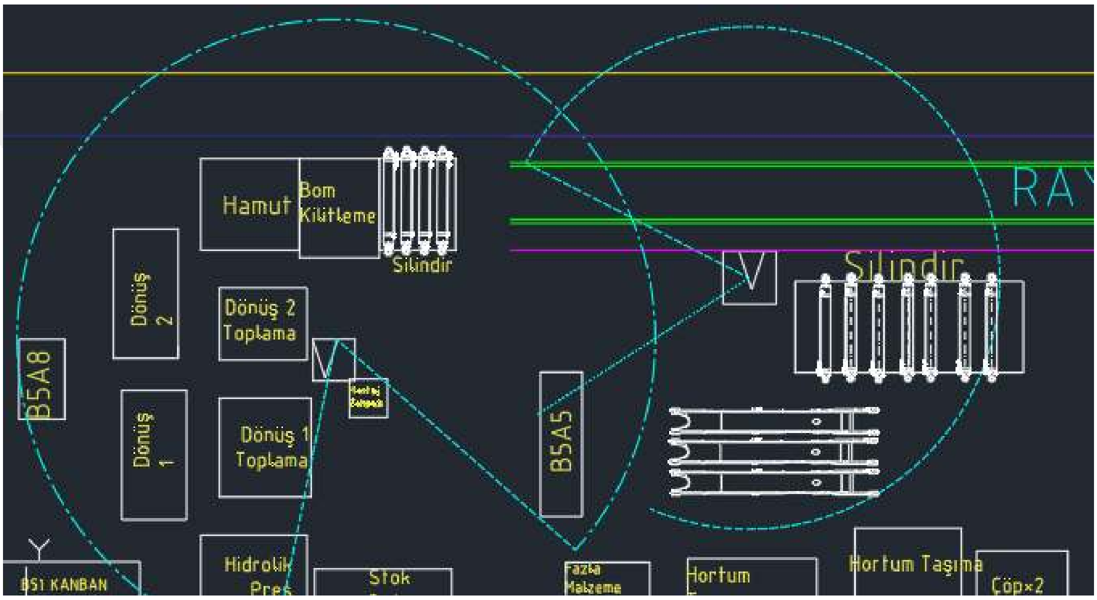

Figure 1.4 Component subassembly line layout of Backhoe Loader

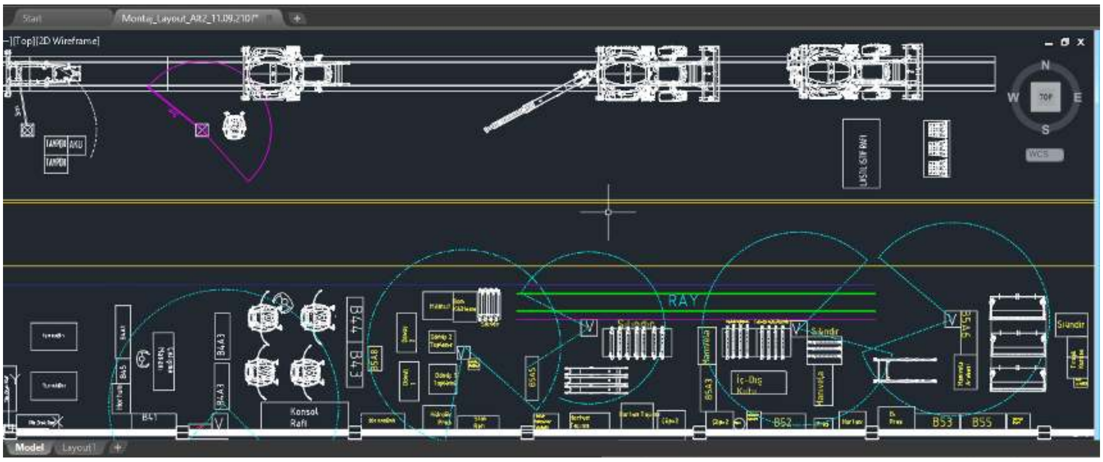

Figure 1.5 Component and cabin assembly line layout of Backhoe Loader

1.2 Thesis Organization

Chapter 2: The literature review is presented in this chapter. We especially focused on ALBP. Previous studies are given detailed information about them and MALBP.

Chapter 3: ALBP is defined in this chapter and given information about specific qualities of them. Assumptions of each problem are described. Then ALBP is defined in detail. Problem definition of the thesis is also given in this chapter.

Chapter 4: Mathematical model of ALBP is presented in this chapter.

Chapter 5: Solution methods are represented to solve ALBP. COMSOAL which is an efficient heuristic method for ALBP is selected among them and explained with an example.

Chapter 6: Results and their effects on performance of proposed mathematical models and COMSOAL method is analyzed in this chapter.

Chapter 7: The summary of the study and the conclusions are given in the last chapter. Also some aspects for the future work are discussed.

CHAPTER II

LITERATURE REVIEW

2.1 Basic Concepts Used in Assembly Line Balancing

The objective of assembly line balancing is to assign operations to workstations in a way that optimizes the appropriate performance criterion that measures line performance under certain constraints (time of transport, assignment of workers and their standard times) (Çelikçapa, 1999).

Workpiece: It is a logically divided part of the total work content in the production process. According to another opinion; the total work to be completed in a few steps and the stages that determine them, the work is enough and meaningful division of the result of the resulting units and actions to be performed (Uzmen, 1990).

Predecence Relations: To perform the assembly process, some workpieces must be done before and after some workpieces. The assignment of these workpieces to workstations must be done by considering these predecence relationships, otherwise, the assembly process cannot be performed due to missing or incorrect order (Tanyaş and Baskak, 2003).

Workstation: It is the name given to the areas where the operators of the assembly line work. For an assembly line; There are constraints where the number of smallest workstations is one and the maximum number of workstations detected during the workstation number balancing operation should not be exceeded(Çelikçapa, 1999).

Positional Constraint: Mounted with the position of the processor on the line refers to the relationship between the position of the object. The processor must be comfortable to move around the product to be assembled. This distance should be adjusted for assembly line balancing, so as not to restrict other equipment and processors.

Fixed equipment constraint: Fixed devices, such as machine tools, test tools, are integral parts of assembly lines and form unchangeable workstations. A fixed hardware constraint reduces the interchangeability of workpieces.

Workstation Load: In some cases, the workstation load can be minimized. In particular, it may be desirable to have a cycle time of less than 100% at these workstations in order not to reflect any disruptions at the beginning of the assembly line(Diri et al. 2015).

Workpieces Desired to Be Assigned to the Same Workstation: Workpieces with this feature must be assigned to the same or following workstations. For example, doing two workpieces requiring the use of special devices by the same worker is a desirable situation because it eliminates the need for a second device (Diri et al. 2015).

Workpieces Not to be Assigned to the Same Worktation: Some workpieces are not required to be assigned to the same workstation with some other operations. For example, it is unthinkable to perform a high-vibration process with a precise measurement process on the same workstation (Tanyaş and Baskak, 2003).

Total Work Time: It is the total time spent during the installation of the product to be produced, it can also be found by to sum up the standard times of each workstation.

Workstation Time: The sum of the time it takes to perform all of the work steps on a workstation. The longest processing time in the workstation cannot be smaller than the step and the cycle time of the line.

Cycle Time: This is the processing time of the workstation with the longest processing time during the installation of the product or the longest cycle time that the product can remain in a workstation. During assembly, the product may span up to the maximum cycle time on each station. For this to happen, this time must pass. Production speed can be calculated based on this period. The most important concept used in the calculations related to the assembly line (Diri et al. 2015).

Cycle time calculation; $C = T / N$

C = Cycle time

T = total duration

N = Daily demand

t_i: task time of task i

When we assign the operations in the assembly line to the workstations, the number of workstations required is N;

$$N=\sum ti/C$$

Loss of Balancing: Indicates the imbalance in the distribution of operations to workstations. The loss of balancing is desired to be ’0’. A unit is found by dividing the difference between the total time allocated for production and the required time, which is usually greater than zero.

$$D=(N*C- \sum ti)*100/N*C$$

We can devide the assembly line balancing problem into two parts and one solution brings the other:

1. By assigning the required cycle time and determining the time, predecence and area of each task, the minimum number of workers is determined to perform the tasks in the assembly line (Type-1).

2. By assigning a certain number of workers and knowing the time, predecence, and sequence of each task, the cycle time required to complete an assembly is determined (Type-2) (Zorlu, 2000).

2.2 Classification of Assembly Lines

There are many ways to classify assembly lines;

2.2.1 Assembly Lines according to Work Structure

According to the structure of the work, there are two types of assembly lines; manual or automatic assembly lines. There are multiple workstations in the manual lines until the product reaches the last workstation and exit as a product. Part of the total workload at each workstation is performed by one or more workers. When balancing these types of assembly lines, where the human factor is at the forefront, it is necessary to take into account the more diverse criteria than automatic lines. In automatic lines, work on workstations and transfers between workstations are done automatically (Yerasi, 2011).

There are also two ways of transfer between workstations; use non-mechanical lines or moving lines. In non-mechanical lines, parts pass from one workstation to another manually. In others, moving conveyors are provided.

2.2.2 Assembly Lines according to Model Types

There are three types of the assembly lines according to the model type;

- Single Model Lines: They are used in the production of a single product or model.
- Multimodel Lines: Different models are produced in these lines. Different models are produced separately. At a given time, a product is produced as a batch, from the back to the production of other models. Models can be different models of the same product or it can be different products. In both cases, the products are not the same but have similar production needs. In practice, the assembly line is prepared for the first model. Then the second, third, etc. Even the necessary arrangements are made for the party production of the models.
- Mixed Model Lines: The lines where more than one similar type of models are produced at the same time. The most important benefit of mixed-model production is that different models are continuously produced and do not require large finished product stocks to meet customer demand. The disadvantages of the models due to different periods are that the workflow is not regular, so there are more workstation idle times and semi-finished products (Acar and Estas, 1991).

2.2.3 Assembly Lines according to the Location of the Workstations

According to their physical location, assembly lines can be designed in various forms such as straight, circular, random, different angles, U-shaped. Conventional assembly lines are designed flat. Later, U-lines became more preferred in new production lines. U type lines are more preferred lines for JIT systems. According to their functional structure, they are classified as series, compound, parallel and feeder assembly lines (Erkut and Baksak, 1997). If the processing times of some jobs exceed the cycle time, parallel or multiple workstations can be used for balancing. With parallelism, more stable lines can be achieved with fewer workstations.

2.2.4 Delayed or Non-delayed Assembly Lines

In the design of an assembly line, a choice should be made between a delayed or non-delayed line design. Because the continuity of the line will be connected accordingly. Even each workstation is given an equal amount of time to produce each product unit without delay (cycle time). At the end of this cycle time, the system automatically assumes that the new workstation is switched. If there are unfinished jobs, they can be completed at a new workstation at the end of the line. On delay, even if a job is completed, a new job is taken. Jobs are allowed to complete, but the amount of delay in the line should also be thoroughly examined (Alağaş, 2013).

2.3 Bottleneck Investigation in Assembly Lines

To determine the method and order to be followed in the investigation of the bottleneck, which is one of the important problems of the production systems, the distinction of production factors (material, machine, labor, method) can be utilized.

- Material bottleneck research; This standard covers raw materials, semi-finished products, finished products, and auxiliary materials.
- All machinery, equipment and all kinds of tools, control and measurement devices are included in the machine bottleneck investigation.
- In human bottleneck research, all problems related to human beings, worker and manager performances and relations between them are taken into consideration.
- In the method bottleneck investigation, management problems such as technical and organizational planning, regulation, cost control, and investment are discussed.

2.4 Assembly Line Balancing Methods

The traditional assembly line balancing problem takes into account the production process in which the tasks are assigned to different workstations to create products.

The distribution of tasks between workstations depends on existing predecence constraints between tasks, as well as the time unit required to complete each task. The product is allowed to remain in each workstation for up to the time called the maximum cycle time (C). The production line modeled in the traditional assembly line balancing problem is organized as a straight line. The balance is created by starting from the first task in the predecence diagram and grouping the tasks in the workstations throughout the diagram (Kalender et al., 2008).

One of the important issues in the assembly lines is the completion time of each operation. The first analytical approach to assembly line balancing problems was made by Bryton in 1954 and many methods were developed thereafter (Acar and Eştaş, 1991).

These methods can be examined in two groups. In the first group, methods that find the optimal solution of the problem (analytical methods); The second group consists of heuristic methods that give the best solutions (Heuristic methods) (Acar and Eştaş, 1991).

2.4.1 Analytical Methods

These methods are also called optimization methods. Linear integer programming developed by E. H. Bowman(1960), 0-1 integer programming by Talbot and Patterson and dynamic programming approaches developed by Karp-Held-Shareshian are examples of analytical methods.

The methods consist of objective function and constraints. However, the increase in the number of transactions in these methods complicates the solution and becomes difficult to reach (Tanyaş and Baskak, 2003).

2.4.2 Heuristic Methods

These methods provide an approximate solution of balancing assembly lines by monitoring a particular procedure and making certain assumptions. In most of the methods, the cycle time is assumed to be fixed and the number of workstations and accordingly the balancing loss is minimized. There are quite several intuitive methods developed so far.

Some heuristic methods in the literature are as follows:

- Position-weighted balancing technique (Helgeson-Birnie)(1961)
- Progressive sequencing solution (Jackson)(1988)
- Solution with predecence diagram (Hoffman)(1973)
- Solution with candidate matrix (Salveson)(1955)
- COMSOAL technique (Arcus)(1966)
- Related activity method (Agrawal)(1977)
- Two-stage balancing technique (Moddie-Young)(1965)
- Kilbridge-Wester method(Kilbridge-Wester)(1961)
- Probabilistic line balancing (Elsayed-Boucher)(1985)
- Raouf-Tsui-Elsayed method(Raouf, A., Elsayed, EA. and Tsui, CL)(1980)
- Grouping method (Tonge)(1961)

Especially in the literature, methods developed by Jackson, Kilbridge-Wester, and Salveson come to the fore.

Branch-bound algorithms are used in the majority of the best solution based methods for assembly line balancing problems. Küçük and Keskinturk(2006) used a genetic algorithm solution method in a study of balancing an assembly line.

In conventional assembly line balancing problems, as the problem size increases, the methods that find the best solution has been replaced by the use of heuristic methods and the researches have shifted in this direction. For example, the shortest path method that can be used in the heuristic algorithms to solve the U type assembly line balancing problems was applied by Aydoğan et al.(2004) in his study which is "For Simple U Type Assembly Line Balancing Problem A New Optimal Solution Method: Shortest Path Model ". In this study, the shortest path model for the simple U type assembly line balancing problem has been developed. The model is based on the shortest path model which is developed by Gutjahr and Nemhauser (1964) for the traditional single-model assembly line balancing problem.

During World War II, the great mathematician Jhon Van Neumann developed the Monte Carlo Simulation Technique, a new technique from this technical military and operational games (Render and Stair, 1991). While working with neutrons in the Los Alamos Scientific Laboratory as a quantity quantification technique, Van Neumann Simulation was used to solve complex and expensive physics problems with manual or physical models (Render and Stair, 1991). Monte Carlo method is a general name given to approaches with random numbers to solve experimental and statistical problems. This method is a technique that started to develop rapidly after the 1930s (Hançerlioğulları, 2006). These methods are subject to probability theory. The application of the method to a problem is based on the idea of simulating the problem using the random numbers and calculating the approximate parameter by looking at the results of these simulations (Hançerlioğulları, 2006).

Several methods have been developed in the literature to solve the problem of assembly line balancing. A detailed examination of such studies has been carried out by Ghosh and Gagnon (1989), Erel and Sarin (1998), Scholl and Becker (2006) and recently by Battaia and Dolgui (2013) and Sivasankaran and Shahabudeen (2014). However, there is not much research on multi-manned assembly line balancing problem. The first study on this subject was made by Dimitriadis (2006). Hoffmann's (1963) algorithm developed a two-level heuristic algorithm. He applies this study to solve various experimental problems. Also, apply this work for a case to solve a real ALBP. Becker and Scholl (2009) have pointed out the problem of multi-manned assembly line balancing with variable parallel working space. They have developed a precise solution procedure for the problem with the branch and bound algorithm. Fattahi et al. (2011) presented a mixed-integer programming model and ant colony optimization approach for a multi-manned assembly line balancing problem. In this study, it is aimed to minimize the number of total line workers and secondly to decrease the number of multi-manned assembly line workstations.

Kellegoz and Toklu (2012) have studied the problem of balancing the multi-manned assembly line with parallel workstations. After defining the problem, a branch and bound algorithm were developed to solve the problem. Roshani et al. (2013) studied on a multipurpose multi-manned assembly line balancing problem. Simulated annealing algorithm is applied to solve the problem and optimization of line efficiency, line length and smoothness index is aimed and these are considered as a performance criterion. Kazemi and Sedighi (2013) have studied a cost-centered multi-manned assembly line balancing problem. The goal is to minimize the cost per product. Also, genetic algorithms have been tried to solve real situation problems. Sepahi and Jalali Naini (2014) also studied the problem of multi-manned assembly line balancing. They have aimed to minimize the number of workstations and have adopted some heuristic approaches based on predecence rules for this purpose. Kellegöz and Toklu (2015) have developed a mathematical model for the multi-manned assembly line balancing problem. It is aimed to minimize the total number of workers on the line.

Yilmaz and Yilmaz (2015) developed a new mathematical model. In this model, not only the number of workers and the number of workstations is intended to be minimized, but also the balance between the workloads of workers is ensured. Again Yilmaz and Yilmaz (2016) studied MALBP but in this problem, the workers assigned to the teams must be skilled or have special equipment. A mathematical model and a heuristic approach have been developed for solving this problem.

