



A NEW MODEL PROPOSAL FOR ERGONOMIC ASSEMBLY LINE BALANCING

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Keywords

*Assembly Line Balancing,
Ergonomic Risk Evaluation,
REBA.*

Abstract

Assembly line balancing is a problem where tasks assign to stations in compliance with precedence constraints and as far as possible to balance delays. Assembly lines which is not designed properly in an ergonomic way cause not only productivity loss but also work-related musculoskeletal disorders on workers. To prevent such problems, it should be aimed to catch acceptable level for each workstation's risk score and assign ergonomic risks equivalently among workers. In this study, for assembly line balancing problem, a new model approach is tackled, which constitute stations by consider ergonomic risk scores in addition to cycle time and precedence constraints. In order to compare proposed model with a classical assembly line balancing technique, a performance criterion which is combination of cycle time and ergonomic risk score were defined. The developed model was applied in a factory's oven assembly line. In the assembly line, task times were measured, precedence diagram was constructed and ergonomic risk levels were evaluated by using REBA method. When balancing lines with using Longest Operation Times technique, performance score was %25.61 but when it comes to balance with developed model performance score was obtained %18.25. It has been detected that developed model provides 7.41% improvement in line's total performance.

ERGONOMİK MONTAJ HATTI DENGELEME İÇİN YENİ BİR MODEL ÖNERİSİ

Anahtar Kelimeler

*Montaj Hattı Dengeleme,
Ergonomik Risk
Değerlendirme,
REBA.*

Öz

Montaj hattı dengeleme probleminde yapılacak işlemler, hattın belirlenen hızda devam etmesi amacıyla ve öncelik ilişkilerini dikkate alarak dengeli bir şekilde istasyonlara atanır. Montaj hattı ve istasyonların tasarımında ergonomik düzenlemeler göz ardı edildiğinde, çalışanlarda kas iskelet sistemi hastalıklarına ve devamında verimlilik kayıplarına da yol açabilir. Çalışan sağlığını ve üretimin verimliliğini korumak için montaj hattı dengelemede her bir istasyonun ergonomik risk düzeyinin kabul edilebilir seviyeye çekilmesi ve zorlanma düzeyinin işçiler arasında dengeli dağıtılması da amaçlanmalıdır. Bu çalışmada, montaj hattı dengelemede, öncelik ilişkileri ile çevrim süresi kısıtına ilaveten, ergonomik risk düzeyini de dikkate alan yeni bir model geliştirilmesi amaçlanmıştır. Ayrıca, önerilen modelin klasik montaj hattı dengeleme modeli ile karşılaştırılması amacıyla, süre ve ergonomik risk düzeyinin bileşkesinden oluşan performans ölçütü tanımlanmıştır. Geliştirilen model, bir işletmenin fırın montaj hattı için uygulanmıştır. Her iki montaj hattında işlem süreleri ölçülmüş, öncelik ilişkileri çıkarılmış ve REBA yöntemi ile ergonomik risk düzeyleri hesaplanmıştır. En Büyük Aday yöntemi kullanılarak yapılan klasik montaj dengelemede, performans skoru %25.61 olurken, geliştirilen model için %18.25 elde edilmiştir. Geliştirilen modelin, toplam performansda %7.41 iyileştirme sağladığı tespit edilmiştir.

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1. Introduction

Musculoskeletal disorders caused by working conditions are an increasing health problems and a leading maker of disabilities. A number of physical, individual, and psychosocial risk factors are correlated with the reinforcing of Work Related Musculoskeletal Disorders (WMSDs). During performing a task, exposure to physically demanding times such as repetition of a movement, vibration, forcible exertion and unsuitable postures generate physical risk factors (Bernard, 1997).

Inadvisable working conditions and poor workplace design in terms of ergonomic aspects, are an important topic today. Because of ergonomic risks in the working place, workers health and life quality are damaged seriously and employers economic output and economy decline on the whole (Otto and Scholl, 2011). Impact of WMSDs in production efficiency through sickness, disability and absence have revealed with latest studies. Musculoskeletal Disorders (MSD) were ranked as the second most pricey health situation responsible for cardiovascular disease by a Health Canada (2002) research while cancer ranking third (Chiasson et al., 2012). As reported by World Health Organization /WHO), in developed countries MSDs have highest responsibility of workplace injury (WHO, 2003). In 2008, as reported in the US, at 315,000 events of workplace MSDs which caused by lack of ergonomic requirements, have need a break from work average of 10 days (Bureau of Labor Statistics, 2009) (Otto and Scholl, 2011).

