(REFEREED RESEARCH)

RESOURCE-CONSTRAINED MIXED MODEL ASSEMBLY LINE BALANCING IN AN APPAREL COMPANY

BİR HAZIR GİYİM İŞLETMESİNDE KAYNAK KISITLI KARMA MODELLİ MONTAJ HATTI DENGELEME

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ABSTRACT

Apparel production has a labor-intense and complex production structure. It is not financially feasible to assign distinct lines and workers for the production of models with low production numbers and high variety. For this reason, assembly lines which allow the production of various models are widely preferred. In addition, the main drawbacks of the apparel industry are low efficiency and line balancing and planning difficulties stemming from low order numbers. In this study, the problems of assembly line balancing and some recommendations in a small scale company producing mixed-model men's shirts have been extensively studied. The main aim is to construct lines which allow the assembly of orders on various volumes and models and to balance the assembly lines in order to deliver goods of the required quality and productivity and at the lowest cost. The data has been analyzed via COMSOAL (Computer Method for Sequencing Operations for Assembly Lines) which is an intuitive and meta-intuitive algorithm. Computer Method for Sequencing Operations for Assembly Lines is also used to tabulate assembly line operation.

Keywords: Men's shirt, Apparel company, Assembly line balancing, Resource-constrained mixed model assembly line balancing, COMSOAL.

ÖZET

Hazır giyim üretimi emek yoğun ve karmaşık bir üretim yapısına sahiptir. Üretim miktarları düşük, çeşitliliği fazla modellerin imalatı için ayrı hat ve çalışan tahsis etmek maliyet ve tesis alanı bakımından uygun değildir. Bu yüzden çok fazla modelin aynı anda üretiminin gerçekleştiği üretim bantları tercih edilmektedir. Buna ek olarak düşük verimlilik, düşük sipariş miktarları arasında geçişten kaynaklanan hat dengeleme ve planlama zorlukları hazır giyim üretiminin önemli sorunlarındandır. Bu araştırmada karma modelli erkek gömleği üreten küçük ölçekli bir işletmede montaj hattı dengeleme problemleri ve çözüm önerileri üzerinde durulmuştur. Amaç farklı parti büyüklüğünde ve farklı modelde siparişlerin en verimli şekilde montajının sağlandığı hatların kurulması ve müşterilere istenilen kalitede, istenilen verimde ve en düşük maliyetle hızlı bir şekilde ürünleri teslim etmek için montaj hatlarının dengelenmesidir. Verilerin analizinde sezgisel bir algoritma olan COMSOAL'dan (Computer Method for Sequencing Operations for Assembly Lines) yararlanılmıştır.

Anahtar Kelimeler: Erkek gömleği, Hazır giyim işletmesi, Montaj hattı dengeleme, Kaynak kısıtlı karma modelli montaj hattı dengeleme, COMSOAL.

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1. INTRODUCTION

Assembly line balancing is one of the most important and complex problems of production sectors (17). The ready-made clothing sector is different from other sectors in this regard. In the sewing process, incorporating a large number of both workers and tasks, line balancing is a vital problem. Each task in the sewing process has a short time span, and each is handled in machines with different characteristics, or on machines and workbenches with different apparatuses. Additionally, there is a high variety of models, and production volumes are low.

The aim of this study is to determine whether there are assembly line balancing problems in small scale companies producing mixed-model men's shirts on various volumes and models, and to recommend solutions. The goal is to construct lines which allow the assembly of orders on various volumes and models and to balance the assembly lines in order to deliver goods of the required quality and productivity and at the lowest cost. With the COMSOAL algorithm, problems in assembly line balancing in resource-constrained, mixed-model men's shirts production are analyzed and possible solutions are suggested. The design has been made for the production of various models and volumes of men's shirts in the span of a day. Unlike the traditional COMSOAL algorithm, constraints pertaining to the ready-made clothing sector have been added, of one single worker manning a machine, the construction of parallel stations and different tasks being handled at different machines.