Kellegöz (2016) has developed a new mathematical model and aims to minimize the number of worker as a primary and to decrease the number of workstations as a secondary. He created a heuristic approach based on the simulated annealing algorithm. Roshani and Giglio (2016) have studied the problem of multi-manned assembly line balancing, which aims at minimizing cycle time for a given number of worktations. He has developed a new mathematical model and 2 simulated annealing approaches for solving the problem.

Roshani and Ghazi Nezami (2017) aims to study a generalized type of mixed-model assembly line with multi-manned workstations where multiple workers simultaneously perform different tasks on the same product. This special kind of assembly line is usually utilized to assemble different models of large products, such as buses and trucks, on the same production line.

Roshani and Giglio (2018) have studied the MALBP with the objective of minimising the cycle time. They have proposed a mixed-integer mathematical programming formulation for the considered problem. This model has the primary objective of minimising the cycle time for a given number of workstations and the secondary objective of minimising the total number of workers.

Chen, Chang and Li (2018) proposes a mixed integer programming model for the resource constrained assembly line balancing problem with multi-manned workstations. Resources refer to machines or tools (such as jigs and hand tools) in the production line. The objective is to minimize the number of workstations, operators, and resources to obtain the optimal allocation of tasks, operators, machines, and resources.

Naderi, Azab and Borooshan (2019) studied a realistic multi-manned five-sided mixed-model assembly line balancing and scheduling problem with moving workers and limited workspace. They deals with a realistic assembly line for the automotive industry inspired by Fiat Chrysler Automotive in North America and Parskhodro in Iran (both large-scale automotive companies). This problem includes some specific requirements that have not been studied in the literature.

Şahin and Kellegöz (2019) dealt with multi-manned assembly line balancing problem with walking workers for minimising the number of workers and workstations as the first and second objectives, respectively. They improved a metaheuristic based on electromagnetic field optimisation algorithm. Also they modified a particle swarm optimisation algorithm from assembly line balancing literature has been modified to compare with the proposed algorithm.

In this study, we have developed a mixed-integer programming model for multi-manned assembly line balancing problem. Developed program can solve small-sized problems, but can not solve large-scale problems. It is inadequate. For this reason, heuristic algorithms are used to solve big problems. COMSOAL method used in this study is one of these algorithms. In this study, small size problems have been applied.

CHAPTER III

PROBLEM DEFINITION

We defined MALBP and the main objective is minimizing the number of the workstation under the given cycle time. We start with the definition of deterministic ALBP. In the case of assembly line balancing problems,

In deterministic ALBP, it is assumed that task times are given and these times do not show any change from one unit to another. This assumption is especially valid in advanced technology industries where robot technology can find application areas.

In deterministic ALBP, there are specific operation times. Assumptions are as follows for the problem:

I. The operation times of tasks are known and constant.
II. The precedence diagram of the assembly line is known.
III. The tasks can not be divided. It is not allowed.
IV. All workers are considered the same. We assume that there is no difference between workers.
V. If task i is coming before the task p in the precedence diagram, then task p must be assigned to the previous or same workstation.

Under the above assumptions, the problem is called simple deterministic ALBP.

3.1 Problem Definition

In this factory, research was done with REFA. This is called REFA check-up analyzer. With the check-up analyzer, all the problems experienced by the factory were identified. One of the major problems be identified is ALBP of the Backhoe Loader assembly line.

REFA Association is considered to be Germany's leading organization in work design, industrial organisation and company development.Work design means creating a process oriented, optimized cooperation of work force, resources, and equipment, taking into account human capacity and demands.

Check-up is a statistical data detection method developed in the United States, with random observations of human, machine and material flow types in one or more identical and similar business processes.

Analyzing the flow types by sampling provides the opportunity for the emergence of problems in terms of resource utilization efficiency and the development of solutions to these problems. In the REFA check-up analysis conducted within the scope of the project, analysis was conducted separately in 13 workstations in the backhoe loader assembly line and 5460 instant observations were taken for 20 days on 24 workers.

In this research, Among the unplanned (lost) time uses, the interruption rate for personal reasons is 16.8%. 6.4% of this is for personal needs and 10.4% is for arbitrary breaks. In international standards, this rate is around 6% (Figure 3.1 and 3.2).

The main reason for the time lost, workers are wasted as a result of ALBP and remain idle as a result of the inability to find work.

A predecence diagram has been created for this factory and the aim is to balance the actual assembly lines according to this predecence diagram in Figure 3.3 and minimizing of the number of workstations.

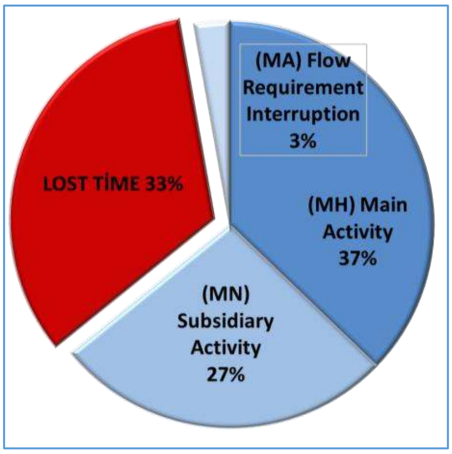

Figure 3.1 Lost time findings.

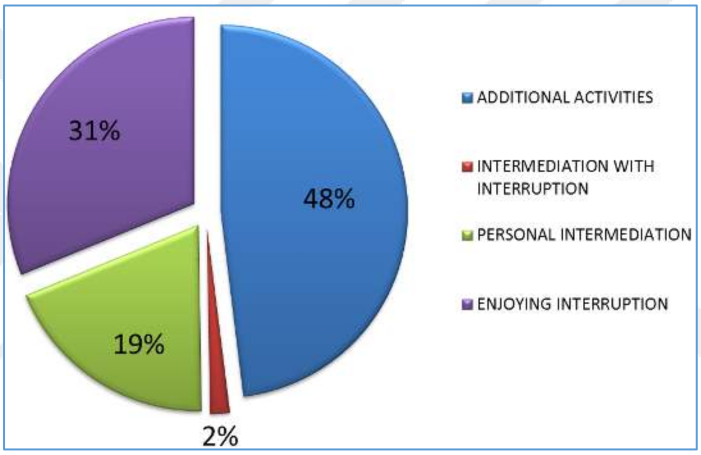

Figure 3.2 Lost time details.

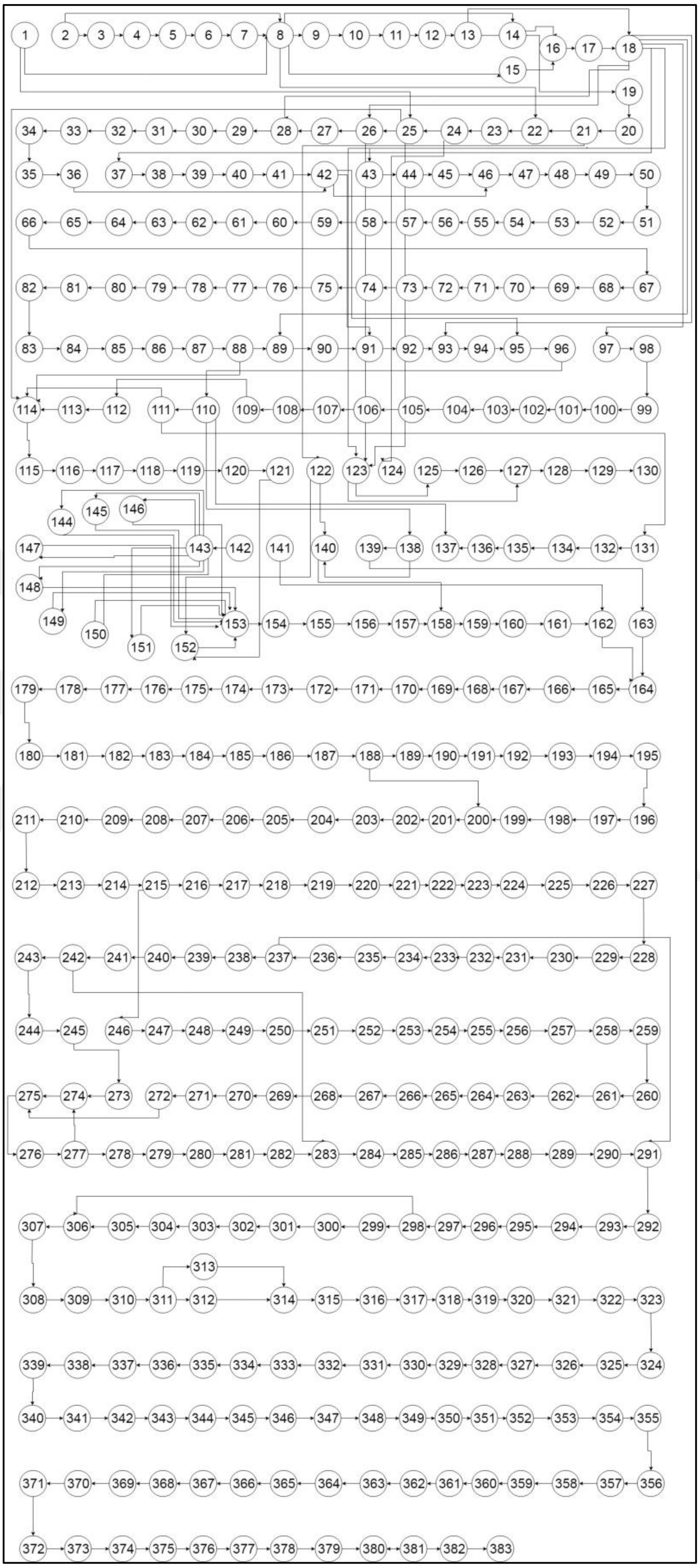

Figure 3.3 Precedence diagram of the case study.

CHAPTER IV

MATHEMATICAL MODEL

In this chapter, mathematical model which is developed with modified constraints is given. With this mathematical model, small-size problems can be solved. However, this model is insufficient for large-size problems.

In the literature, similar mathematical model is available. Şahin and Kellegöz (2019) first tries to minimise the total number of workers used on the line, secondly tries to minimize the total number of workstations with their MIP. Roshani and Giglio (2017) minimizes the cycle time as the primary objective and the number of workers as the secondary one with their MIP. The mathematical model was developed based on the MIP model of Roshani and Giglio (2017).

The following table (Table 4.1) shows the mean of the notations in the mathematical model.

Table 4.1 Notations

i,j	Task (i=1,..,I, j=1,..,J)
k	Workstation (k=1,…K)
r	Operators (r=1,…,R)
t_i	Operation time of task *i*
W_k	Total number of worker for workstation k
C	Cycle time
ts_i	Starting time of task i
SE_{ij}	1 if task i is assigned earlier than task j in the same workstation
P	Set of pairs of tasks (i,j) in which task i is immediate predecessor of task j
$(X_{ikr}) \in \{0,1\}$	1, if task i is assigned to workstation k and performed by operator r
$(A_{kr}) \in \{0,1\}$	1, if operator r is assigned to workstation k
B	Large number
Z_k	1, if workstation k is employed

$$\text{Min Obj} = \sum_{k=1}^{K} Z_k \tag{4.1}$$

$$\sum_{k=1}^{K} \sum_{r=1}^{R} x_{ikr} = 1 \text{ for } i = 1, \dots, I \tag{4.2}$$

$$\sum_{k=1}^{K} \sum_{r=1}^{R} k * X_{ikr} - \sum_{k=1}^{K} \sum_{r=1}^{R} k * X_{jkr} \leq 0 \text{ for } (i,j) \in P \tag{4.3}$$

$$\sum_{i=1}^{I} t_i * x_{ikr} \leq C * Z_k \quad \text{for } k = 1, \dots, K, \text{ for } r = 1, \dots, R \tag{4.4}$$

$$ts_i + \sum_{r}^{R} (t_i \sum_{k=1}^{K} x_{ikr}) \leq C \quad \text{for } i = 1, \dots, I \tag{4.5}$$

$$ts_i + t_{ir} * x_{ikr} + B_1.(x_{ikr} + x_{jkr} - 2) \leq ts_j \quad \text{for } k = 1, \dots, K, \; r = 1, \dots, R, i < j \text{ and } (i,j) \in P \tag{4.6}$$

$$ts_i + t_i * x_{ikr} + B_1.\left(x_{ikr} + \sum_{r_j} x_{jkr_j} - 2\right) \leq ts_j \text{ for } k = 1, \dots, K, r = 1, \dots, R, i < j \text{ and } (i,j) \in P \tag{4.7}$$

$$ts_i + t_i * x_{ikr} - 2 * B_2.(2 - x_{ikr} - x_{jkr}) \leq ts_j + B_1.(1 - SE_{ij}) \text{ for } k = 1, \dots, K, r = 1, \dots, R \text{ and } i,j = 1, \dots, I: i < j \wedge (i,j) \notin P \tag{4.8}$$

$$ts_j + t_j * x_{jkr} - 2 * B_2.(2 - x_{ikr} - x_{jkr}) \leq ts_i + B_1.SE_{ij} \text{ for } k = 1, \dots, K, r = 1, \dots, R \text{ and } i,j = 1, \dots, I: i < j \wedge (i,j) \notin P \tag{4.9}$$

$$ts_i \geq 0 \text{ for } i = 1, \dots, I \tag{4.10}$$

$$\sum_{i=1}^{I} X_{ikr} - B * A_{kr} \leq 0 \text{ for } k = 1, \dots, K \text{ and } r = 1, \dots, R \tag{4.11}$$

$$\sum_{r} A_{kr} \leq W_k \quad \text{for } k = 1, \dots, K \tag{4.12}$$

Objective function (4.1) is to minimize sum of number of the workstation. Constraint (4.2) is the assignment constraint. All tasks in the assembly line must be assigned to workstations, and a task can be assigned to a workstation. Assignment constraints are another feature of the ALBP in practical life. In particular, in the production of complex products, it is often not possible to provide the same characteristics to each sworktation and this entails assignment constraints related to the workstation. Constraint (4.3) is the predecence constraint. These are the relations between the operations of the product on the assembly line. For an operation to begin processing at a workstation, it may technically need to follow each other. In order to this operation to begin, prior operations must be completed. Operation assignments to workstations must not be contrary to these predecence relationships.

Constraint (4.4) is the cycle time constraint. It provides that sum of task times on the same sworktation is less than cycle time. Finish time of each task for all models must be less than cycle time. It is ensured by constraints (4.5)

Because more than one worker can be assigned to the workstation, scheduling within the workstation is required. First case task pair, which has precedence relations are assigned to same workstation and worker (Constraint 4.6). If task pair has precedence relations and they are assigned to same workstation but different worker (Constraints 4.7).

By the Constraint (4.8), (4.9) the start time is determined, If there is no precedence relation between the two jobs and if it is done by the same worker. If task pair does not have precedence relation and they are assigned to same workstation and worker, tasks can be performed in one of two sequences, first i after j or first j after I. Each first task in the workstation must be greater than zero. It is ensured by constraints (4.10). Constraints (4.11) ensure that if a task is assigned to workstation k and performed by worker r, then, worker r is assigned to workstation k. Constraints (4.12) provide that only a robot can be assigned to a station.

CHAPTER V

HEURISTIC PROCEDURE

We can divide into two parts which methods developed for the solution of MALBP. The first one is optimal methods and the second one is heuristic methods. Optimal methods are unsufficient to solve real MALBP. It also takes too long. So the applicability of these methods disappears.

The most simple of assembly line balancing problems is single model deterministic assembly line balancing problem is included in np-hard problem. There is no optimal solution for big ALB problems and guaranteed other classes methodology is not available. The researchers of the subject have developed a set of heuristic algorithms that produce solutions near optimal.

In this study, we use COMSOAL methods to solve real case problems.

5.1 COMSOAL

The COMSOAL method is computer-based which uses a record-keeping system. The system allows you to test countless approximate solutions. Also, the method uses a simple record-keeping system. Sequences are created by selecting from the appropriately assigned series. The trial can be made in the desired multiplicity. A line design is created in each attempt. The first precise solution created by the system is kept in memory. When the next precise solution is obtained, it is retained. Others are forgotten. This process continues for the specified number of iterations (Diri, 2015).

COMSOAL (computer method for sorting for assembly lines) method, assigning to workstations without a random selection of assignable tasks according to precedence diagram, and the best method of repeating this process repeatedly is a method based on acceptance (Diri, 2015).

For an assembly line balancing problem, it is possible to manually solve any of the aforementioned heuristic methods. However, the COMSOAL method is a method that provides different solutions with the help of a computer.

In the COMSOAL method, a set of assignable tasks, consisting of tasks with no predecessor or with all predecessors assigned, is identified by proceeding through the precedence diagram. Then, one of the tasks in this set of assignable tasks is randomly selected and saved in a list (Ağpak, 2001).

After all, tasks are saved in the list, the tasks are assigned to the workstations according to the order in the list. If the cycle time is exceeded when the next task is assigned to the current workstation, a new workstation is opened and that task is assigned to the newly opened workstation. This ensures that all tasks in the list are assigned to workstations (Ağpak, 2001).

In the COMSOAL method, all the processes described so far correspond to an iteration. All these operations are repeated by the number of trials to be determined by the decision maker and the results found in each trial are compared to the best results so far. If it is better, it is considered the best result. Thus, the best number of solutions found in the number of experiments will be found (Ağpak, 2001).

Arcus(1966) has developed 9 samplings adopted to improve the effectiveness of the method and to be able to get a good performance in the problems related to large scale problems.

COMSOAL has several advantages. You can encode COMSOAL in any computer language and high possibility to achieve the optimal solution in long working hours. Constrains can be easily modeled and displayed in COMSOAL.

Because of the above advantages, we use the COMSOAL method in this study. In this method important point is too many feasible solutions be produced and the method selects the best one.

We can define COMSOAL algorithm(the traditional) in 6 steps:

Step 1 Firstly precedence diagram is created. After, a list(List A) is constructed which consists of all the tasks, and in an adjacent column, operation time and predecessors' number.