MSDs also responsible for the highest morbidity prices of all diseases combined. Employers in the US pay 15 to 20 million US dollars for MSDs compensation cost annually. Conforming to some predictions, in Europe nearly 44 million workers are abused from occupational musculoskeletal disorders (Nunes, 2009).

Workplace ergonomics is gaining importance especially in assembly lines since assembly workers are subject to a lot of repetitive, short cycle tasks with a monotonous body posture and heavy work load. Thus the daily operations of the assembly line workers is affiliated with higher ergonomic risks and some occupational diseases, such as carpal tunnel, muscular pains in the various body regions like the back, shoulder, neck, arms and wrists. 35% of plant and machine operators and assemblers report having regular backaches and muscular pains. As reported by the Fourth European Survey on Working Conditions,

muscular pains and constant backaches occur to 35% of assemblers, machine and plant operators. (Schneider and Irastorza, 2010)

Different researches about operator working on assembly line in various countries approve high pervasiveness rates of musculoskeletal disorders indeed (e.g. Bao et al., 2000; Pullopdisakul et al., 2013). Such occupational diseases take a long time to cure so high medical expenditures for the company and also decrease the life quality of the worker. For this reason, increasing attention is being paid to assembly line production and widely studied. Among ergonomics and productivity a connection in assembly systems has displayed by a study of the authors (Battini et al., 2014). Thus the ergonomic risks must be assessed in assembly lines and incorporated into techniques of assembly line balancing and line design, so strains of worker's and work conditions can be improved.

During the last decade, a high number of studies agree to the requirement of integrate ergonomic risk factors into assembly line balancing for both the mathematical models and heuristic methods. The studies have focused on ergonomic risk assessment approaches into different aspects such as work related injuries (Baykasoglu and Akyol, 2014), physical workload (Mutlu and Özgörmüş, 2012), energy expenditure (Battini et al., 2016a) using Occupational Repetitive Actions (OCRA), Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA) methods for assembly line balancing problem Type 1 and Type 2. In this study, a new heuristic approach considering REBA as ergonomic risk score in addition to cycle time and precedence constraints was proposed to balance an assembly line. A performance approach was suggested to compare both the classical assembly line balancing model and proposed models. This method is the first attempt to solve an ergonomic assembly line balancing problem by using Longest Operation Times technique. The model was applied in an oven assembly line. By means of this model, we can accomplish a serious decline in ergonomic risk score without increasing at the number of workstations in the line is achieved.

The rest of paper is organized as follows: in Section 2, the literature review on the ergonomic assembly line balancing is presented. In Section 3, an overview of assembly lines and ergonomic risk assessment methods are introduced. In Section 4, model development and performance criteria definitions are given. In Section 5, the developed model is applied in

a real problem. Finally, results and recommendations are presented in the last section.

2. Literature Review

Assembly line balancing problems considering ergonomical issues have newly appealed to many researchers due to they are gaining more and more importance in practice. Ergonomical factors has great influence in the quality of the product and the motivation of workers. Yeow and Nath Sen (2006) have improved the ergonomical conditions of assembly lines and observed that the production cost has decreased, the efficiency and the level of quality has increased.

It is shown by various research in ergonomics and occupational health that overwhelming workload is one of the dominant reasons for work-related afflictions. Carnahan et al. (2001) examined three line balancing heuristics, namely, a ranking heuristics, a combinatorial genetic algorithm and a problem space genetic algorithm, which embody physical demand criteria so as to resolve the problem. The target was to diminish the cycle time and the maximum manual grasp requests of the workers. Battini et al. (2001) investigated the close relationship between ergonomics and design methods of assembly system. From this investigation, he came up with a new theoretical architecture that considers technological variables (affiliated with work times and techniques), environmental variables (i.e absenteeism, employee turnover, work force spirit boost) and lastly, ergonomics assessment (i.e. human diverseness). By studying the accumulative effects of repetitious assignments, Baykasoglu and Akyol (2014) made an evaluation about ergonomic risks on assembly lines. The outcome of weak-designed (from a point of view of ergonomics) assembly lines, is responsible for lack of productivity and even, work-related injuries. For the sake of averting these problems, an analysis for each station should be conducted and ergonomic risks must stay below the maximum acceptance level.