In 1994, Gökçen studied mixed-model deterministic assembly line balancing problems, analyzed optimal solution techniques for this type of problem in the literature, and suggested alternative models (7). In their 2002 study, Ağpak, Gökçen, Saray and Özel used the COMSOAL method for traditional, deterministic single-model lines (1). In a 2004 study by Günay, Çetin and Baykoç , type U assembly lines and traditional lines in an appliance production company adopting the JIT philosophy were analyzed (8). Illeez developed a mathematical model for the tabulation of apparel production planning stages in 2006, which deadlines for the production of ten different T-shirts as the same and minimized preparation times in switching from one product to the other on the production floor in the tabulation (10). In 2008, Eryürük, Başkak and Kalaoğlu performed an assembly line balancing for two different models for the sewing department of a mixed-model ready-made clothing company. In this study, the location-based line balancing method developed by Helgeson and Birnie and the probabilistic line balancing technique established by El-Sayed and Boucher were used (5). For parameters in assembly line problems in the production of automobile indicators, that could not be positively identified or for which there were no past data readily available, Kalender, Yılmaz ve Türkbey used the fuzzy logic approach in their 2008 study (11). In 2009, Orbak, Gündüz, Cengiz, Ulusoy, Akgöz, Kiriş and İrice performed balancing on two assembly lines for the automotive sub-industry, using the Hoffman intuitive method and the sorted position weights method developed by Helgeson and Birnie (1961) for mixed-model lines (14). Another mixed-model line balancing study in the automotive industry was done by Özalp, Orbak, Korkmaz, Yarkın, Aktaş and Dinçer in 2009 (15). In a 2009 study, Hwang and Katayama used a genetic algorithm called the priority-based chromosome method for mixed-model line balancing, performing an amelioration procedure with the genetic algorithm to develop the workload variety on the assembly line (13). Kurşun and Kalaoğlu performed an assembly line balancing study for clothing companies with a simulation method in 2010 in which values like the average number of tasks, cycle duration, work bench use capacity, waiting times for work and average system output in the system for the production of trousers were compared to the actual system. The enterprise dynamics simulation program was used for the model (12). Unlike the previous study by Eryürük et al., in the 2011 study by Başkak, Kalaoğlu and Eryürük the assembly line balancing problem was studied in more detail and analyzed based on five different models (4). In 2011, Bahadır performed a simulation line balancing study for the ready-made clothing sector, balancing an assembly line for the production of trousers. Values like the average number of tasks, cycle duration, daily output number, work bench use capacity, waiting times for work etc. were compared to the actual system. The enterprise dynamics simulation program was used for the model (2). Güzel performed a value stream mapping, line design and balancing study in 2011, demonstrating the sources of wastage and an amelioration procedure to prevent this wastage. For the model to balance the line, a traditional line balancing was performed. Different line balancing problems were solved for various production volumes (9). In 2011, Rabbani, Moghaddam and Manavizadeh recommended a new multiple U-type assembly line placement for mixed-model two-sided line balancing. A new integer programming model was developed (16). Cakir, Altiparmak and Dengiz performed a single-model stochastic line balancing in 2011, creating a parallel station with a hybrid annealing algorithm (3).

Unlike previous research, this study has taken recourse constraints in mixed-model line balancing into consideration, and the constraint that work to be done on the same machine be assigned to the same work station has been added to the algorithm. This is because due to the shortness of task durations and the high number of tasks in ready-made clothing companies, a machine can only be manned by one worker at a time, and it is usually not possible for a worker to use more than one machine in quick succession.

2. MATERIAL AND METHOD

In this research, the COMSOAL method was used with the development of an algorithm for resource-constrained mixed-model assembly line balancing.

The flowchart for the resource-constrained mixed-model COMSOAL algorithm that has been developed is shown in Figure 1.