Step 2 From list A, list B is constructed, constituted of tasks which have zero predecessors.

Step 3 The tasks whose time is less than or equal idle time of workstation are Added to C list in the B list.

Step 4 From the C list, A task is selected randomly (The formation of different balances is created because of this random selection causes).

Step 5 If the C list is empty, a new workstation opens and C list is created again, and then return 4.

Step 6 From the precedence diagram, the selected task is removed. Balancing has been completed If all tasks assigned to a workstation. If there are tasks that are not assigned, return to Step 1.

5.2 COMSOAL for MALBP

Assumptions for the presented heuristic algorithm are summarized as follows:

- Parameters of heuristic are known.
- The objective function is to minimize the number of the workstation.
- Task times are known.
- We assumed that task times are deterministic.

Iteration number is defined as iteration number which is 1000 number of tasks for each scenario. Iteration number has occurred after a specific number of trial. The general procedure details of the deterministic model approach based on COMSOAL algorithm are summarized below:

Step 1 Firstly precedence diagram is created. After, a list(List A) is constructed which consists of all the tasks, and in an contiguous column, task time and predecessors' number.

Step 2 First, list B is created from list A. These tasks in list B consist of zero predecence tasks. If the assigned task is the first assigned task at the relevant workstation, step 3 is returned. Otherwise, go to Step 4.

Step 3 In list B, those whose operating times are less than or equal to the idle time for any available human operator of the relevant workstation are selected and list C is created. Then continue to Step 5.

Step 4 If the C list is empty, a new station opens and returns step 3. Otherwise, continue.

Step 5 A task is selected according to number of followers from the C list. It is assigned to current workstation.

Step 6 The starting time of the selected task is determined according to precedence relations.

Step 7 In step 7, we remove the tasks selected from the predecence diagram. The workstation is then updated to the idle time. If all tasks are distributed to workstations, balancing is completed. But if there are still unassigned tasks, go to Step 2 again.

For this study, our predecence is to find solutions as good as the best existing procedures provide for the real case problem. Real case MALBP is solved by using COMSOAL which is an effective heuristic for MALBP.

5.3 An Illustrative Example

We solved an example of deterministic MALBP. For an illustrative problem, time of the operations is given at Table 5.1, we create a task list by randomly choosing between assignable tasks with COMSOAL logic (Table 5.2) and assign it to workstations for C = 10 (Figure 5.1). Also we solved this problem with mathematical model in GAMS. Both of COMSOAL and Mathematical model give us the same results.

Example

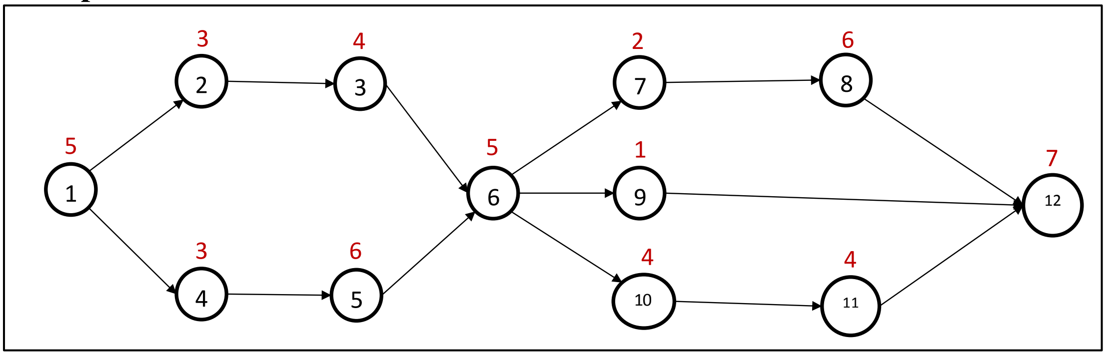

Figure 5.1 An example of precedence diagram with 12 tasks

Table 5.1 Time of the operations.

task	1	2	3	4	5	6	7	8	9	10	11	12
tt	5	3	4	3	6	5	2	6	1	4	4	7

tt:task time

Table 5.2 Solution stage of the COMSOAL algorithm for MALBP.

A list	
Tasks	The number of predecessors of task i
1	-
2	1
3	2
4	1
5	4
6	5,3
7	6
8	7
9	6
10	6
11	10
12	8,9,11

This task list is assigned to workstations in the below order:

Table 5.3 Task list of the workstations

1st workstation	2nd workstation	3rd workstation	4th workstation	5th workstation
1,2,4	3,5	6,7,10	8,9,11	12

In this example our aim minimizing of the number of the workstation. We start with 8 workstations. However, with COMSOAL method, the number of the workstations drop 8 to 5 (Table 5.3). We gain two workstations which means two men.

CHAPTER VI

COMPUTATIONAL RESULTS

In this thesis, we solved real case data. In this study, it is aimed to minimize the number of workstations and workers. We will see the comparison of the workstation minimization results and the workstation and worker minimization results for case problem. In the real case, the production speed may vary from time to time. This change in production speed also means a change in cycle time.

In this factory, the daily machine production speed can be changed from 1 to 4. Therefore, in this thesis, the status of 3 different workstation worker distributions according to 4 different cycle times will be examined for two aim. These aims are workstation minimization and worker and workstation minimization.

6.1 Results for C=10800 sec

For daily machine production speed is 3 machines/day, cycle time is 10800 sec. Especially we start with this cycle time because this is the current production speed of the factory.

When we look at the scenarios, scenario 3 for workstation and worker minimization objective seems to be more advantageous at 10800 second cycle time (Table 6.1).

This shows us that the most sensible scenario is scenario 3 for the cycle time is 10800 seconds and for workstation and worker minimization. With scenario 3 for workstation and worker minimization(WWM) , optimal workstation number and worker number is ensured.

Table 6.1 Comparing workstation number and worker number of 3 scenarios for C=10800 sec for two objective

	C=10800 sec					
	Workstation and Worker Minimization			Workstation Minimization		
	1st scenario	2nd scenario	3rd scenario	1st scenario	2nd scenario	3rd scenario
Worker Number	35	47	41	37	48	43
Workstation Number	20	17	18	19	17	18

We examine all the scenarios separately for C=10800 sec.

In the first scenario, we ran COMSOAL with 2000 iteration. When we look at the results of the first scenario, workstation number is decreasing in worker minimization(WM) and worker number is decreasing in WWM. WM can be selected in the first scenario because the number of workstations that are important to us (Table 6.2 and Table 6.3).

Table 6.2 Workload of workers 1st scenario C=10800 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	6137	20th workstation 1st worker	526
2nd workstation 1st worker	8116	2nd workstation 2nd worker	5352
3rd workstation 1st worker	7800	3rd workstation 2nd worker	1977
4th workstation 1st worker	5038	4th workstation 2nd worker	4007
5th workstation 1st worker	3349	5th workstation 2nd worker	6659
6th workstation 1st worker	5578	6th workstation 2nd worker	3820
7th workstation 1st worker	4474	7th workstation 2nd worker	3781
8th workstation 1st worker	3620	8th workstation 2nd worker	2572
9th workstation 1st worker	8215	9th workstation 2nd worker	9464
10th workstation 1st worker	6865	10th workstation 2nd worker	2006
11th workstation 1st worker	6150	11th workstation 2nd worker	204
12th workstation 1st worker	3726	12th workstation 2nd worker	2399
13th workstation 1st worker	3094	13th workstation 2nd worker	3510
14th workstation 1st worker	3788	14th workstation 2nd worker	1938
15th workstation 1st worker	5283	15th workstation 2nd worker	908
16th workstation 1st worker	4523	16th workstation 2nd worker	1691
17th workstation 1st worker	6120	17th workstation 2nd worker	120
18th workstation 1st worker	2521	18th workstation 2nd worker	4883
19th workstation 1st worker	1765	19th workstation 2nd worker	9352

Table 6.3 Workload of workers 1st scenario C=10800 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	6137	2nd workstation 2nd worker	8392
2nd workstation 1st worker	3790	3rd workstation 2nd worker	9126
3rd workstation 1st worker	1174	4th workstation 2nd worker	5123
4th workstation 1st worker	4151	5th workstation 2nd worker	7209
5th workstation 1st worker	3117	6th workstation 2nd worker	4792
6th workstation 1st worker	3109	7th workstation 2nd worker	4896
7th workstation 1st worker	4877	8th workstation 2nd worker	3734
8th workstation 1st worker	2473	9th workstation 2nd worker	7873
9th workstation 1st worker	9680	10th workstation 2nd worker	2312
10th workstation 1st worker	7015	11th workstation 2nd worker	204
11th workstation 1st worker	6300	12th workstation 2nd worker	3835
12th workstation 1st worker	2420	13th workstation 2nd worker	2590
13th workstation 1st worker	2959	14th workstation 2nd worker	2447
14th workstation 1st worker	3904	15th workstation 2nd worker	23
15th workstation 1st worker	10446	16th workstation 2nd worker	6100
16th workstation 1st worker	256	17th workstation 2nd worker	5034
17th workstation 1st worker	1470	18th workstation 2nd worker	2900
18th workstation 1st worker	4098	19th workstation 2nd worker	7126

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.1 and Figure 6.2. To eliminate this situation, work pieces must be further divided.

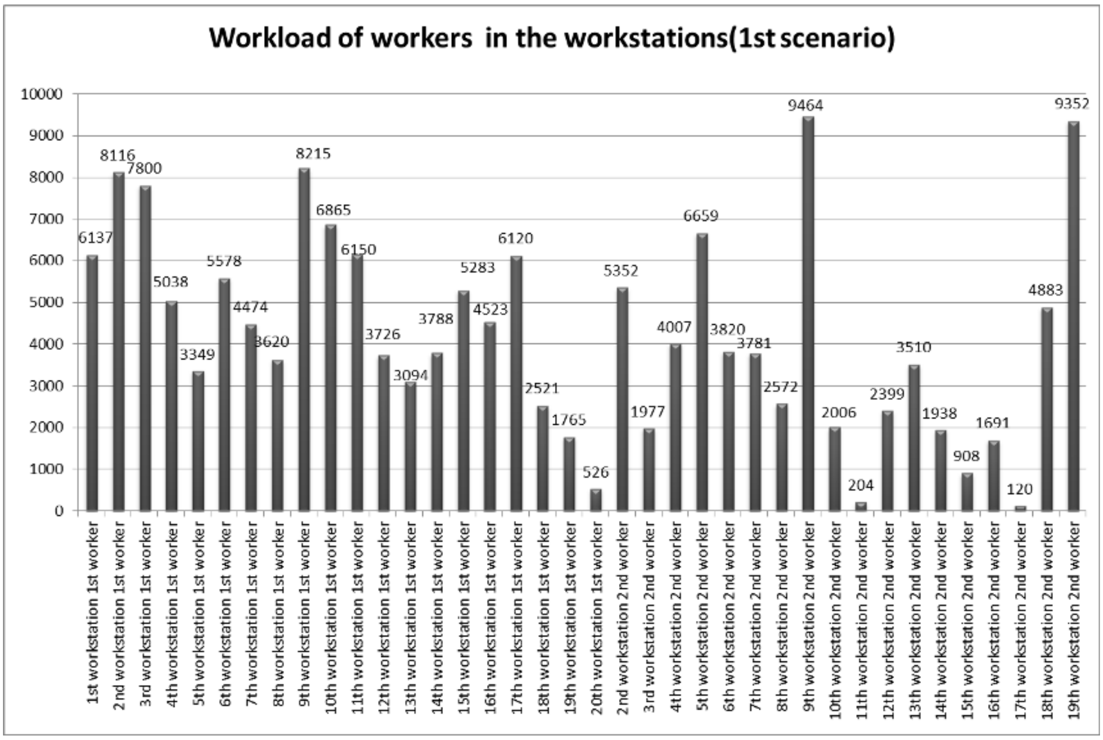

Figure 6.1 Workload of workers of 1st scenario C=10800 sec for WWM.

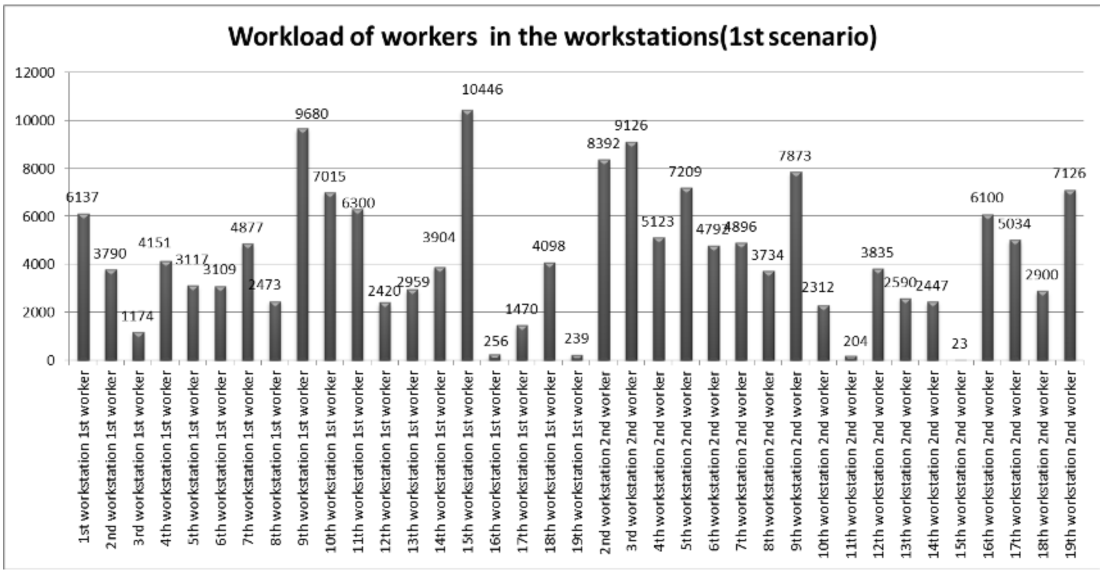

Figure 6.2 Workload of workers of 1st scenario C=10800 sec for WM.

In the second scenario, we also ran COMSOAL with 2000 iteration. When we look at the results of the second scenario, workstation number remains same in WWM and WM and worker number is decreasing in WWM.

WWM can be selected in the second scenario because the number of workstations is same for WWM and WM however number of worker is less in WWM (Table 6.4 and Table 6.5). In this scenario, the worker in workstations is increased.

Table 6.4 Workload of workers 2nd scenario C=10800 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	4470	9th workstation 2nd worker	4846
2nd workstation 1st worker	2450	10th workstation 2nd worker	480
3rd workstation 1st worker	3818	11th workstation 2nd worker	36
4th workstation 1st worker	2818	12th workstation 2nd worker	2575
5th workstation 1st worker	3729	13th workstation 2nd worker	3881
6th workstation 1st worker	4861	14th workstation 2nd worker	268
7th workstation 1st worker	1929	15th workstation 2nd worker	60
8th workstation 1st worker	3370	16th workstation 2nd worker	6648
9th workstation 1st worker	6865	17th workstation 2nd worker	2605
10th workstation 1st worker	7110	2nd workstation 3rd worker	1453
11th workstation 1st worker	6887	3rd workstation 3rd worker	2748
12th workstation 1st worker	3243	4th workstation 3rd worker	4496
13th workstation 1st worker	630	5th workstation 3rd worker	5572
14th workstation 1st worker	2205	6th workstation 3rd worker	2204
15th workstation 1st worker	4659	7th workstation 3rd worker	2311
16th workstation 1st worker	1942	8th workstation 3rd worker	2534
17th workstation 1st worker	1201	9th workstation 3rd worker	1350
1st workstation 2nd worker	2611	10th workstation 3rd worker	387
2nd workstation 2nd worker	7759	11th workstation 3rd worker	1936
3rd workstation 2nd worker	4457	12th workstation 3rd worker	548
4th workstation 2nd worker	3473	13th workstation 3rd worker	1525
5th workstation 2nd worker	2513	14th workstation 3rd worker	6754
6th workstation 2nd worker	4698	15th workstation 3rd worker	6000
7th workstation 2nd worker	1930	16th workstation 3rd worker	4574
8th workstation 2nd worker	3715	17th workstation 3rd worker	2197

Table 6.5 Workload of workers 2nd scenario C=10800 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	4443	9th workstation 2nd worker	5333
2nd workstation 1st worker	7232	10th workstation 2nd worker	837
3rd workstation 1st worker	4915	11th workstation 2nd worker	607
4th workstation 1st worker	4225	12th workstation 2nd worker	2083
5th workstation 1st worker	2890	13th workstation 2nd worker	2637
6th workstation 1st worker	1208	14th workstation 2nd worker	1200
7th workstation 1st worker	4275	15th workstation 2nd worker	219
8th workstation 1st worker	4574	16th workstation 2nd worker	1112
9th workstation 1st worker	7289	17th workstation 2nd worker	1036
10th workstation 1st worker	7495	2nd workstation 3rd worker	6538
11th workstation 1st worker	6951	3rd workstation 3rd worker	583
12th workstation 1st worker	7317	4th workstation 3rd worker	4086
13th workstation 1st worker	1605	5th workstation 3rd worker	3958
14th workstation 1st worker	6319	6th workstation 3rd worker	4777
15th workstation 1st worker	10380	7th workstation 3rd worker	1072
16th workstation 1st worker	3929	8th workstation 3rd worker	2749
17th workstation 1st worker	1652	9th workstation 3rd worker	4380
1st workstation 2nd worker	2249	10th workstation 3rd worker	245
2nd workstation 2nd worker	2169	11th workstation 3rd worker	900
3rd workstation 2nd worker	1441	12th workstation 3rd worker	2098
4th workstation 2nd worker	2554	13th workstation 3rd worker	1526
5th workstation 2nd worker	3850	14th workstation 3rd worker	68
6th workstation 2nd worker	3927	15th workstation 3rd worker	60
7th workstation 2nd worker	2072	16th workstation 3rd worker	2311
8th workstation 2nd worker	2168	17th workstation 3rd worker	3787

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.3 and Figure 6.4. To eliminate this situation, work pieces must be further divided.