Because a few factors about the measurement job are present, like (1) demands of job activities (2) the state of the workplace, and (3) environmental conditions (4) factors of human psychology such as stress, the physical work load concept has various aspects. (Fallentin et al., 2001; Mutlu and Özgörmüş, 2012; Polat et al, 2018). The physical workload is considered by certain studies as an additional restraint for the pursuit of assembly lines that are well-designed. Choi (2009) presented a model of integer program that incorporates excessive work load of processing duration and physical work load including several risk factors. In order to solve it, the target programming approach and a suitable algorithm process techniques were used. Different computational tests like, model with only processing duration work load, model with only physical work load and the integrated model.

Mutlu and Özgörmüş (2012), regarding the physical work load as an fuzzy concept, came up with an fuzzy linear programming model for type 1 ALBP. The model that was proposed was put into work for an assembly line balancing issue of a textile company. Kara et al. (2014) suggested a model which is basically an economically feasible formulation for ALB under the influence of psychological constrain, physical constrain, skills of workers, hardware, postures while working and lighting level limitations. The total costs related with the operating costs of staff and the resources consumed under the influence of ergonomics and resource limitations are reduced to minimum by the model. The ergonomic constraints make sure that the overall of task harshness of each station does not go beyond the suggested limits. Furthermore, each and every limit on the sum of energy consumption should be under the limits.

Battini et al (2015) and Battini et al. (2016), presented a multi-objective model that is rooted from the energy expense. Taking into account the performance factors of the workers, the quantity of energy consumed and maladjustment of tasks, Güner and Hasgül (2012) proposed a brand new mathematical model of U-type assembly line balancing issue.

Scholl and Klein (1997,1999) came up with a two-stage method that utilizes the exact solution method SALOME to solve with the least number of stations on the first stage, than a simulated annealing method is used to improve equalization of ergonomic risks between certain number of stations that are decided on the first stage. Rajabalipour Cheshmehgaz et al. (2012) generated a model that helps to vary the operators body postures periodically. Fuzzy goal programming is employed and a suitable genetic algorithm was created to solve the model. Assembly line is balanced by not taking into account the ergonomical risks in the first stage, afterwards, in the second stage it is re-balanced on the criteria of ergonomic risk factors. It is proved that although a vast amount of ergonomic risk evaluations include nonlinear functions, it is possible to assimilate them in the assembly line balancing methods with minor extra computational costs. Computational research of theirs showed that re-balancing, often supplies a major relief of ergonomic risks. Xu et al. (2012) brought about upper levels of extremity ergonomic measures. While not worsening hugely the efficiency of the line, it is shown by the case studies presented in this paper that the new model is able to balance efficiently and keep the exposure levels in the upper levels of extremity ergonomic measures under control. Al Zuheri et al. (2013) delved into ergonomically assembly line balancing issues of the workers whose tasks include walking and increased the line efficiency. Bautista et al. (2016a) and Bautista et al. (2016b) came up with a set of line balancing models that take into account temporal and spatial features in addition to combining the ergonomic risk features. Otto and Battaia (2017)

presented a summary of the present optimization approaches for balancing assembly lines and scheduling of work rotations that take into account physical ergonomic risks. By this study, major indications to ensure beneficial ideas for practitioners and to show research directions.

More basic observation methods like REBA, OCRA as ergonomic risk factors in balance of assembly line are rarely taken into account in the literature. A software called ErgoAnalysis that is presented by Di Benedetto and Fanti (2012) which ease the control of all the production flow and creates a Risk Index for the real tasks of an assembly line. Pulkurte et al. (2014) mostly took a close look at increasing the total efficiency of multi-model assembly line by finding and removing the non value added activities. To decrease the amount of moves, REBA is employed which analyze the posture of workers. A new problem about Assembly Line Worker Assignment and Balancing (ALWABP) is proposed by Akyol and Baykasoglu (2016) by taking into account ergonomic risk factors named as ErgoALWABP. Simultaneous operator-to-station tasks and assembly line balancing including a few lexicographically aligned objective functions. Minimizing cycle time for a number of stations is the primary aim. Further aims are ergonomics oriented aims and measure ergonomic risks with OCRA and present an algorithm of multistart greedy heuristic for tackling with the formulated problem. Baykasoglu et al. (2017) took into account the ergonomic criteria on design stage of assembly line and employed OCRA technique to decide upon ergonomic risks and rule-based constructive search algorithm for resolving the issue. Lately, Tiacci and Mimmi (2018) combined the evaluation of ergonomic risks through OCRA index so as to balance mixed model stochastic assembly lines. A genetic algorithm technique which is able to incorporate the ergonomic risks assessment and balancing/sequencing is presented. Looking at the outcome of this presented approach, the expenses that are obligated by the ergonomic legislation can be minimized. Polat et al. (2018) referred to Assembly Line Balancing Problem (ALBP) Type 2. Balancing the cycle time and physical workload of the stations concurrently was the main purpose. To tackle with the problem a goal programming model was made and to clarify the methodology, a familiar small sized benchmark example is used. To decide upon the workload workload of operations REBA technique was used.