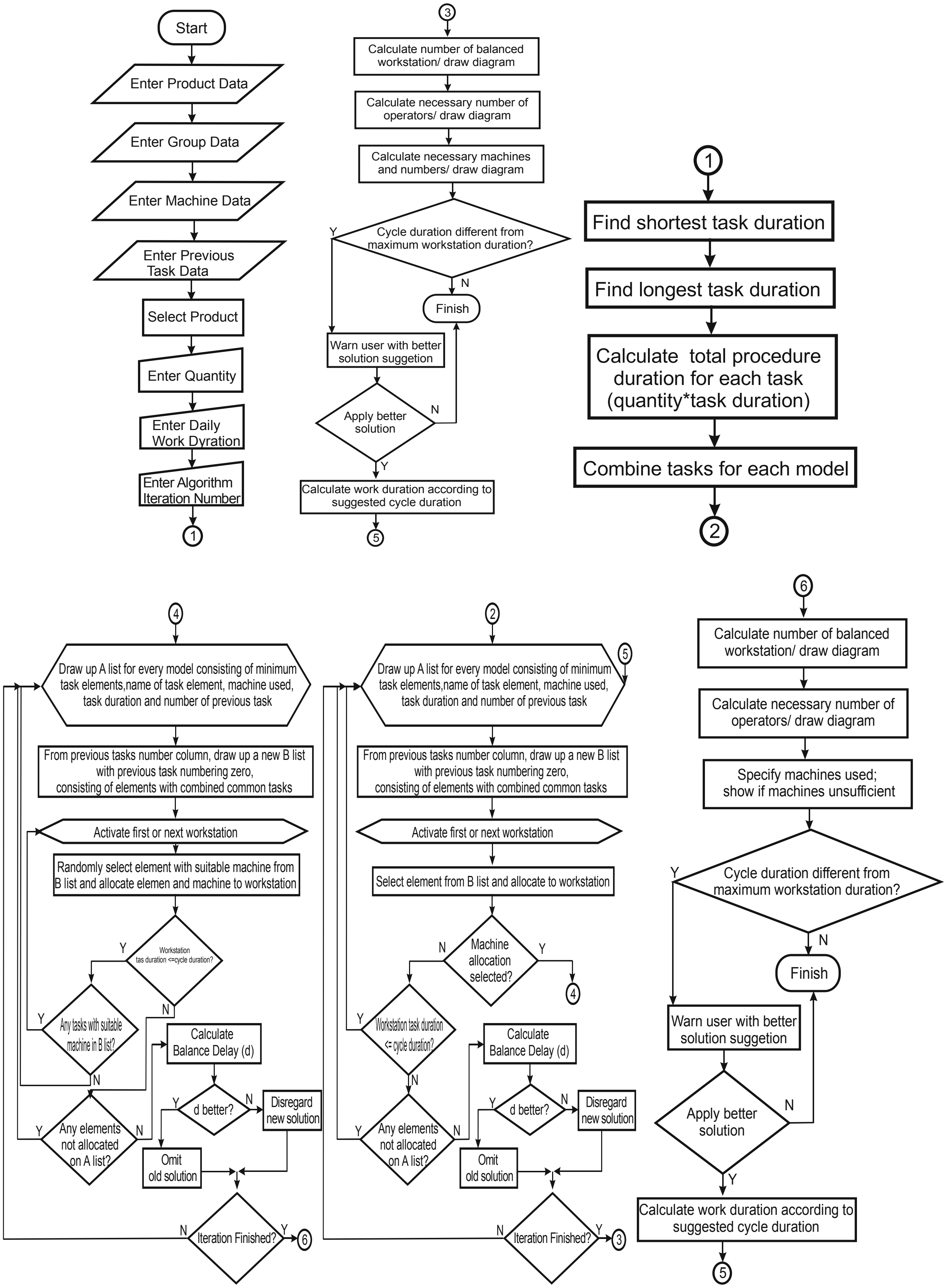

Figure 1. Flowchart for the resource-constrained mixed-model COMSOAL algorithm that has been developed.