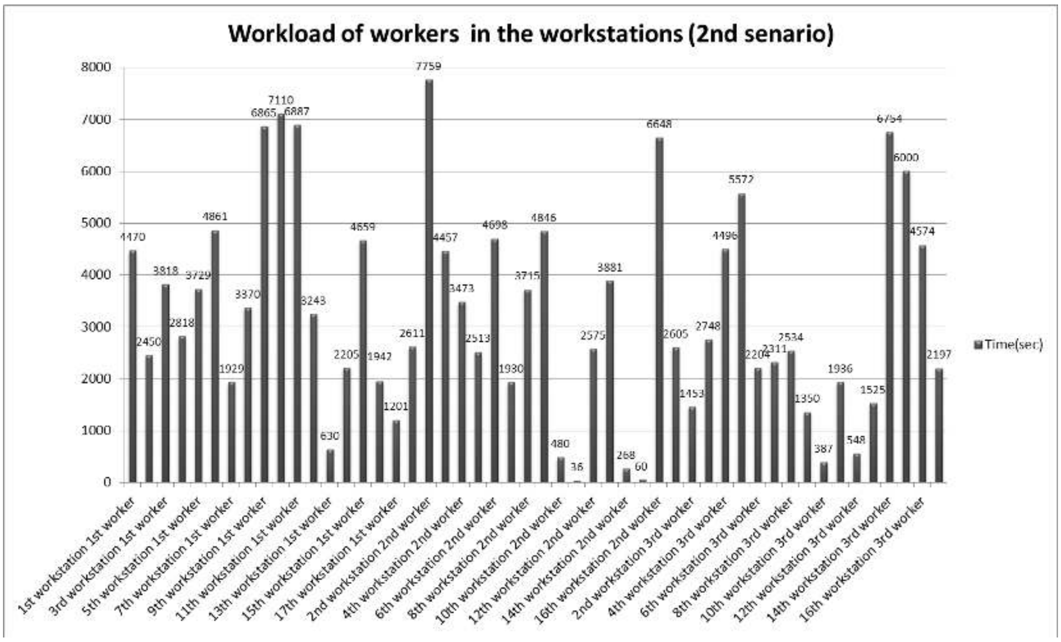

Figure 6.3 Workload of workers of 2nd scenario C=10800 sec for WWM.

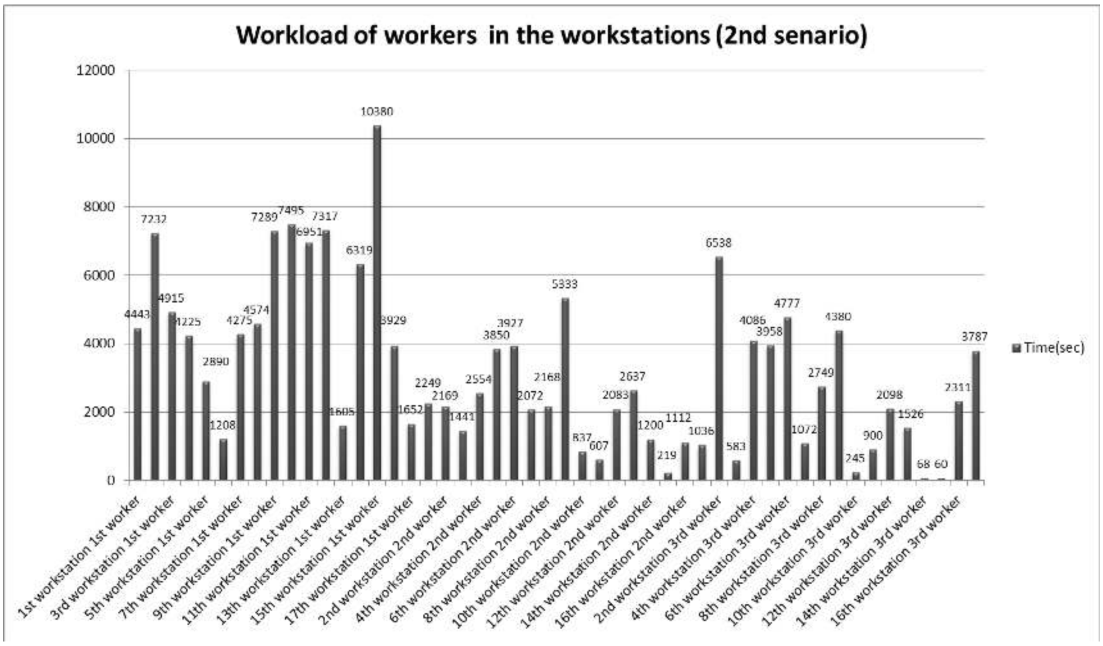

Figure 6.4 Workload of workers of 2nd scenario C=10800 sec for WM.

In the third scenario,worker number of the workstation is between the first and second scenario's workstation worker number. When we look at the results of the third scenario, workstation number remains same in WWM and WM and worker number is decreasing in WWM. WWM can be selected in the third scenario because the number of workstations is same for WWM and WM however number of worker is less in WWM (Table 6.4 and Table 6.5). In this scenario, the worker in workstations is increased.

Table 6.6 Workload of workers 3rd scenario C=10800 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	3696	6th workstation 2nd worker	4841
2nd workstation 1st worker	7842	7th workstation 2nd worker	1050
3rd workstation 1st worker	4379	8th workstation 2nd worker	3662
4th workstation 1st worker	4846	9th workstation 2nd worker	3574
5th workstation 1st worker	3399	10th workstation 2nd worker	1050
6th workstation 1st worker	2839	11th workstation 2nd worker	607
7th workstation 1st worker	3141	12th workstation 2nd worker	3364
8th workstation 1st worker	2830	13th workstation 2nd worker	3232
9th workstation 1st worker	9084	14th workstation 2nd worker	2458
10th workstation 1st worker	6450	15th workstation 2nd worker	146
11th workstation 1st worker	6180	16th workstation 2nd worker	60
12th workstation 1st worker	2703	17th workstation 2nd worker	1903
13th workstation 1st worker	2380	18th workstation 2nd worker	4633
14th workstation 1st worker	6289	1st workstation 3rd worker	3386
15th workstation 1st worker	1004	3rd workstation 3rd worker	1993
16th workstation 1st worker	6172	5th workstation 3rd worker	4060
17th workstation 1st worker	5156	7th workstation 3rd worker	4110
18th workstation 1st worker	6954	9th workstation 3rd worker	7396
1st workstation 2nd worker	467	11th workstation 3rd worker	951
2nd workstation 2nd worker	3640	13th workstation 3rd worker	678
3rd workstation 2nd worker	4848	15th workstation 3rd worker	4500
4th workstation 2nd worker	4841	17th workstation 3rd worker	1255

Table 6.7 Workload of workers 3rd scenario C=10800 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	1759	6th workstation 2nd worker	4252
2nd workstation 1st worker	8999	7th workstation 2nd worker	1904
3rd workstation 1st worker	4529	8th workstation 2nd worker	3989
4th workstation 1st worker	6168	9th workstation 2nd worker	6635
5th workstation 1st worker	5303	10th workstation 2nd worker	932
6th workstation 1st worker	6287	11th workstation 2nd worker	20
7th workstation 1st worker	4621	12th workstation 2nd worker	1388
8th workstation 1st worker	5810	13th workstation 2nd worker	2825
9th workstation 1st worker	6766	14th workstation 2nd worker	5314
10th workstation 1st worker	6682	15th workstation 2nd worker	60
11th workstation 1st worker	7115	16th workstation 2nd worker	3332
12th workstation 1st worker	5298	17th workstation 2nd worker	1894
13th workstation 1st worker	1877	1st workstation 3rd worker	4295
14th workstation 1st worker	7073	3rd workstation 3rd worker	3925
15th workstation 1st worker	10576	5th workstation 3rd worker	2315
16th workstation 1st worker	3746	7th workstation 3rd worker	2184
17th workstation 1st worker	2737	9th workstation 3rd worker	1983
1st workstation 2nd worker	1495	11th workstation 3rd worker	1815
2nd workstation 2nd worker	1982	13th workstation 3rd worker	2326
3rd workstation 2nd worker	2927	15th workstation 3rd worker	83
4th workstation 2nd worker	3859	17th workstation 3rd worker	2058
5th workstation 2nd worker	2193		

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.5 and Figure 6.6. To eliminate this situation, work pieces must be further divided.

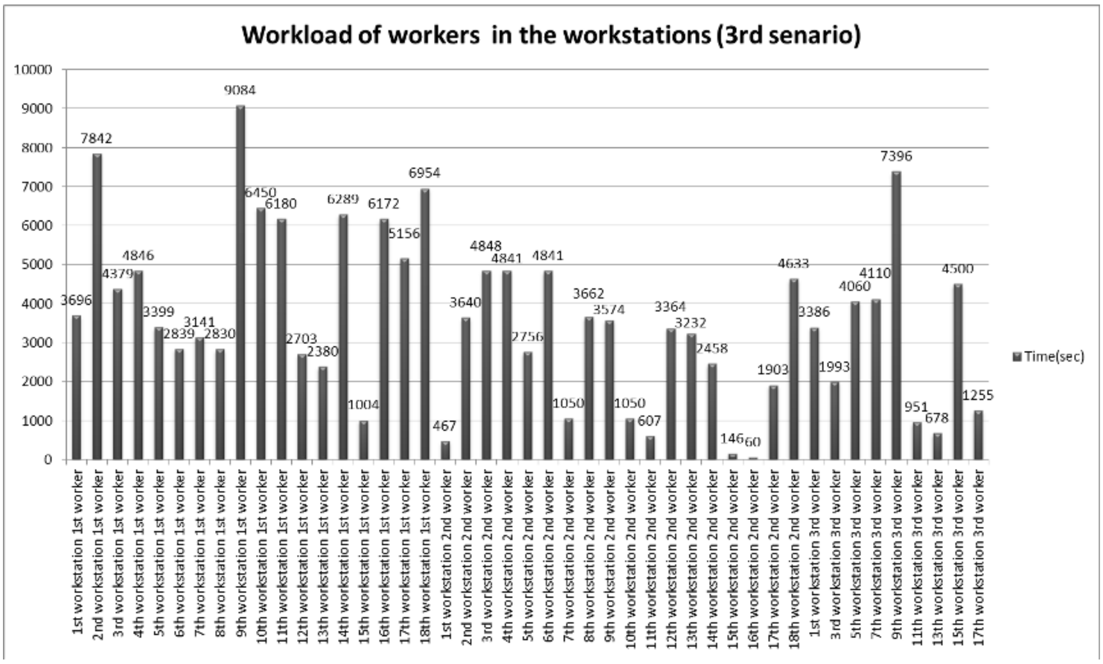

Figure 6.5 Workload of workers of 3rd scenario C=10800 sec for WWM.

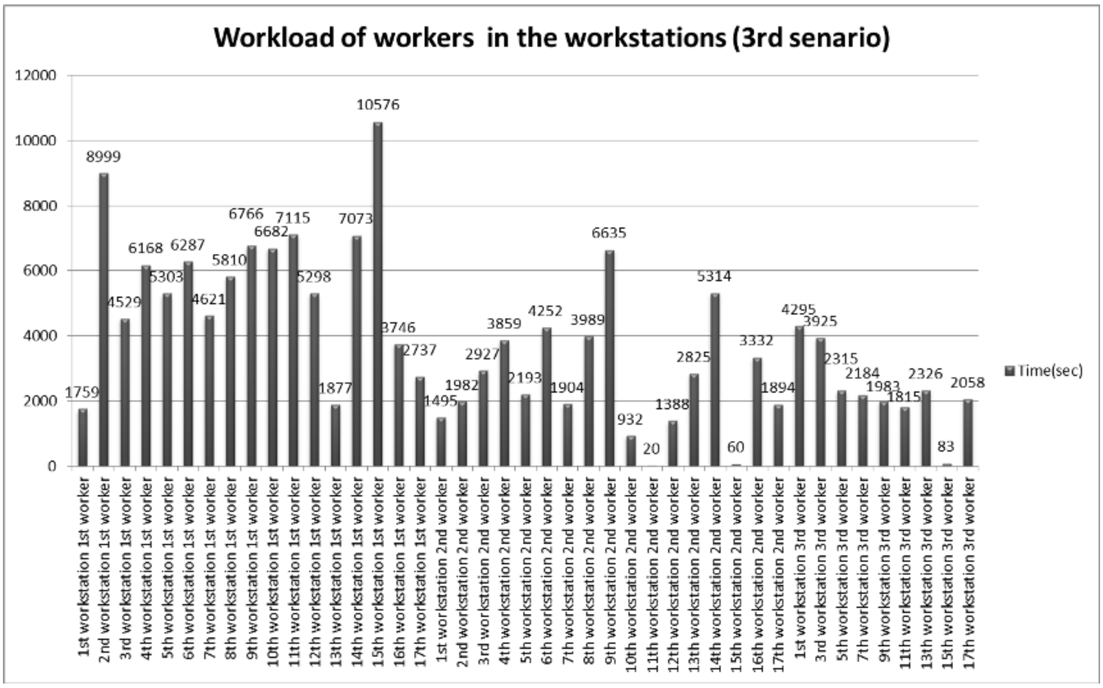

Figure 6.6 Workload of workers of 3rd scenario C=10800 sec for WM.

6.2 Results for C=32400 sec

For daily machine production speed is 1 machine/day, cycle time is 32400 sec.

That the cycle time is increasing means that the production speed decreases. Low production speed means fewer workers. This means that the number of workers and the number of workstations are automatically minimized to a certain level. The important thing here is to use the limited resource effectively.

Table 6.8 Comparing workstation number and worker number of 3 scenarios for C=32400 sec for two objective

	C=32400 sec					
	Workstation and Worker Minimization			Workstation Minimization		
	1st scenario	2nd scenario	3rd scenario	1st scenario	2nd scenario	3rd scenario
Worker Number	14	21	18	14	18	15
Workstation Number	8	7	7	8	7	7

When we look at the scenarios, the number of workstations in the second and third scenarios seems the same. But when we look at overall table (Table 6.8), scenario 3 for WM seems to be most advantageous. With scenario 3 for WWM, optimal workstation number and worker number is ensured.

Let us examine the results in detail for c = 32400 seconds.

In the first scenario, we ran COMSOAL with 2000 iteration. When we look at the results of the first scenario, workstation and worker number remain same for WM and WWM. WWM or WM can be selected in the first scenario because the number of workstations and workers are same (Table 6.9 and Table 6.10).

Table 6.9 Workload of workers 1st scenario C=32400 sec for WWM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	18959
2nd workstation 1st worker	13750
3rd workstation 1st worker	11357
4th workstation 1st worker	11729
5th workstation 1st worker	8333
6th workstation 1st worker	3112
7th workstation 1st worker	10084
8th workstation 1st worker	5400
2nd workstation 2nd worker	7844
3rd workstation 2nd worker	13904
4th workstation 2nd worker	17930
5th workstation 2nd worker	8609
6th workstation 2nd worker	19542
7th workstation 2nd worker	10778

Table 6.10 Workload of workers 1st scenario C=32400 sec for WM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	18959
2st workstation 1st worker	14520
3st workstation 1st worker	9970
4st workstation 1st worker	12376
5st workstation 1st worker	11055
6st workstation 1st worker	7127
7st workstation 1st worker	8518
8st workstation 1st worker	2541
2st workstation 2nd worker	10444
3st workstation 2nd worker	12241
4st workstation 2nd worker	19305
5st workstation 2nd worker	5732
6st workstation 2nd worker	9415
7st workstation 2nd worker	10859
8st workstation 2nd worker	8269

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.7 and Figure 6.8. To eliminate this situation, work pieces must be further divided.

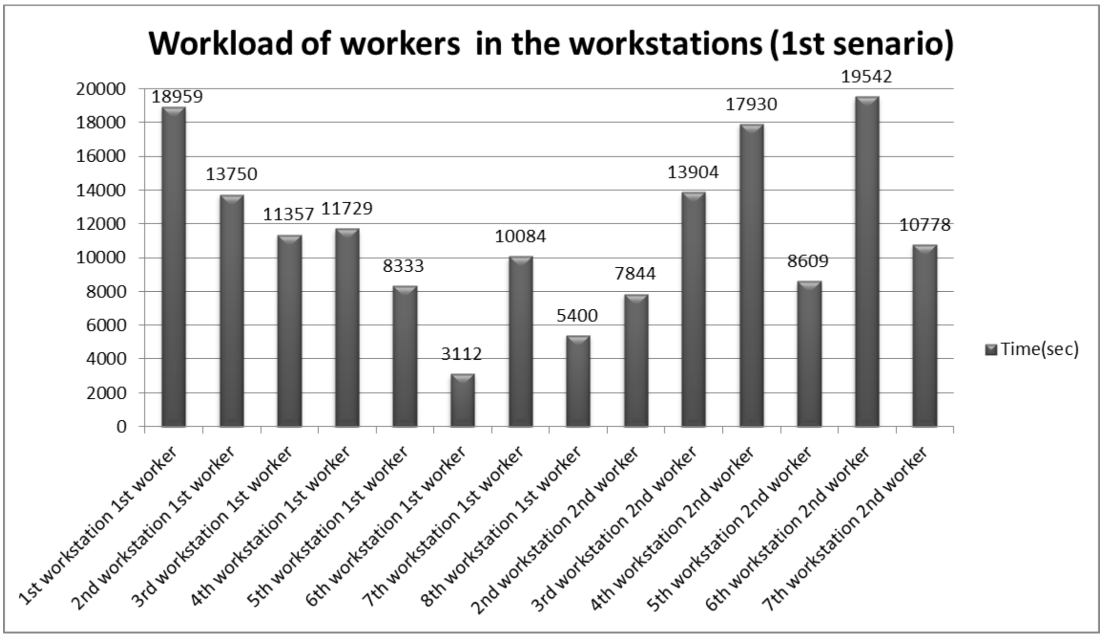

Figure 6.7 Workload of workers of 1st scenario C=32400 sec for WWM.