Kahya et al. (2018) presented a study balancing the cycle time and ergonomic risk of a station by using COMSOAL technique. The results showed that the developed model provides 3.34% improvement in line's performance. Şahin and Kahya (2018) solved the ergonomic assembly line balancing problem Type I with the goal programming approach. The model was developed to predict workload and the number of workstation. For each workstation, maximum REBA

score was determined as 10 and added to model as constraint. The model was solved with GAMS package program. In the result of study, more fair balanced line is obtained, in terms of working environment and risk levels.

To conclude, a number of studies acknowledge the necessity to integrate ergonomics into different planning aspects of assembly lines. There are many of mathematical models and some heuristic methods in the literature but, to the best of our knowledge, a few attempt has been made yet to incorporate ergonomic risk factors into a known heuristic assembly line balancing model, simultaneously.

3. Ergonomic Risk Assessment Methods

Frequency, intensity and duration of physical workload factors determines the degree of physical ergonomic risk. These factors constitute of repetitive movements, continuous sitting or standing, vibrations, awkward postures, lifting of heavy loads in addition environmental factors such as noise, lighting, temperature and humidity. By estimating these factors, physical health risks at workplace can be identified and evaluate.

In work related MSD, frequently used exposure computation ergonomic methods are determined in three categories:

- a) self-assessment evaluation techniques
- b) systematic observation methods using video recordings or software tools to measure ergonomics indexes
- c) direct measurement techniques

Self-reports of workers by using methods such as interviews and questionnaires can be help to detect physical and psychosocial factors in workplace by collecting data. Uncomplicated to use, costly efficient, applicability to huge range of circumstances, and able to survey with all workers provide advantage apparently (David, 2005). Some methods are Nordic Musculoskeletal Questionnaire, Dutch Musculoskeletal Discomfort Questionnaire, Cornell Musculoskeletal Discomfort Questionnaire and Swedish Occupational Fatigue Inventory.

Simpler observational techniques have been developed for systematically recording workplace exposure to be assessed by an observer and recorded on pro-forma sheets. These methods have the advantages of being inexpensive and practical for use in a wide range of workplaces where using other methods of observing workers would be difficult because of the disruption caused. Some method are given below:

- ❖ Rapid Entire Body Assessment (REBA)
- ❖ Rapid Upper Limb Assessment (RULA)
- ❖ Occupational Repetitive Actions Index (OCRA)

- ❖ Ovako Working Posture Analyzing System (OWAS)
- ❖ Quick Exposure Check (QEC)
- ❖ NIOSH Lifting Equation
- ❖ The Strain Index (SI)

Advanced observational techniques have been developed for the evaluation of postural difference for rather dynamic activities. The analysis might include the usage of biomechanical models that represent the human body as a set of articulated links in a kinetic chain and use anthropometric, postural and hand-load data to calculate intersegmental moments and forces (David, 2005). Widely used methods include ErgoMan, Sammie Cad, Safework, Creo Manikin, 3DSSPP, Jack, RAMSIS, AnyBody, OpenSIM, HumanCAD, LifeMod.

Direct methods, e.g. Lumbar Motion Monitor (LMM), elektromiyografi (EMG), have been developed that rely on sensors that are attached directly to the subject for the measurement of exposure variables at work.