2.1. Design And Model Of Research

Methods developed for solving assembly line balancing problems are generally divided in two: mathematical programming methods to find the best solution, and heuristic methods (6). As the line balancing problem gets bigger, mathematical methods tend to be replaced by heuristic models (7). In this study, COMSOAL (Computer Method for Sequencing Operations for Assembly Lines), an heuristic and meta- heuristic algorithm, was used for data analysis and assembly line procedure tabulation.

Microsoft Access in the Delphi programming language was used, since data are archived, organized, and edited on a database, and the program can easily be downloaded onto a computer in a ready-made clothing company and run without the need for setup. In the research, procure durations were dealt with deterministically, assuming that production in all units runs under the same circumstances. Since the production of more than one model a day was required and since there are more than 50 tasks necessary for the production of a shirt, a new heuristic algorithm for resource-constraint mixed-model line balancing was developed for the research, a variation on the heuristic COMSOAL algorithm. The constraint that a machine can be manned by only one worker, as well as the constraint that work to be done on the same machine can be assigned to the same machine as long as priorities are taken into account, were added to the algorithm. Also added was an option to warn the user about better options for solution, after the solution with the best balancing option in the solution universe was obtained, in case the longest station durations were shorter than cycle durations due to the ability to form parallel work stations, and the look for better solutions.

The resource constraint, not normally part of the COMSOAL algorithm, was also added to the algorithm, as was a module where as a conclusion to the assembly line balancing, the balancing results are compared to the number of machines owned by the company and a warning is issued if the number of available machines is inadequate. Another addition is the option to balance and choose daily output volume according to the number of machines owned by the company.

In the algorithm that was developed, assumptions are shortly as follows: tasks that must be performed on the same machine due to apparel production conditions must be allocated to the same workstation. A machine can be manned by one worker at a time. Deadlines are assumed to be met. Daily order volumes for each model have been determined. Task durations are deterministic (can be determined). If the task duration is longer than the cycle duration, a parallel workstation can be set up.

2.2. Data Collection

Data were collected by the researcher in the company offices of the company producing men's shirts. To analyze the men's shirts assembly line, a time study was first performed along the line. Only data pertaining to assembly were collected. Cutting and material preparation were disregarded in the line balancing. For the analysis of the assembly line, work flowcharts were designed for seven different shirt models in production. Through the analysis of observations, work study and company records, information on the following were obtained: model name (i.e. Classic Model Men's Shirt), model characteristics (i.e. Long-Sleeved or With Slit), machine code (m01, m02, m03…), sub-assembly tasks (Groups; Cuff, Collar, Front, Back, Sleeve, Tie), main assembly tasks (Assembly of Groups), machine used ((i.e. Straight Stitch M., Ironing, Buttonhole Stitching, Button M.), duration of task (in seconds), priority of tasks (i.e. cuffs are rolled back after matching, which means that rolling cannot take place before matching).

The daily shirt output of the company is shown in Table 1.

The company owns a total of 68 machines.

On some days, the same shirt model is produced all day, while on other days two or three different models are produced on the same day. The company's total daily work duration is assumed as 9.5 hours. The example model description form is given in Figure 2; the example business flowchart is given in Figure 3.