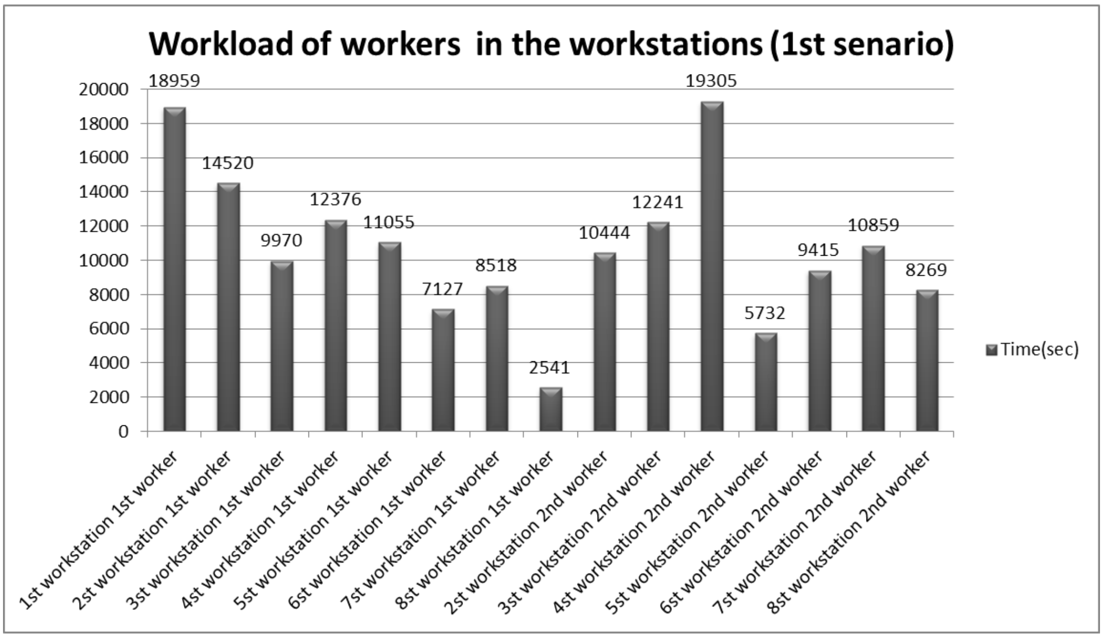

Figure 6.8 Workload of workers of 1st scenario C=32400 sec for WM.

In the second scenario, we also ran COMSOAL with 2000 iteration. When we look at the results of the second scenario, workstation number remains same in WWM and WM and worker number is decreasing in WM. WM can be selected in the second scenario because the number of workstations is same for WWM and WM however number of worker is less in WM (Table 6.11 and Table 6.12). In this scenario, the worker number in workstations is increased.

Table 6.11 Workload of workers 2nd scenario C=32400 sec for WWM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	11458
2nd workstation 1st worker	13566
3rd workstation 1st worker	4737
4th workstation 1st worker	9471
5th workstation 1st worker	9334
6th workstation 1st worker	9846
7th workstation 1st worker	9562
1st workstation 2nd worker	12123
2nd workstation 2nd worker	7154
3rd workstation 2nd worker	12454
4th workstation 2nd worker	2409
5th workstation 2nd worker	5231
6th workstation 2nd worker	6316
7th workstation 2nd worker	6478
2nd workstation 3rd worker	4652
3nd workstation 3rd worker	5956
4th workstation 3rd worker	19231
5th workstation 3rd worker	4101
6th workstation 3rd worker	1071
7th workstation 3rd worker	6181

Table 6.12 Workload of workers 2nd scenario C=32400 sec for WM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	12460
2nd workstation 1st worker	10380
3rd workstation 1st worker	6470
4th workstation 1st worker	16066
5th workstation 1st worker	9526
6th workstation 1st worker	5423
7th workstation 1st worker	5193
1st workstation 2nd worker	6890
2nd workstation 2nd worker	9400
3rd workstation 2nd worker	7650
4th workstation 2nd worker	7717
5th workstation 2nd worker	5728
6th workstation 2nd worker	4917
7th workstation 2nd worker	3153
2nd workstation 3rd worker	8300
3nd workstation 3rd worker	8115
4th workstation 3rd worker	10979
5th workstation 3rd worker	7210
6th workstation 3rd worker	7448
7th workstation 3rd worker	8306

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.9 and Figure 6.10. To eliminate this situation, work pieces must be further divided.

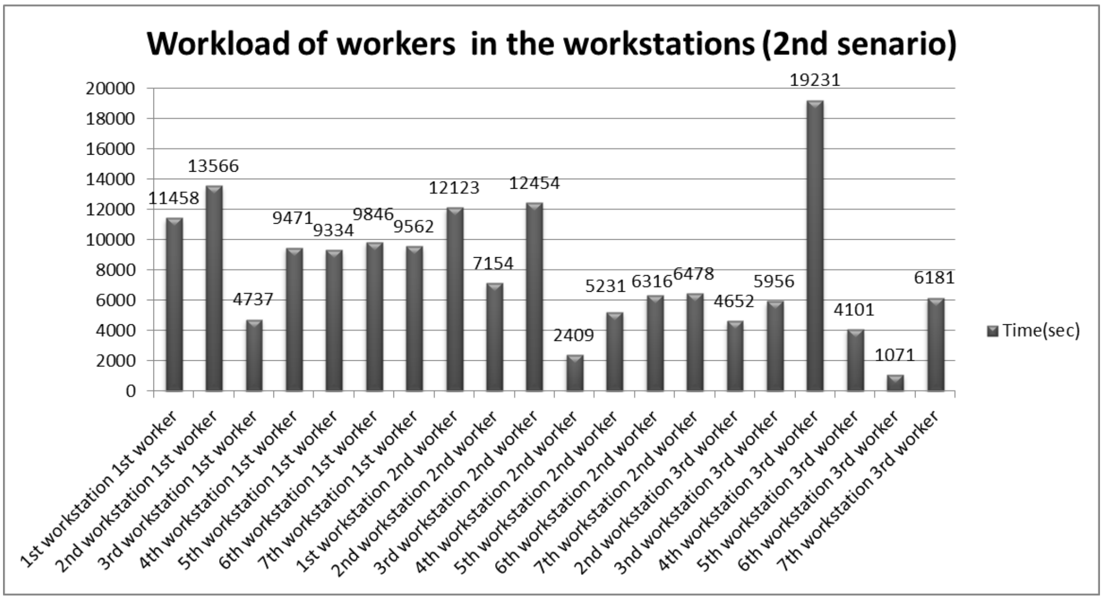

Figure 6.9 Workload of workers of 2nd scenario C=32400 sec for WWM.

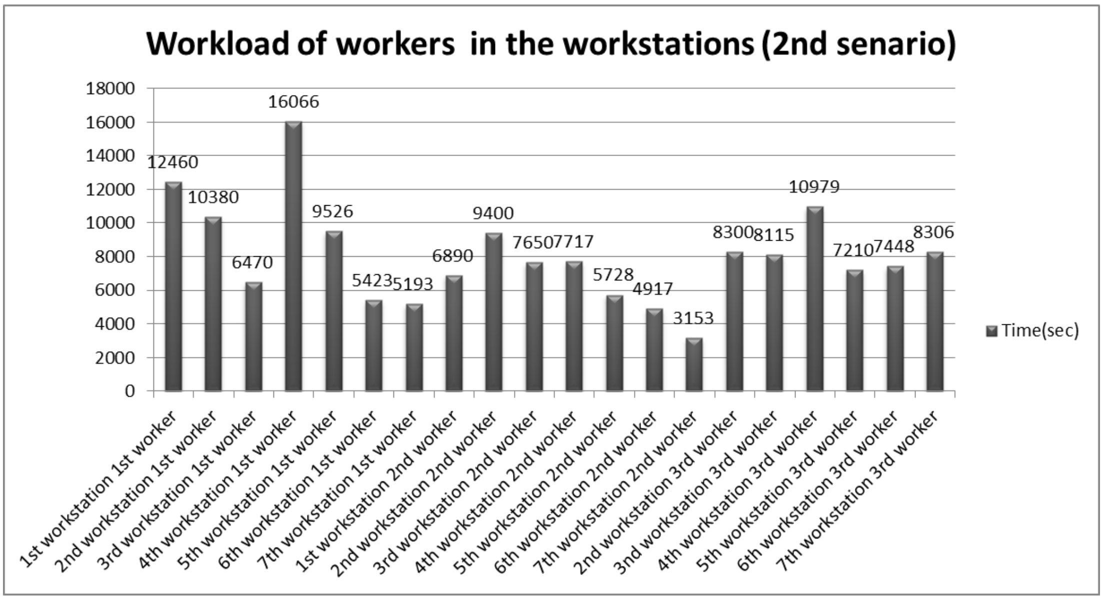

Figure 6.10 Workload of workers of 2nd scenario C=32400 sec for WM.

In the third scenario,worker number of the workstation is between the first and second scenario's workstation worker number. When we look at the results of the third scenario, workstation number remains same in WWM and WM and worker number is decreasing in WM. WM can be selected in the third scenario because the number of workstations is same for WWM and WM however number of worker is less in WM (Table 6.13 and Table 6.14).

Table 6.13 Workload of workers 3rd scenario C=32400 sec for WWM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	11820
2nd workstation 1st worker	13259
3rd workstation 1st worker	6209
4th workstation 1st worker	13974
5th workstation 1st worker	6866
6th workstation 1st worker	16190
7th workstation 1st worker	9463
1st workstation 2nd worker	8043
2nd workstation 2nd worker	8871
3rd workstation 2nd worker	8136
4th workstation 2nd worker	13830
5th workstation 2nd worker	6280
6th workstation 2nd worker	1008
7th workstation 2nd worker	5656
1st workstation 3rd worker	8492
3nd workstation 3rd worker	9019
5th workstation 3rd worker	5613
7th workstation 3rd worker	8602

Table 6.14 Workload of workers 3rd scenario C=32400sec for WM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	6886
2nd workstation 1st worker	11293
3rd workstation 1st worker	4943
4th workstation 1st worker	11884
5th workstation 1st worker	5998
6th workstation 1st worker	11062
7th workstation 1st worker	6101
1st workstation 2nd worker	5811
2nd workstation 2nd worker	13320
3rd workstation 2nd worker	9364
4th workstation 2nd worker	20104
5th workstation 2nd worker	4227
6th workstation 2nd worker	6471
7th workstation 2nd worker	5416
1st workstation 3rd worker	10591
3nd workstation 3rd worker	7457
5th workstation 3rd worker	6718
7th workstation 3rd worker	13685

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.11 and Figure 6.12. To eliminate this situation, work pieces must be further divided.

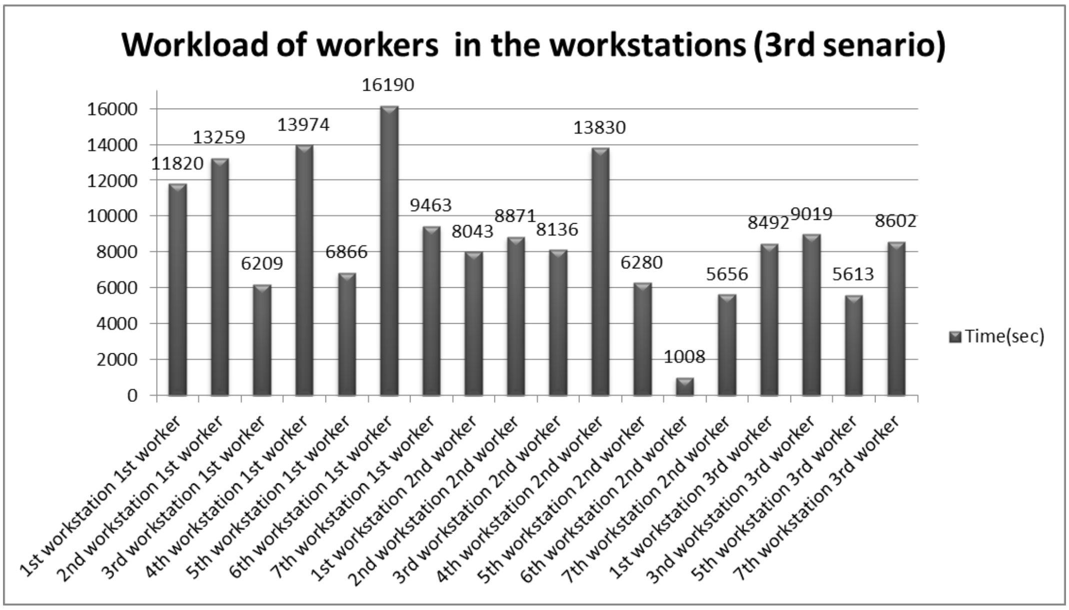

Figure 6.11 Workload of workers of 3rd scenario C=32400 sec for WWM.

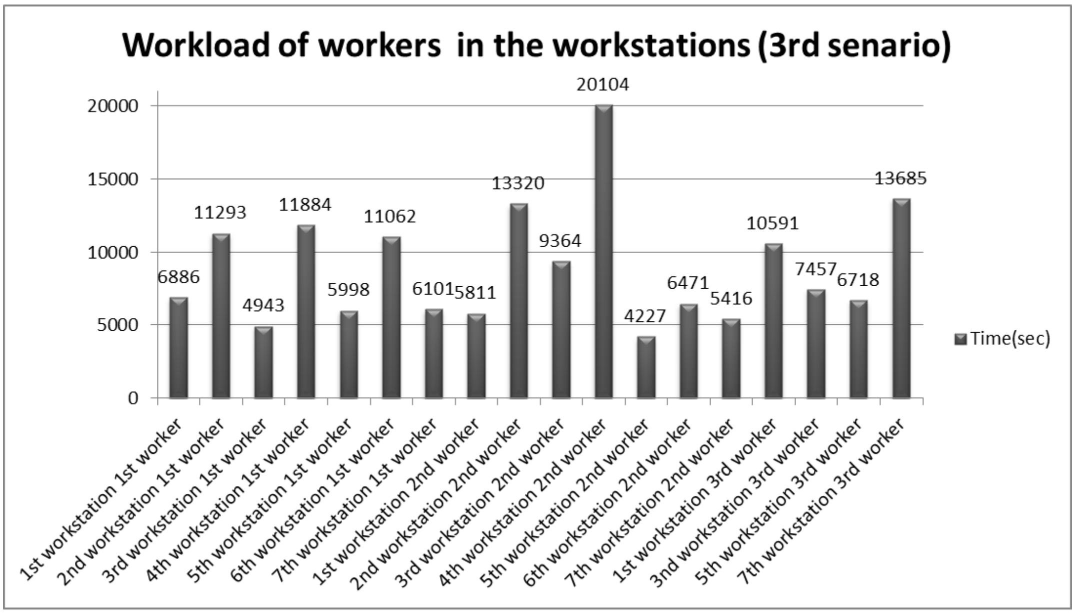

Figure 6.12 Workload of workers of 3rd scenario C=32400 sec for WM.

6.3 Results for C=16200 sec

For daily machine production speed is 2 machines/day, cycle time is 16200 sec.

3 different scenarios are applied for 2 machine/day production speeds and C = 16200 seconds cycle time. Comparison tables related to the scenarios are given below. When we look at the comparison table (Table 6.15). That the cycle time is increasing means that the production speed decreases. Low production speed means fewer workers. This means that the number of workers and the number of workstations are automatically minimized to a certain level. The important thing here is to use the limited resource effectively.

Table 6.15 Comparing workstation number and worker number of 3 scenarios for C=16200 sec for two objective

	C=16200 sec					
	Workstation and Worker Minimization			Workstation Minimization		
	1st scenario	2nd scenario	3rd scenario	1st scenario	2nd scenario	3rd scenario
Worker Number	26	34	30	26	36	30
Workstation Number	14	12	13	14	13	13

When we look at the scenarios, the number of workstations in the second for WWM is the lowest. But when we look at overall table (Table 6.15), scenario 2 for WWM seems to be most advantageous. With scenario 3 for WWM , optimal workstation number and worker number is ensured.

Let us examine the results in detail for c = 32400 seconds.

In the first scenario, we ran COMSOAL with 2000 iteration. When we look at the results of the first scenario, workstation and worker number remain same for WM and WWM. WWM or WM can be selected in the first scenario because the number of workstations and workers are same (Table 6.16 and Table 6.17).

Table 6.16 Workload of workers 1st scenario C=16200 sec for WWM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	11054
2nd workstation 1st worker	7400
3rd workstation 1st worker	9817
4th workstation 1st worker	6349
5th workstation 1st worker	5889
6th workstation 1st worker	6572
7th workstation 1st worker	7799
8th workstation 1st worker	11280
9th workstation 1st worker	6240
10th workstation 1st worker	4611
11th workstation 1st worker	3072
12th workstation 1st worker	10809
13th workstation 1st worker	6395
14th workstation 1st worker	7845
2nd workstation 2nd worker	1928
3rd workstation 2nd worker	3057
4th workstation 2nd worker	5535
5th workstation 2nd worker	5192
6th workstation 2nd worker	4545
7th workstation 2nd worker	4782
8th workstation 2nd worker	6000
9th workstation 2nd worker	3150
10th workstation 2nd worker	4408
11th workstation 2nd worker	8061
12th workstation 2nd worker	60
13th workstation 2nd worker	4588
14th workstation 2nd worker	4893

Table 6.17 Workload of workers 1st scenario C=16200 sec for WM.