In this study, REBA method was used to measure ergonomic risk of the tasks. Hignett and McAtamney (2000) proposed REBA in the UK, for a necessity observed within the scope of postural analysis too, especially with sensitivity to the varying working positions appearing in health care (e.g., animate load handling) and other service industries. REBA supports a quick and easy measurement to evaluate a variety of working postures for risk of WMSDs (Madani and Dababneh, 2016). It ensures that the postures are analyzed and scored during all body movements, thus determining the numerical value and attitudes that can create an occupational risk. When choosing jobs for REBA, it is important to consider postures that can be identified and cared for improperly, frequently repeated, time consuming, requiring high force or muscle activity, disturbing the worker.

REBA method is used to measure the workload of stations since this method enables to analyze various postures adopted by workers. It is an observational method that was developed to quantify the risk level of various body postures. In the practice of the REBA method, the stance of the trunk, neck and legs is angularly observed and scored. A score is obtained by posture scores of body, neck and legs from table A of the method during this scorer stance, the applied force or the score of the carrying load is added. Thus, a score of A is obtained. On the other hand, the posture of the upper arm, lower arm and ankles is analyzed and scored. Similar to the A score, a score is obtained with the posture points of the upper arm, lower arm and wrists from the B table, and the score related to this score is added so that the B score is calculated. The A and B scores are combined in Table C to give a total of 144 possible combinations. Depending on the case, an activity score is also added to score C in order to calculate final REBA score which is scaled between 1

and 15 (see Figure 1). Based on the calculated final score, the risk level and actions required for the improvement of working conditions on the assessed position can be classified by using Table 1.

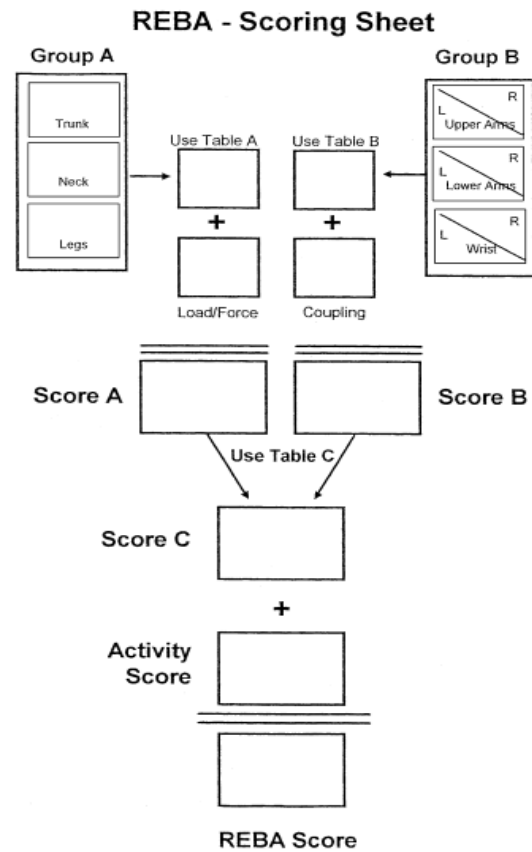


Figure 1. REBA score sheet (Madani and Dababneh, 2016)

Table 1. REBA action levels (Madani and Dababneh, 2016)

Action level	REBA score	Risk level	Action (including further assessment)
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very high	Necessary NOW

4. Assembly Line Balancing Considering Ergonomic Risks

Assignments of tasks to stations can considerably impact the amount of ergonomic risks at the workstations, even save profitability parameters same such as cycle time and station number. Beside, due to ergonomics can also reduce the injury rate (Eklund, 1995) and number of days away from work, assembly line balancing considering ergonomics could develop production's profitability (Otto and Scholl, 2011).

4.1. Assembly line balancing problem

The Assembly Line Balancing Problem (ALBP) aims assignment the elementary tasks required to assemble or disassemble a product to the workstation's set or modules that constitute the line. These workstations are generally designed in series one after another and attached by a conveyor system with constant speed which provides the movement of the working progress. Thus, each workstation has access for a constant time (cycle time) to complete the assigned tasks. Required time to perform all the tasks in a station must not exceed the cycle time.

Precedence relations emerge as a result of technological and organizational constraints. A precedence relation $(i,j) \in A$ states that task i must be processed before task j , task i is called predecessor of task j and set A is the set of precedence relations.