Table 1. Daily Output

Date	Model Name	Output (pcs)	Beginning and End Times	Total Daily Output
2.4.2012	Classic Model Short-Sleeved Shirt (p2)	620 pcs.	$8.^{00}$-$18.^{45}$	620 Pcs.
3.4.2012	Classic Model Long-Sleeved Shirt (p1) Long-Sleeved Slim Model Shirt (p7) Classic Model Short-Sleeved Shirt (p2)	200 pcs. 310 pcs. 90 pcs.	$8.^{00}$-$11.^{40}$ $11.^{40}$-$17.^{00}$ $17.^{00}$-$18.^{45}$	600 Pcs.
4.4.2012	Short-Sleeved Slim Model Shirt with Sleeve and Shoulder Epaulets (p3)	540 pcs.	$8.^{00}$-$18.^{45}$	540 Pcs.
5.4.2012	Short-Sleeved Slim Model Shirt with Sleeve and Shoulder Epaulets (p3) Classic Model Long-Sleeved Shirt (p1)	200 pcs. 400 pcs.	$8.^{00}$-$12.^{00}$ $12.^{00}$-$18.^{45}$	600 Pcs.
09.4.2012	Short-Sleeved Slim Model Shirt (p6)	625 pcs.	$8.^{00}$-$18.^{45}$	625 Pcs.
10.4.2012	Long-Sleeved Slim Model Shirt (p7) Classic Model Long-Sleeved Shirt (p1)	380 pcs. 230 pcs.	$8.^{00}$-$14.^{15}$ $14.^{15}$-$18.^{45}$	610 Pcs.
11.4.2012	Classic Model Long-Sleeved Shirt (p1) Classic Model Short-Sleeved Shirt (p2) Long-Sleeved Slim Model Shirt (p7)	190 pcs. 220 pcs. 200 pcs.	$8.^{00}$-$11.^{00}$ $11.^{00}$-$15.^{00}$ $15.^{00}$-$18.^{45}$	610 Pcs.
12.4.2012	Classic Model Short-Sleeved Shirt (p2)	620 pcs.	$8.^{00}$-$18.^{45}$	620 Pcs.
13.4.2012	Classic Model Long-Sleeved Shirt (p1) Short-Sleeved Slim Model Shirt (p6)	265 pcs. 350 pcs.	$8.^{00}$-$12.^{00}$ $12.^{00}$-$18.^{45}$	615 Pcs.
			Average Daily Output:	**604 Pcs.**