Workstation and Worker	Time(sec)
1st workstation 1st worker	11054
2nd workstation 1st worker	7913
3rd workstation 1st worker	7270
4th workstation 1st worker	7174
5th workstation 1st worker	5785
6th workstation 1st worker	5252
7th workstation 1st worker	8346
8th workstation 1st worker	8560
9th workstation 1st worker	4378
10th workstation 1st worker	3796
11th workstation 1st worker	4636
12th workstation 1st worker	6775
13th workstation 1st worker	2257
14th workstation 1st worker	5400
2nd workstation 2nd worker	1510
3rd workstation 2nd worker	7740
4th workstation 2nd worker	5648
5th workstation 2nd worker	8955
6th workstation 2nd worker	3799
7th workstation 2nd worker	15207
8th workstation 2nd worker	484
9th workstation 2nd worker	4072
10th workstation 2nd worker	9798
11th workstation 2nd worker	6173
12th workstation 2nd worker	4268
13th workstation 2nd worker	5081

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.13 and Figure 6.14. To eliminate this situation, work pieces must be further divided.

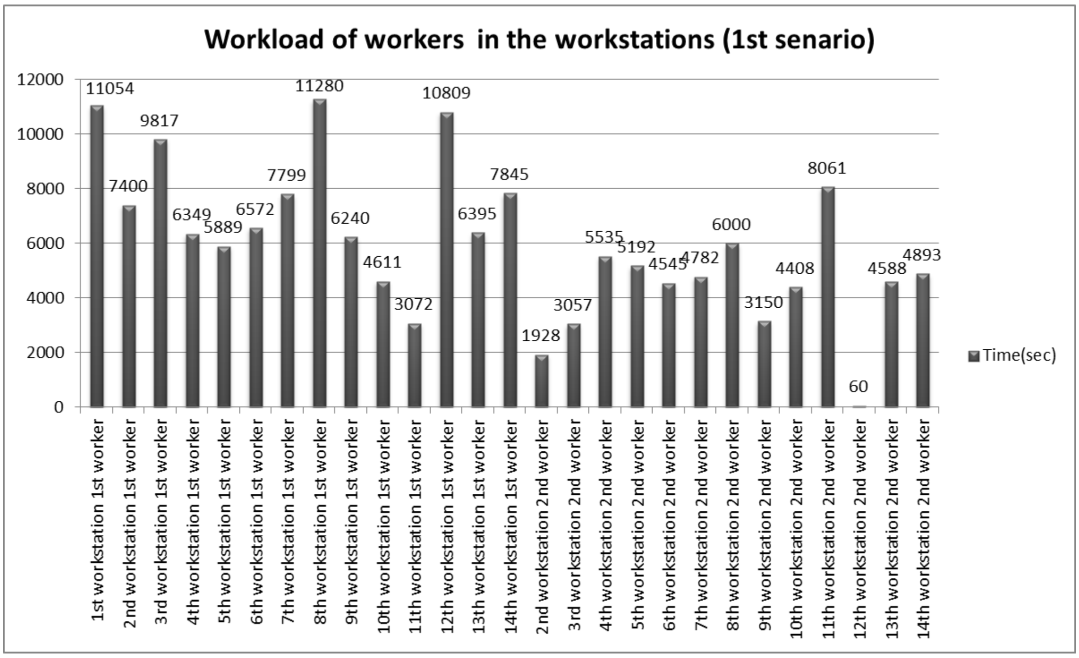

Figure 6.13 Workload of workers of 1st scenario C=16200 sec for WWM.

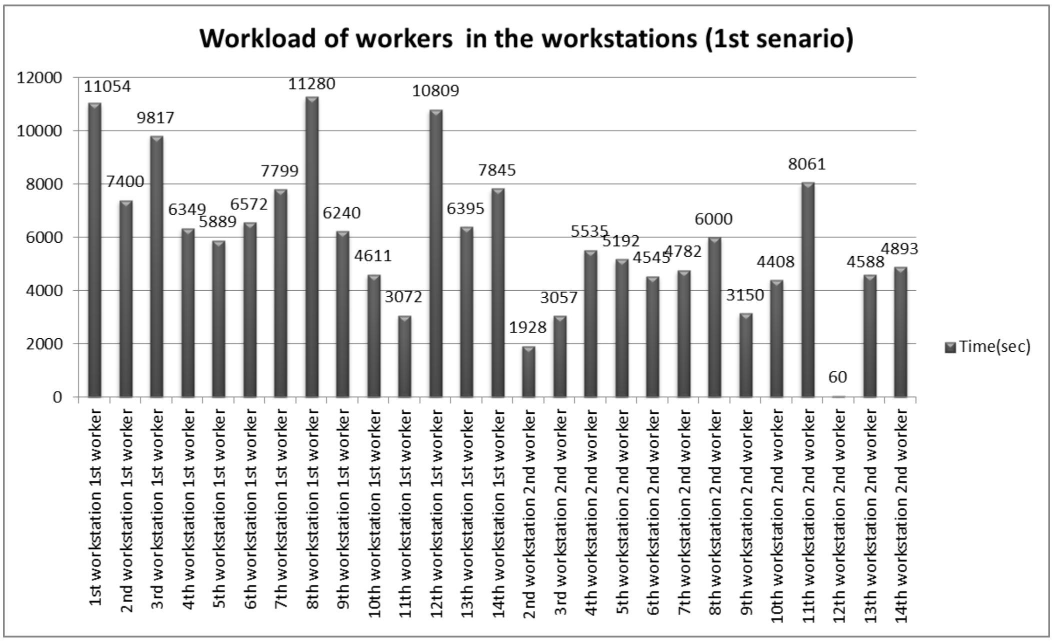

Figure 6.14 Workload of workers of 1st scenario C=16200 sec for WM.

In the second scenario, we also ran COMSOAL with 2000 iteration. When we look at the results of the second scenario, workstation number and worker number is lower in WWM. WWM can be selected in the second scenario because the number of workstations and workers is lower for WWM (Table 6.18 and Table 6.19). In this scenario, the worker number in workstations is increased.

Table 6.18 Workload of workers 2nd scenario C=16200 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	4417	7th workstation 2nd worker	204
2nd workstation 1st worker	11305	8th workstation 2nd worker	4005
3rd workstation 1st worker	5200	9th workstation 2nd worker	4490
4th workstation 1st worker	6290	10th workstation 2nd worker	4440
5th workstation 1st worker	2741	11th workstation 2nd worker	5931
6th workstation 1st worker	7337	12th workstation 2nd worker	2028
7th workstation 1st worker	6306	2nd workstation 3rd worker	431
8th workstation 1st worker	3086	3rd workstation 3rd worker	5256
9th workstation 1st worker	1651	4th workstation 3rd worker	4143
10th workstation 1st worker	11743	5th workstation 3rd worker	4032
11th workstation 1st worker	3357	6th workstation 3rd worker	9155
12th workstation 1st worker	6773	7th workstation 3rd worker	6040
1st workstation 2nd worker	7913	8th workstation 3rd worker	2381
2nd workstation 2nd worker	4090	9th workstation 3rd worker	3611
3rd workstation 2nd worker	4521	10th workstation 3rd worker	120
4th workstation 2nd worker	4267	11th workstation 3rd worker	3298
5th workstation 2nd worker	4130	12th workstation 3rd worker	2214
6th workstation 2nd worker	4425		

Table 6.19 Workload of workers 2nd scenario C=16200 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	8297	7th workstation 2nd worker	4120
2nd workstation 1st worker	7601	8th workstation 2nd worker	1259
3rd workstation 1st worker	7509	9th workstation 2nd worker	1926
4th workstation 1st worker	4963	10th workstation 2nd worker	6763
5th workstation 1st worker	3681	11th workstation 2nd worker	256
6th workstation 1st worker	5003	12th workstation 2nd worker	1835
7th workstation 1st worker	12306	13th workstation 2nd worker	2089
8th workstation 1st worker	6615	2nd workstation 3rd worker	3600
9th workstation 1st worker	3021	3rd workstation 3rd worker	2158
10th workstation 1st worker	2821	4th workstation 3rd worker	3844
11th workstation 1st worker	4463	5th workstation 3rd worker	5245
12th workstation 1st worker	6123	6th workstation 3rd worker	5694
13th workstation 1st worker	8838	7th workstation 3rd worker	1380
1st workstation 2nd worker	4033	8th workstation 3rd worker	1516
2nd workstation 2nd worker	1501	9th workstation 3rd worker	4072
3rd workstation 2nd worker	2977	10th workstation 3rd worker	1699
4th workstation 2nd worker	4441	11th workstation 3rd worker	6300
5th workstation 2nd worker	5723	12th workstation 3rd worker	3271
6th workstation 2nd worker	3123	13th workstation 3rd worker	1265

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.15 and Figure 6.16. To eliminate this situation, work pieces must be further divided.

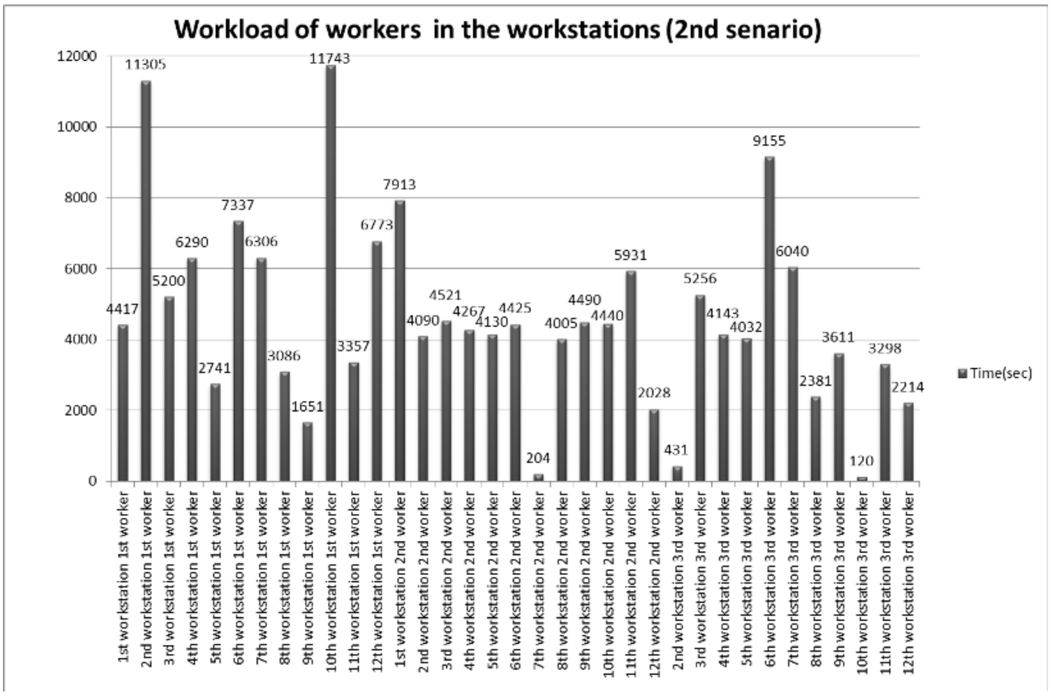

Figure 6.15 Workload of workers of 2nd scenario C=16200 sec for WWM.

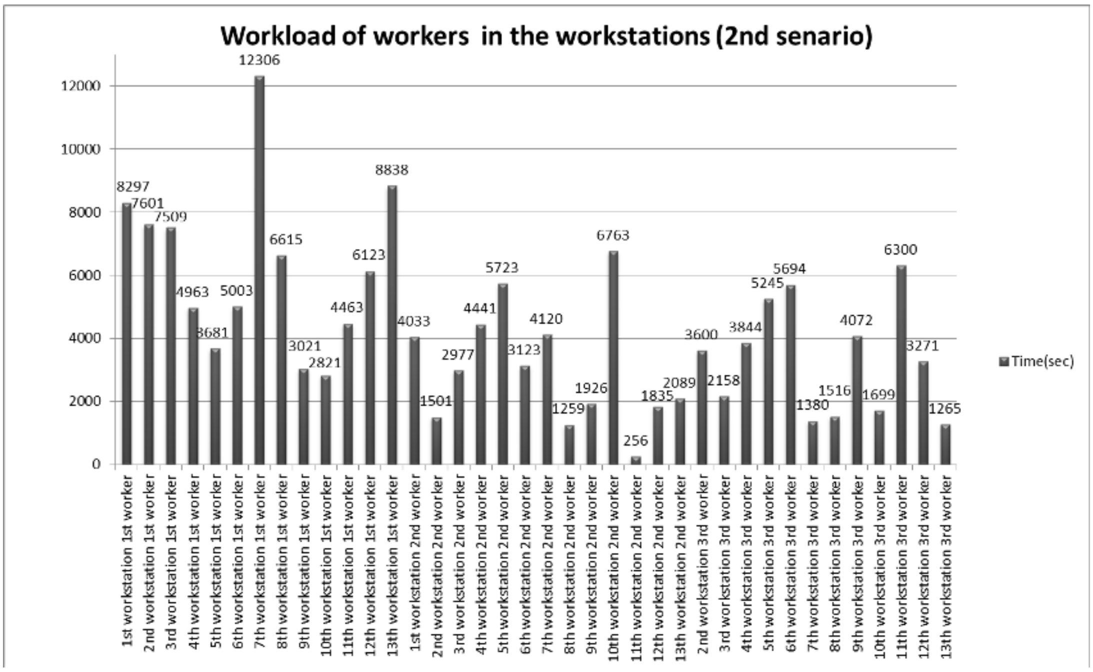

Figure 6.16 Workload of workers of 2nd scenario C=16200 sec for WM.

In the third scenario,worker number of the workstation is between the first and second scenario’s workstation worker number. When we look at the results of the third scenario, workstation number remains same in WWM and WM and worker number is decreasing in WM. WM can be selected in the third scenario because the number of workstations is same for WWM and WM however number of worker is less in WM (Table 6.20 and Table 6.21).

Table 6.20 Workload of workers 3rd scenario C=16200 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	4522	5th workstation 2nd worker	2403
2nd workstation 1st worker	10438	6th workstation 2nd worker	5537
3rd workstation 1st worker	5945	7th workstation 2nd worker	4696
4th workstation 1st worker	4734	8th workstation 2nd worker	1486
5th workstation 1st worker	4788	9th workstation 2nd worker	2345
6th workstation 1st worker	7017	10th workstation 2nd worker	2663
7th workstation 1st worker	13546	11th workstation 2nd worker	120
8th workstation 1st worker	7572	12th workstation 2nd worker	6724
9th workstation 1st worker	3975	13th workstation 2nd worker	6772
10th workstation 1st worker	7530	1st workstation 3rd worker	3865
11th workstation 1st worker	4560	3rd workstation 3rd worker	3327
12th workstation 1st worker	3387	5th workstation 3rd worker	5664
13th workstation 1st worker	2523	7th workstation 3rd worker	1045
1st workstation 2nd worker	4347	9th workstation 3rd worker	4020
2nd workstation 2nd worker	3907	11th workstation 3rd worker	6549
3rd workstation 2nd worker	5222	13th workstation 3rd worker	2425
4th workstation 2nd worker	7677		

Table 6.21 Workload of workers 3rd scenario C=16200 sec for WM.

Workstation and Worker	Time(sec)	Idle time	IT ratio
1st workstation 1st worker	4264	5th workstation 2nd worker	2186
2nd workstation 1st worker	9886	6th workstation 2nd worker	4220
3rd workstation 1st worker	5475	7th workstation 2nd worker	6987
4th workstation 1st worker	8220	8th workstation 2nd worker	3024
5th workstation 1st worker	5552	9th workstation 2nd worker	4334
6th workstation 1st worker	4350	10th workstation 2nd worker	665
7th workstation 1st worker	15873	11th workstation 2nd worker	399
8th workstation 1st worker	6615	12th workstation 2nd worker	5668
9th workstation 1st worker	2245	13th workstation 2nd worker	1259
10th workstation 1st worker	10768	1st workstation 3rd worker	4203
11th workstation 1st worker	10680	3rd workstation 3rd worker	1971
12th workstation 1st worker	3867	5th workstation 3rd worker	6553
13th workstation 1st worker	7677	7th workstation 3rd worker	2255
1st workstation 2nd worker	4267	9th workstation 3rd worker	1725
2nd workstation 2nd worker	1410	11th workstation 3rd worker	1020
3rd workstation 2nd worker	4182	13th workstation 3rd worker	3570

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.17 and Figure 6.18. To eliminate this situation, work pieces must be further divided.

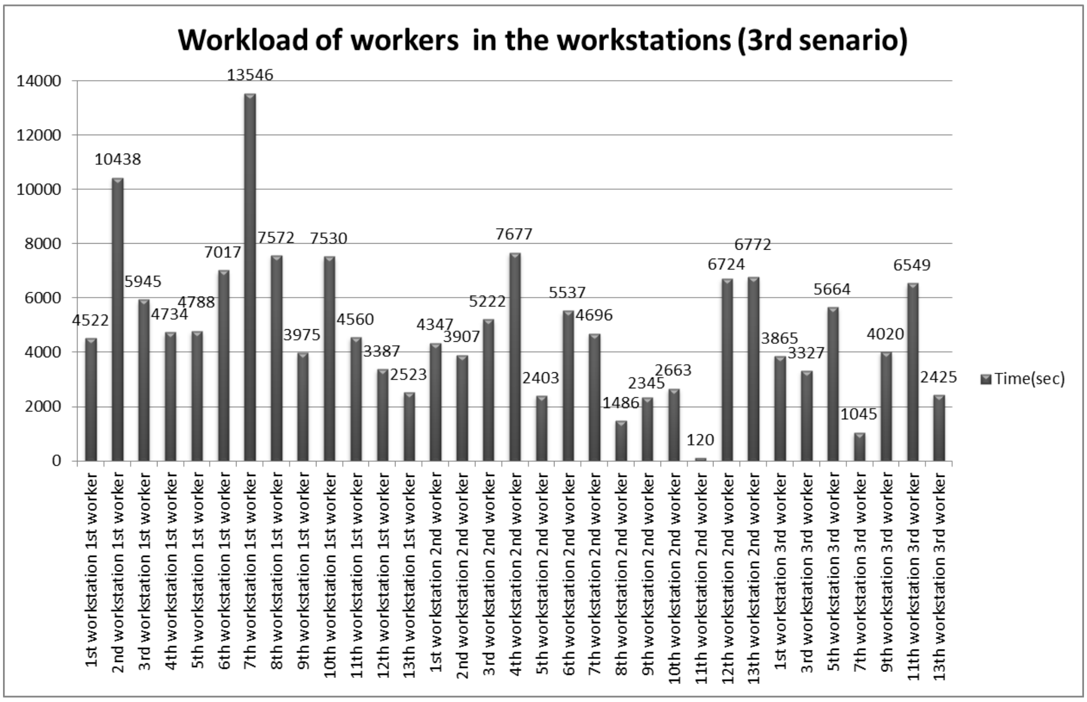

Figure 6.17 Workload of workers of 3rd scenario C=16200 sec for WWM.