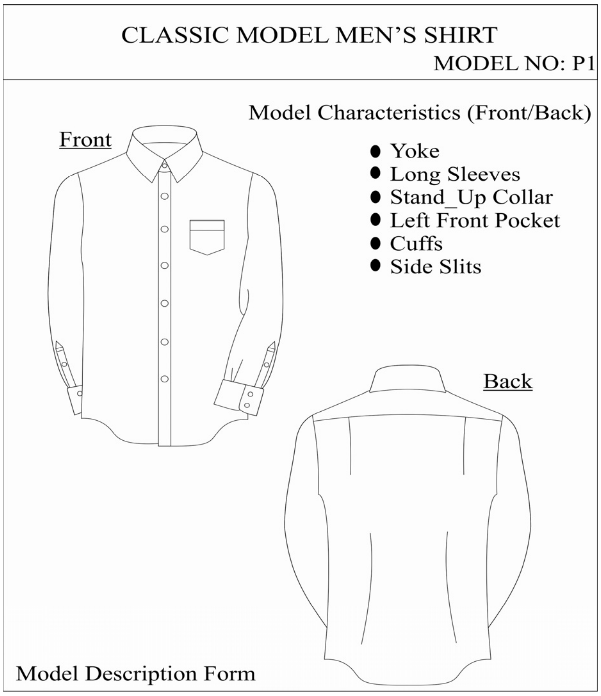

Figure 2. Example Model Description Form

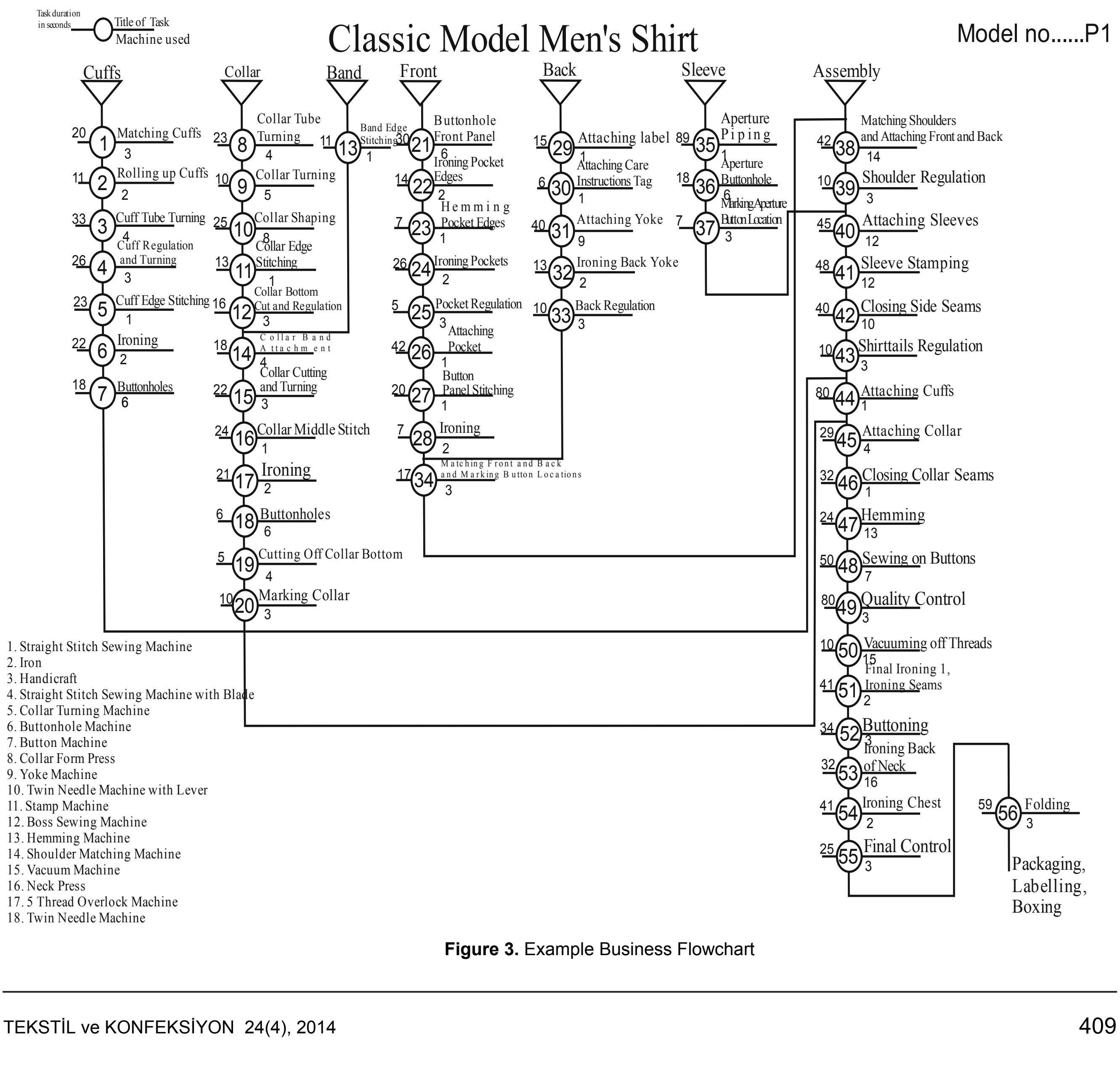

Figure 3. Example Business Flowchart

The company producing men's shirts studied in this research has a production system in which a single model is daily produced on some days, and three or four different models are produced daily on other days.

2.3. Analysis of Data

For every model, task data from the flowchart was entered into the resource-constrained mixed-model COMSOAL program. The existing machines belonging to the company that is the subject of the research was also entered into the program. A machine number constraint was added to the line balancing study in order to compare the existing machines with the line balanced as a result of the developed program and to design the infrastructure necessary for resource planning. Due to the intuitive algorithm, the user is offered better recommendations, if available, as a result of balancing.

3. RESULTS AND DISCUSSION

Table 2 shows daily output of this company as well as balancing delays, station numbers and operator numbers after the balancing. According to this table the production of a single product model within a day necessitates fewer employees and fewer stations than the production of several different models in the same day, and also leads to less balancing delay at workstations.

For the mixed production on April 3rd, 2012, the balancing results after 1000 iterations are given in Table 3. The company's total daily work duration is assumed as 9.5 hours.