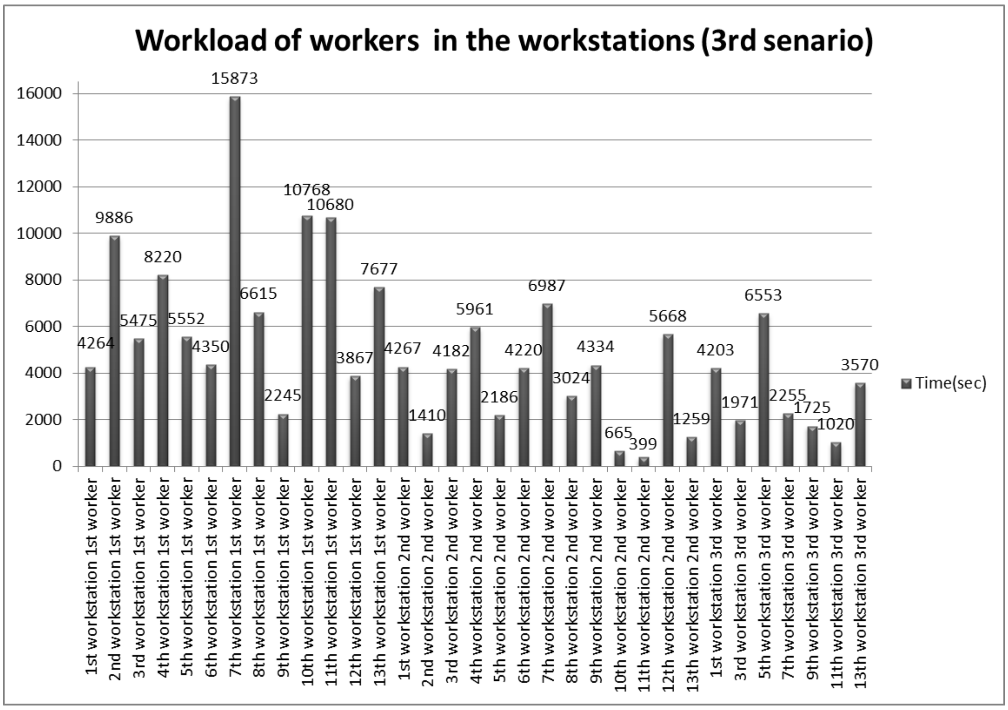

Figure 6.18 Workload of workers of 3rd scenario C=16200 sec for WM.

6.4 Results for C=8100 sec

For daily machine production speed is 4 machine/day, cycle time is 8100 sec. Different situations were tested and interpreted according to 3 different workstation sequences for 3 different Cycle times. For the last cycle time C = 8100 seconds, the balancing states will be evaluated according to 3 different scenarios.

Table 6.22 Comparing workstation number and worker number of 3 scenarios for C=16200 sec for two objective

	C=8100 sec					
	Workstation and Worker Minimization			Workstation Minimization		
	1st scenario	2nd scenario	3rd scenario	1st scenario	2nd scenario	3rd scenario
Worker Number	45	59	52	48	65	53
Workstation Number	24	22	22	25	23	22

For C = 8100 seconds, the daily production rate of 4 machines/day balancing according to the results obtained are summarized in the Table 6.22 above. In order to achieve this speed of production, the number of workers and the number of workstations should naturally increase. However, it is here that the optimum number of workstations and optimum task distribution are important.

For this, C = 8100 seconds production rate was balanced by the COMSOAL method according to 3 different scenarios. We will examine the results separately. However, when you look at the summary table (Table 6.22), it can be seen that the optimal scenario is scenario 3 for WWM.

Let us examine the results in detail for c=8100 seconds.

In the first scenario, we ran COMSOAL with 2000 iteration. When we look at the results of the first scenario, workstation and worker number are lower WWM. WWM can be selected in the first scenario because the number of workstations and workers are lower (Table 6.23 and Table 6.24).

Table 6.23 Workload of workers 1st scenario C=8100 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	5233	2nd workstation 2nd worker	1524
2nd workstation 1st worker	5823	3rd workstation 2nd worker	496
3rd workstation 1st worker	6410	4th workstation 2nd worker	7588
4th workstation 1st worker	1461	5th workstation 2nd worker	2661
5th workstation 1st worker	4462	6th workstation 2nd worker	3545
6th workstation 1st worker	3447	7th workstation 2nd worker	2622
7th workstation 1st worker	6059	8th workstation 2nd worker	4416
8th workstation 1st worker	3586	9th workstation 2nd worker	1642
9th workstation 1st worker	5159	10th workstation 2nd worker	2041
10th workstation 1st worker	2725	11th workstation 2nd worker	3630
11th workstation 1st worker	5043	12th workstation 2nd worker	4386
12th workstation 1st worker	6000	13th workstation 2nd worker	40
13th workstation 1st worker	7816	14th workstation 2nd worker	204
14th workstation 1st worker	6865	15th workstation 2nd worker	2442
15th workstation 1st worker	1879	16th workstation 2nd worker	2417
16th workstation 1st worker	1834	17th workstation 2nd worker	2842
17th workstation 1st worker	1463	18th workstation 2nd worker	2359
18th workstation 1st worker	2837	19th workstation 2nd worker	295
19th workstation 1st worker	5701	20th workstation 2nd worker	777
20th workstation 1st worker	4699	21st workstation 2nd worker	181
21st workstation 1st worker	6720	22nd workstation 2nd worker	2238
22nd workstation 1st worker	3708	23rd workstation 2nd worker	2429
23rd workstation 1st worker	3862	24th workstation 2nd worker	6406
24th workstation 1st worker	1358		

Table 6.24 Workload of workers 1st scenario C=8100 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	5233	25th workstation 1st worker	5400
2nd workstation 1st worker	6202	2nd workstation 2nd worker	967
3rd workstation 1st worker	6664	3rd workstation 2nd worker	633
4th workstation 1st worker	4123	4th workstation 2nd worker	5053
5th workstation 1st worker	3173	5th workstation 2nd worker	4509
6th workstation 1st worker	4257	6th workstation 2nd worker	4056
7th workstation 1st worker	1706	7th workstation 2nd worker	3562
8th workstation 1st worker	2410	8th workstation 2nd worker	3917
9th workstation 1st worker	3943	9th workstation 2nd worker	3967
10th workstation 1st worker	2774	10th workstation 2nd worker	1689
11th workstation 1st worker	2727	11th workstation 2nd worker	1485
12th workstation 1st worker	6864	12th workstation 2nd worker	5965
13th workstation 1st worker	6000	13th workstation 2nd worker	4120
14th workstation 1st worker	7200	14th workstation 2nd worker	204
15th workstation 1st worker	3663	15th workstation 2nd worker	1124
16th workstation 1st worker	3567	16th workstation 2nd worker	1399
17th workstation 1st worker	1210	17th workstation 2nd worker	3095
18th workstation 1st worker	2781	18th workstation 2nd worker	2535
19th workstation 1st worker	6066	19th workstation 2nd worker	962
20th workstation 1st worker	4405	20th workstation 2nd worker	23
21st workstation 1st worker	256	21st workstation 2nd worker	6120
22nd workstation 1st worker	1287	22nd workstation 2nd worker	3651
23rd workstation 1st worker	4701	23rd workstation 2nd worker	1829
24th workstation 1st worker	1996	24th workstation 2nd worker	1858

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.19 and Figure 6.20. To eliminate this situation, work pieces must be further divided.

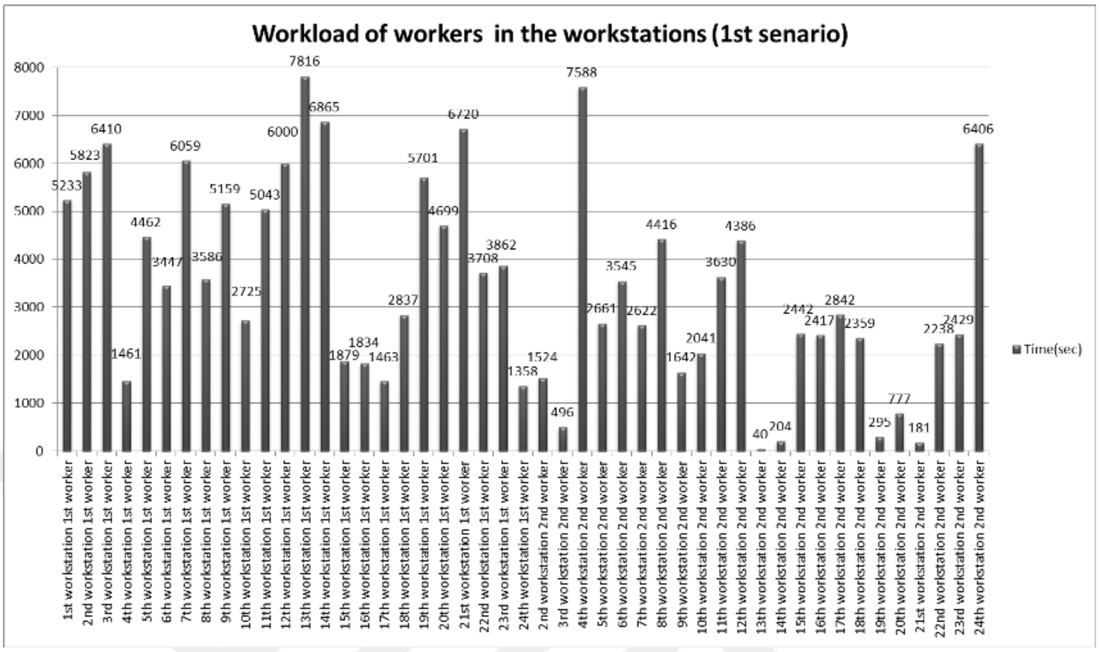

Figure 6.19 Workload of workers of 1st scenario C=8100 sec for WWM.

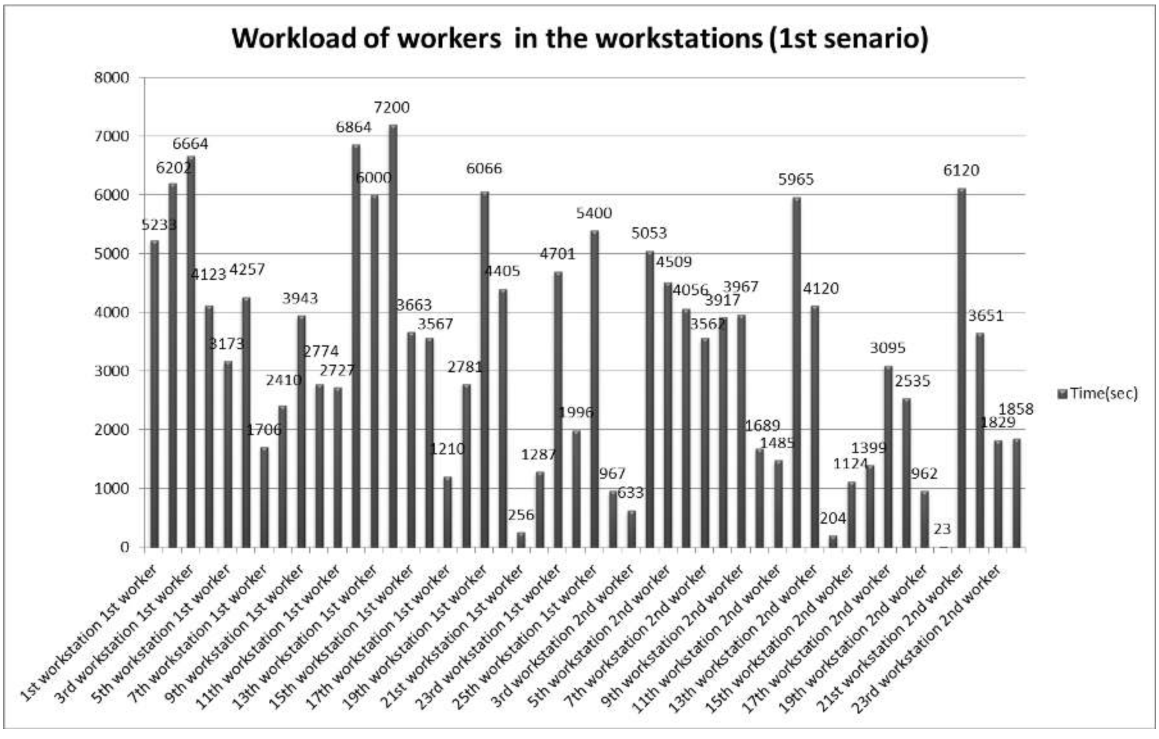

Figure 6.20 Workload of workers of 1st scenario C=8100 sec for WM.

In the second scenario, we also ran COMSOAL with 2000 iteration. When we look at the results of the second scenario, workstation number and worker number is lower in WWM. WWM can be selected in the second scenario because the number of workstations and workers is lower for WWM (Table 6.25 and Table 6.26). In this scenario, the worker number in workstations is increased.

Table 6.25 Workload of workers 2nd scenario C=8100 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	4035	11th workstation 2nd worker	5445
2nd workstation 1st worker	3635	12th workstation 2nd worker	2711
3rd workstation 1st worker	6238	13th workstation 2nd worker	372
4th workstation 1st worker	4800	14th workstation 2nd worker	868
5th workstation 1st worker	2408	15th workstation 2nd worker	3566
6th workstation 1st worker	2889	16th workstation 2nd worker	2132
7th workstation 1st worker	2702	17th workstation 2nd worker	808
8th workstation 1st worker	4720	19th workstation 2nd worker	60
9th workstation 1st worker	714	20th workstation 2nd worker	2830
10th workstation 1st worker	3216	21st workstation 2nd worker	1326
11th workstation 1st worker	4844	22nd workstation 2nd worker	783
12th workstation 1st worker	6387	2nd workstation 3rd worker	2742
13th workstation 1st worker	6085	3rd workstation 3rd worker	307
14th workstation 1st worker	2736	4th workstation 3rd worker	548
15th workstation 1st worker	3318	5th workstation 3rd worker	4005
16th workstation 1st worker	1979	6th workstation 3rd worker	2867
17th workstation 1st worker	4506	7th workstation 3rd worker	2057
18th workstation 1st worker	4380	8th workstation 3rd worker	787
19th workstation 1st worker	6000	9th workstation 3rd worker	2036
20th workstation 1st worker	858	10th workstation 3rd worker	1470
21st workstation 1st worker	2630	11th workstation 3rd worker	6000
22nd workstation 1st worker	2273	12th workstation 3rd worker	660
1st workstation 2nd worker	1318	13th workstation 3rd worker	579
2nd workstation 2nd worker	1424	14th workstation 3rd worker	1756
3rd workstation 2nd worker	180	15th workstation 3rd worker	283
4th workstation 2nd worker	3807	16th workstation 3rd worker	1500
5th workstation 2nd worker	2149	17th workstation 3rd worker	5400
6th workstation 2nd worker	3826	18th workstation 3rd worker	219
7th workstation 2nd worker	2586	19th workstation 3rd worker	60
8th workstation 2nd worker	3198	20th workstation 3rd worker	1147
9th workstation 2nd worker	2446	21st workstation 3rd worker	1148
10th workstation 2nd worker	1800	22nd workstation 3rd worker	772

Table 6.26 Workload of workers 2nd scenario C=8100 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	1128	12th workstation 2nd worker	766
2nd workstation 1st worker	2830	13th workstation 2nd worker	375
3rd workstation 1st worker	6238	14th workstation 2nd worker	2336
4th workstation 1st worker	3905	15th workstation 2nd worker	1639
5th workstation 1st worker	3516	16th workstation 2nd worker	297
6th workstation 1st worker	4443	17th workstation 2nd worker	2428
7th workstation 1st worker	2640	18th workstation 2nd worker	808
8th workstation 1st worker	4466	19th workstation 2nd worker	196
9th workstation 1st worker	1105	20th workstation 2nd worker	120
10th workstation 1st worker	3236	21st workstation 2nd worker	1210
11th workstation 1st worker	7304	22nd workstation 2nd worker	1613
12th workstation 1st worker	7015	23rd workstation 2nd worker	765
13th workstation 1st worker	6900	2nd workstation 3rd worker	1832
14th workstation 1st worker	1207	3rd workstation 3rd worker	81
15th workstation 1st worker	1013	4th workstation 3rd worker	3935
16th workstation 1st worker	2542	5th workstation 3rd worker	2411
17th workstation 1st worker	2672	6th workstation 3rd worker	1932
18th workstation 1st worker	4506	7th workstation 3rd worker	3438
19th workstation 1st worker	4403	8th workstation 3rd worker	3460
20th workstation 1st worker	6060	9th workstation 3rd worker	1186
21st workstation 1st worker	3305	10th workstation 3rd worker	978
22nd workstation 1st worker	1460	11th workstation 3rd worker	4277
23rd workstation 1st worker	1125	12th workstation 3rd worker	300
1st workstation 2nd worker	4225	13th workstation 3rd worker	204
2nd workstation 2nd worker	3413	14th workstation 3rd worker	884
3rd workstation 2nd worker	180	15th workstation 3rd worker	1760
4th workstation 2nd worker	1287	16th workstation 3rd worker	2317
5th workstation 2nd worker	2336	17th workstation 3rd worker	277
6th workstation 2nd worker	1748	18th workstation 3rd worker	5400
7th workstation 2nd worker	1279	20th workstation 3rd worker	60
8th workstation 2nd worker	2115	21st workstation 3rd worker	443
9th workstation 2nd worker	2389	22nd workstation 3rd worker	3278
10th workstation 2nd worker	1524	23rd workstation 3rd worker	448
11th workstation 2nd worker	6362		

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.21 and Figure 6.22. To eliminate this situation, work pieces must be further divided.