Table 2. Daily output, balancing losses, and station numbers and operator numbers after the balancing. The company's total daily work duration is assumed as 9.5 hours.

Date	Model Name	Output (pcs.)	Total Daily Output	Balancing Delay	Number of Stations	Number of Employees
2.4.2012	Classic Model Short-Sleeved Shirt (p2)	620 pcs.	620 Pcs.	0,52	44	46
3.4.2012	* Classic Model Long-Sleeved Shirt (p1) * Long-Sleeved Slim Model Shirt (p7) * Classic Model Short-Sleeved Shirt (p2)	200 pcs. 310 pcs. 90 pcs.	600 Pcs.	0,54	51	55
4.4.2012	* Short-Sleeved Slim Model Shirt with Sleeve and Shoulder Epaulets (p3)	540 pcs.	540 Pcs.	0,53	40	41
5.4.2012	* Short-Sleeved Slim Model Shirt with Sleeve and Shoulder Epaulets (p3) * Classic Model Long-Sleeved Shirt (p1)	200 pcs. 400 pcs.	600 Pcs.	0,56	54	57
9.4.2012	* Short-Sleeved Slim Model Shirt (p6)	625 pcs.	625 Pcs.	0,48	37	39
10.4.2012	* Long-Sleeved Slim Model Shirt (p7) * Classic Model Long-Sleeved Shirt (p1)	380 pcs. 230 pcs.	610 Pcs.	0,52	51	55
11.4.2012	* Classic Model Long-Sleeved Shirt (p1) * Classic Model Short-Sleeved Shirt (p2) * Long-Sleeved Slim Model Shirt (p7)	190 pcs. 220 pcs. 200 pcs.	610 Pcs.	0,55	52	55
12.4.2012	* Classic Model Short-Sleeved Shirt (p2)	620 pcs.	620 Pcs.	0,52	44	46
13.4.2012	* Classic Model Long-Sleeved Shirt (p1) * Short-Sleeved Slim Model Shirt (p6)	265 pcs. 350 pcs.	615 Pcs.	0,57	52	54

Table 3. Mixed-model balancing results, 1000 iterations (repetitions) for Classic Model Long-Sleeved Shirt (p1) 200 pcs, Long-Sleeved Slim Model Shirt (p7) 310 pcs, Classic Model Short-Sleeved Shirt (p2) 90 pcs.

sn	Station	Operator	Codes of Tasks assigned to Station	Name of Task	Name of Machine	Duration (seconds)	Lost time (seconds)	Delay (%)
1	1	2	p1g6_035, p7g6_030	Aperture Piping	Lock Stitcher	45390	23010	33.64
2	2	1	p2g6_028	Cuff Edge Stitching	Lock Stitcher	4320	29880	87.36
3	3	1	p1g6_036, p7g6_031	Aperture Buttonhole	Buttonhole Machine	9180	25020	73.15
4	4	1	p1g5_029, p7g5_024, p2g5_022	Attaching label	Lock Stitcher	9000	25200	54.38
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51	47	1	p1g7_052, p7g7_047, p2g7_042	Buttoning	Handicraft	20400	13800	40.35
52	48	1	p1g7_053, p7g7_048, p2g7_043	Ironing Back of Neck	Neck Press	19200	15000	43.85
53	49	1	p1g7_054, p7g7_049, p2g7_044	Ironing Chest	Iron	24600	9600	28.07
54	50	1	p1g7_055, p7g7_050, p2g7_045	Final Control	Handicraft	15000	19200	56.14
55	51	2	p1g7_056, p7g7_051, p2g7_046	Folding	Handicraft	35400	33000	48.24
	51	**55**				**Balancing Loss: 0,54**		

Table 3 shows the results of the production of three different models on the same line within the same day. This requires 51 machines manned by 55 operators. Column 4 of this table shows what tasks are performed at specific workstations. For example, on workstation 3 two different tasks are performed on the same day. The delay column shows the average delay percentages for each workstation. The average delays constitute the balancing loss of the line (here the balancing loss is 0.54). By increasing the number of iterations, the setup of a line with less balancing loss is attempted.