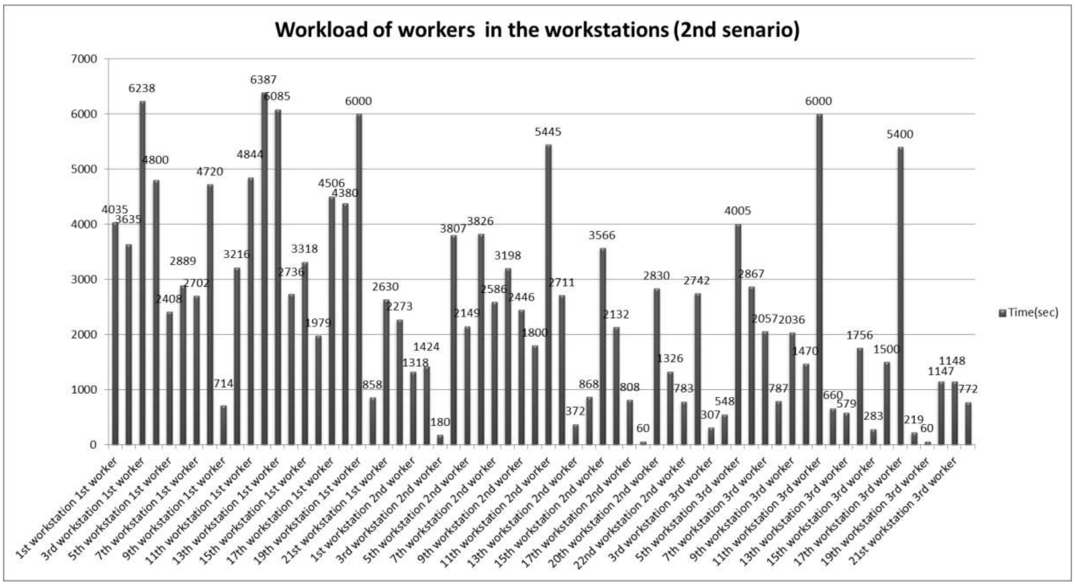

Figure 6.21 Workload of workers of 2nd scenario C=8100 sec for WWM.

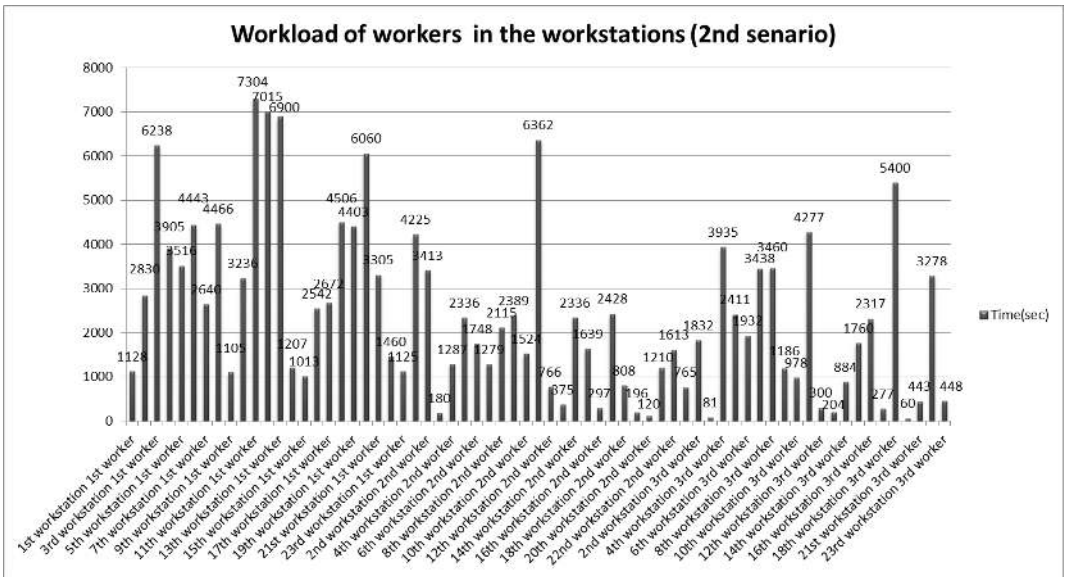

Figure 6.22 Workload of workers of 2nd scenario C=81000 sec for WM.

In the third scenario,worker number of the workstation is between the first and second scenario's workstation worker number. When we look at the results of the third scenario, workstation number remains same in WWM and WM and worker number is decreasing in WWM. WWM can be selected in the third scenario because the number of workstations is same for WWM and WM however number of worker is less in WWM (Table 6.27 and Table 6.28).

Table 6.27 Workload of workers 3rd scenario C=8100 sec for WWM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	1092	7th workstation 2nd worker	2613
2nd workstation 1st worker	5324	8th workstation 2nd worker	3968
3rd workstation 1st worker	1233	9th workstation 2nd worker	2031
4th workstation 1st worker	4197	10th workstation 2nd worker	3268
5th workstation 1st worker	3922	11th workstation 2nd worker	4589
6th workstation 1st worker	3508	12th workstation 2nd worker	450
7th workstation 1st worker	2799	13th workstation 2nd worker	747
8th workstation 1st worker	2787	14th workstation 2nd worker	2909
9th workstation 1st worker	1443	15th workstation 2nd worker	88
10th workstation 1st worker	4845	16th workstation 2nd worker	1383
11th workstation 1st worker	6865	17th workstation 2nd worker	2305
12th workstation 1st worker	6150	18th workstation 2nd worker	23
13th workstation 1st worker	7104	19th workstation 2nd worker	6060
14th workstation 1st worker	1742	20th workstation 2nd worker	1349
15th workstation 1st worker	1717	21st workstation 2nd worker	1893
16th workstation 1st worker	3571	22nd workstation 2nd worker	719
17th workstation 1st worker	6514	1st workstation 3rd worker	1570
18th workstation 1st worker	4380	3rd workstation 3rd worker	4020
19th workstation 1st worker	376	5th workstation 3rd worker	1332
20th workstation 1st worker	3609	7th workstation 3rd worker	3206
21st workstation 1st worker	3111	9th workstation 3rd worker	918
22nd workstation 1st worker	6729	11th workstation 3rd worker	2633
1st workstation 2nd worker	3475	13th workstation 3rd worker	607
2nd workstation 2nd worker	7144	15th workstation 3rd worker	3206
3rd workstation 2nd worker	4421	17th workstation 3rd worker	272
4th workstation 2nd worker	3402	19th workstation 3rd worker	180
5th workstation 2nd worker	4188	21st workstation 3rd worker	1457
6th workstation 2nd worker	1887		

Table 6.28 Workload of workers 3rd scenario C=8100 sec for WM.

Workstation and Worker	Time(sec)	Workstation and Worker	Time(sec)
1st workstation 1st worker	1462	7th workstation 2nd worker	5436
2nd workstation 1st worker	6596	8th workstation 2nd worker	1620
3rd workstation 1st worker	4286	9th workstation 2nd worker	1152
4th workstation 1st worker	3205	10th workstation 2nd worker	2905
5th workstation 1st worker	3934	11th workstation 2nd worker	2221
6th workstation 1st worker	2968	12th workstation 2nd worker	616
7th workstation 1st worker	2291	13th workstation 2nd worker	579
8th workstation 1st worker	4451	14th workstation 2nd worker	663
9th workstation 1st worker	2000	15th workstation 2nd worker	479
10th workstation 1st worker	4493	16th workstation 2nd worker	1021
11th workstation 1st worker	7200	17th workstation 2nd worker	1030
12th workstation 1st worker	7465	18th workstation 2nd worker	196
13th workstation 1st worker	6900	19th workstation 2nd worker	120
14th workstation 1st worker	4125	20th workstation 2nd worker	1695
15th workstation 1st worker	1729	21st workstation 2nd worker	911
16th workstation 1st worker	3381	22nd workstation 2nd worker	1213
17th workstation 1st worker	6787	1st workstation 3rd worker	4146
18th workstation 1st worker	4526	3rd workstation 3rd worker	5233
19th workstation 1st worker	6292	5th workstation 3rd worker	2756
20th workstation 1st worker	4463	7th workstation 3rd worker	1263
21st workstation 1st worker	2449	9th workstation 3rd worker	1014
22nd workstation 1st worker	6525	11th workstation 3rd worker	4080
1st workstation 2nd worker	925	13th workstation 3rd worker	372
2nd workstation 2nd worker	713	15th workstation 3rd worker	2752
3rd workstation 2nd worker	5192	17th workstation 3rd worker	852
4th workstation 2nd worker	4312	19th workstation 3rd worker	180
5th workstation 2nd worker	2306	21st workstation 3rd worker	2811
6th workstation 2nd worker	3039		

When we examine the above tables, we observe some idle time. This is also seen in Figure 6.23 and Figure 6.24. To eliminate this situation, work pieces must be further divided.

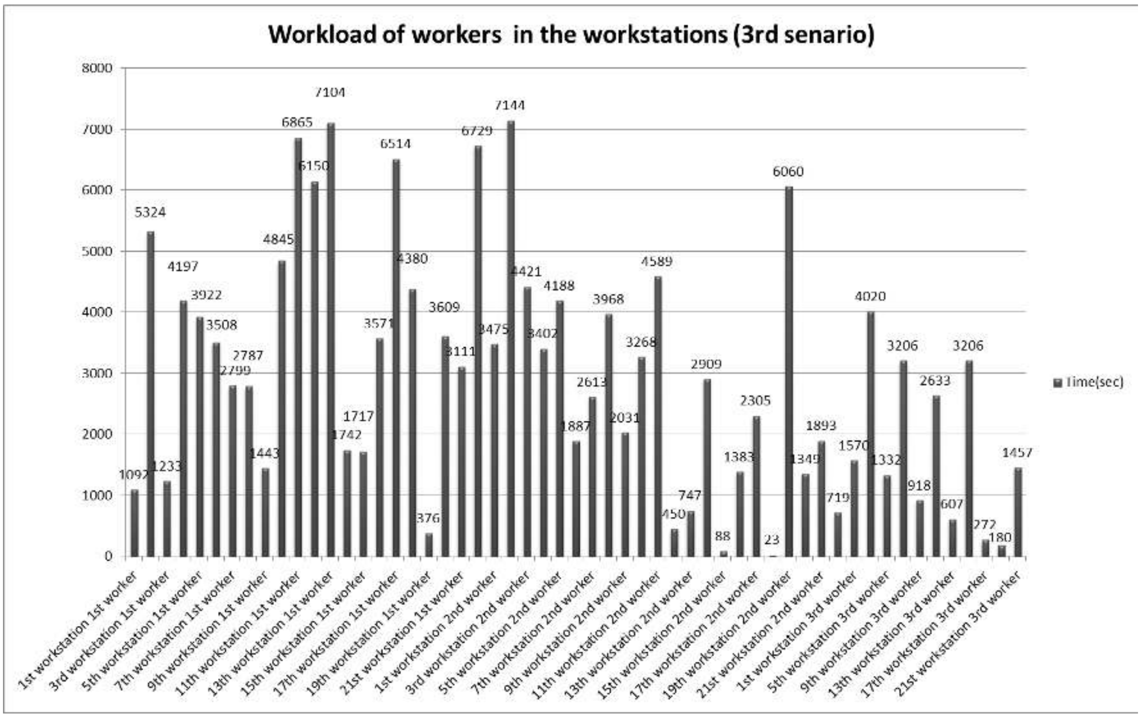

Figure 6.23 Workload of workers of 3rd scenario C=8100 sec for WWM.

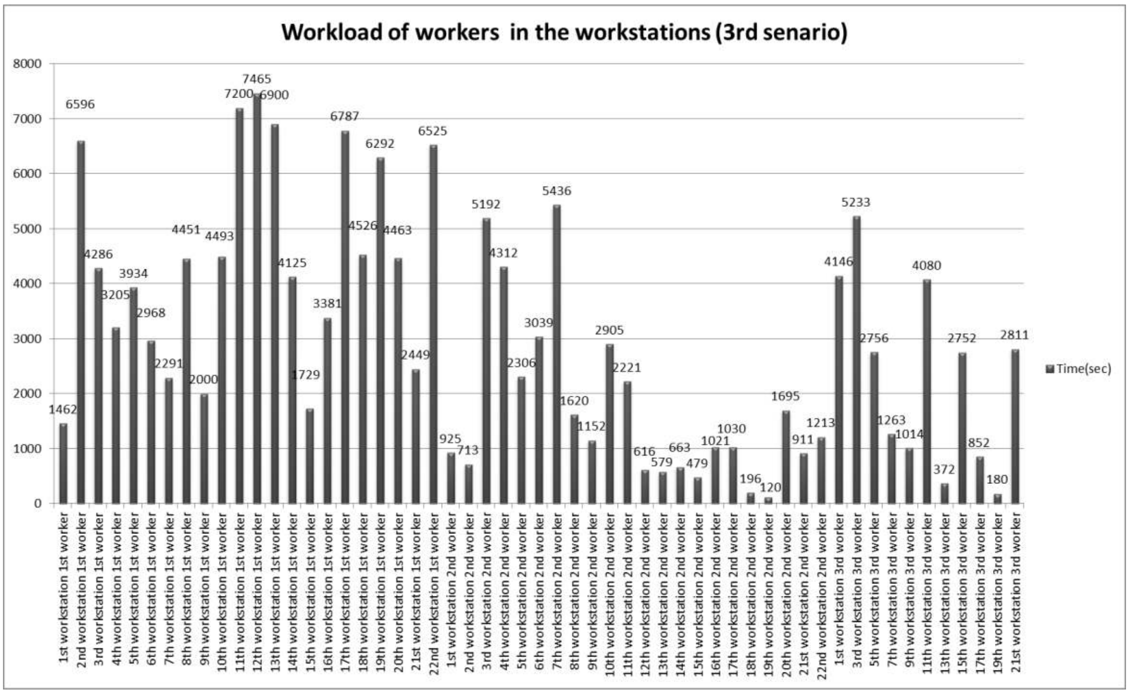

Figure 6.24 Workload of workers of 3rd scenario C=8100 sec for WM.

CHAPTER VII

CONCLUSIONS

The objectives of the assembly lines, which are widely used in the sector at sunrise, are the last stages of production processes, and their perspective with them is quite effective. In recent years, customer preferences are highly differentiated and customers demand their own products, as well as the development of technology in the future. Under this competitiveness, it uses an efficient, flexible and flexible production system in its production and it directs customer demands very quickly without sacrificing quality. Assembly was allowed to meet these demands. A number of problems with the possibility of assembly lines were introduced. The most important of these is the assembly line balancing problem.

So far, academic studies have mostly been done on traditional assembly lines and these studies have not been associated with real assembly line balancing problems. Industry could not benefit from these studies. However, recent studies on multi-manned assembly line balancing problems have gradually eliminated this situation. Because academic studies and real problems are largely overlapping. In this study, we tried to solve a real multi-manned assembly line balancing problem by taking this situation one step further. The following findings and conclusions show that the heuristic algorithm has been optimally solved the problem of factory.

In this thesis, a real case study is discussed. It is aimed to balance the assembly line of a plant in the field of construction equipment. At the beginning of this study, the factory was introduced and the layout of the assembly line was given. Afterwards, definitions related to assembly line were made. Types of assembly line are mentioned. A comprehensive literature study was conducted and the details were shared.

After explaining the assembly line balancing problem and mentioning the literature studies on the subject, the mathematical model was introduced. In this study, unlike traditional assembly line balancing, a mathematical model is developed for multi-manned assembly line balancing of a factory producing machine. The study offers a mixed integer linear programming model to balance the assembly line. This model aims to minimiz the number of workstations. With this model, small scale balancing problems can be solved. However, this model is insufficient to solve large-scale problems. For this reason, heuristic algorithm has been developed for the solution of large scale balancing problems.

The developed heuristic algorithm is COMSOAL method. COMSOAL method was run with MATLAB program and tried to find the optimum result with 2000 iterations for WWM and WM. Since the production rate varies from time to time in this factory, balancing has been made according to 4 different production speeds in order to meet the needs of the factory. In this study, 4 different cycle times were tested according to 3 different workstation worker distribution. The results are indicated by tables and graphs.

Firstly, 3 different workstation worker distributions for 3 machines/day production speed and 10800 second cycle time, which is the production speed of the factory, were studied.

In the following scenarios, the production rate was 1 machine/day, 2 machine/day and 4 machine/day respectively.

Turkey's economic environment of healing with sales in mind the increasing availability of factory production machine speed of 4 machine/day situations that were examined. 3 different worker placement conditions were examined for 4 machines/day and 8100 seconds cycle time.

In addition, material flow maps should be prepared for the assembly line discussed in the study and material flow should be regulated. There are also problems in feeding material to the assembly line. A comprehensive study can be done on this subject. In addition, the arrangement of the shelves in the assembly line and the effective implementation of the KANBAN system will minimize downtime due to lack of material in the assembly line. Finally, a new REFA analysis study can be carried out in the continuation of the implementation of the distribution of workers and workstations. With this study, the situation of lost times is observed and new causes of loss are created if any.

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