Figure 4 shows the results of the production of three different models on the same line within the same day. The distance of each workstation to the red line shows the periods of time they spend without any production. The production of three different models on the same line within the same day leads to longer periods without any production.

With the program that has been developed, the line can be adjusted by any employee instead of being manually balanced every day by a specialized production planner. Waiting times and unproductive workstations on the factory floor can also be determined quickly. By increasing the number of iterations in the algorithm, different alternatives for production can be obtained. This way, the business can conclude whether orders can be met within a working day with available machines and operators without overtime, and the obligatory overtime troubling the ready-made clothing sector can be avoided.

4. CONCLUSIONS

The production structure of apparel production is labor-intense and complex. Because of this, it is hard to adapt to automated systems. It is not financially or logistically feasible to assign distinct lines and workers for the production of models with low production numbers and high variety. Thus, assembly lines where several different models are produced simultaneously are preferred. In addition, the main drawbacks of the apparel industry are low efficiency and line balancing and planning difficulties stemming from low order numbers.

With the newly developed resource-constrained mixed-model COMSOAL algorithm, mixed-model assembly line balancing problems in the production of men’s shirts were analyzed and some recommendations were offered. The algorithm was designed taking into account the necessity to produce different batch volumes and different models of men’s shirts on the same day and the same line. New shirt models, possible new durations on shirt models and changes concerning employees can also be entered into the program.

An analysis of daily production output and models produced (Table 2) shows that balancing losses and the numbers of both stations and employees of a balancing line where only one shirt model is produced in a given day are lower than in an assembly line where several different shirt models are produced in one day. This means that if the production of different shirt models on the same assembly line in the same day is required, an increase in balancing losses, stations and employees must be tolerated.

Unlike the traditional COMSOAL algorithm, the constraint that a machine can be manned by only one worker, as well as the constraints of forming parallel stations and of different tasks requiring different machines were added to the resource-constrained mixed-model COMSOAL algorithm. New academic studies may be performed by adding options to the algorithm like rotating different tasks, machines that can be combined, and employee constraints.

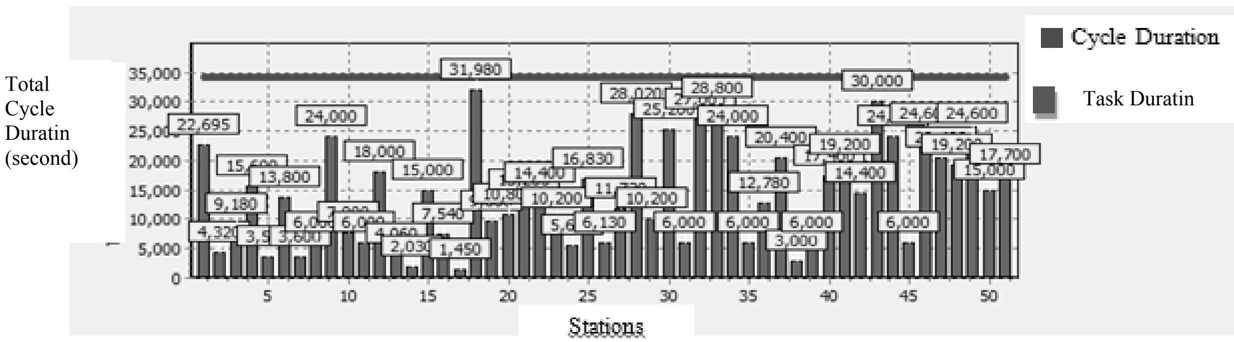

Figure 4. Graph for balancing loss after mixed-model balancing for Classic Model Long-Sleeved Shirt (p1) 200 pcs, Long-Sleeved Slim Model Shirt (p7) 310 pcs, Classic Model Short-Sleeved Shirt (p2) 90 pcs, 1000 iterations (repetitions), The company’s total daily work duration is assumed as 9.5 hours.

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