The Assembly Line Balancing Problem (ALBP) purposes assign task to stations considering of meeting restrictions such as cycle time, effectiveness in conjunction with precedence constraints and some time optimizes cost, capacity, and profit-oriented goals. A feasible assignment of tasks is called (line) balance. The most basic and classical version of ALBP is called Simple ALBP of type 1 (SALBP-1); it minimizes the number of stations subject to a fixed cycle time (Otto and Scholl, 2011). SALBP describes straight assembly lines, where work pieces are transferred along a set of stations. The assignment of tasks has to respect cycle time and precedence constraints.

4.2. Development of The Model

In assembly line balancing problems, tasks are assigned equivalently among workstations, to satisfy acquired production rate and precedence constraints. To assign workload equivalently among workstations, it is not only sufficient to keep close total task times, also risk levels which are exposed by workers should be assign as far as possible equivalently among workstations. Otherwise, in a result of overloaded workers, WMSD and productivity losses will be occur and will not be justice in terms of work strain among workers.

In this study, it was aimed to construct workstations which have acceptable risk levels in terms of ergonomic working environment and developed a model to provide balancing risks equivalently. For this purpose, a method was developed, which consider ergonomic risk scores with Longest Operation Times Technique (LOTT) as a line balancing technique. LOTT is the most easy technique to understand and to apply among line balancing techniques. The objective is to minimize the number of stations for a given cycle time. According this technique, if the longest task time is assigned firstly, other tasks can be assigned more

easily to remaining spaces. Average risk score is calculated with consideration of ergonomic risk scores of tasks. Acceptable maximum risk score is determined by adding a tolerance to the average. In this way, when balancing line, precedence constraints, cycle time and ergonomic risk scores of workstations are taken into account together. New algorithm steps were defined by revising the LOTT as follows.

Longest Operation Times Method's Algorithm Under Ergonomic Risk;

Step 1: Obtain the number of workstations. This can be calculated with LOTT or theoretic minimum number of stations.

Step 2: Sum all tasks' ergonomic risk scores and then compute the average. Decide the maximum ergonomic risk score in consideration with the average score.

Step 3: Sequence the tasks descending order to assign workstations.

Step 4: Assign an appropriate task to available workstation, such that :

- a) All precedence constraints are satisfied.
- b) No workstation with station time greater than the cycle time.
- c) None workstation has a risk score greater than the maximum ergonomic risk score

Step 5: Apply Step 4 to all the tasks not to assign to a station. If there is no task to assign, skip to Step 6.

Step 6: If all tasks are assigned, go to Step 7; otherwise increase station number. If required, create a new station. Go to step 4.

Step 7: The current station number specifies the (new) number of stations.

4.3. Performance Criteria

A performance assessment method including two performance criteria, as idle time and ergonomic risk, were proposed so that the developed model can be compared with the solution results produced by the LOTT. In order to collect the results of two criteria, each criterion value was turned to a percentage.

- i. The first criterion is based on the balancing delay. It was defined as a percent of the sum of the idle (deviations from the cycle) time.
- ii. The second criterion is a measure of the imbalance between the ergonomic risk levels of the post-assignment stations. It is calculated by dividing the sum of the deviations of the ergonomic risk scores from the maximum.

In terms of duration and ergonomic risk level, total performance is calculated by taking the average of two criteria. It is desirable that this value is as small as possible.

CT: Cycle time

S_i : The total time of tasks in station i

n : The number of stations

ERS_i : The total of ergonomic risk scores of tasks in station i

\overline{ERS} : Average ergonomic risk score

ERS_{max} : Acceptable maximum ergonomic risk score

TP : Time Performance

ERP : Ergonomic Risk Performance

$$\overline{ERS} = \frac{\sum_{i=1}^n ERS_i}{n} \quad (1)$$

$$TP = \frac{\sum_{i=1}^n |CT - S_i|}{n \cdot CT} \quad (2)$$

$$ERP = \frac{\sum_{i=1}^n |ERS_{max} - ERS_i|}{n \cdot ERS_{max}} \quad (3)$$

$$\text{Total Performance} = 0.50 \cdot TP + 0.50 \cdot ERP \quad (4)$$

5. Application of the Proposed Model

In order to make the developed model more understandable, it has to be tested for an sample assembly line. The model was applied to a line in an oven factory in Eskişehir city, where the final assembly of the ovens are done. In order to determine ergonomic risk levels, REBA method was chosen for posture analysis because of using various body (trunk, neck, leg etc.) postures throughout assembly process. Figure 2 shows the precedence diagram for the line. The task times and REBA scores of tasks are given in Table 2.

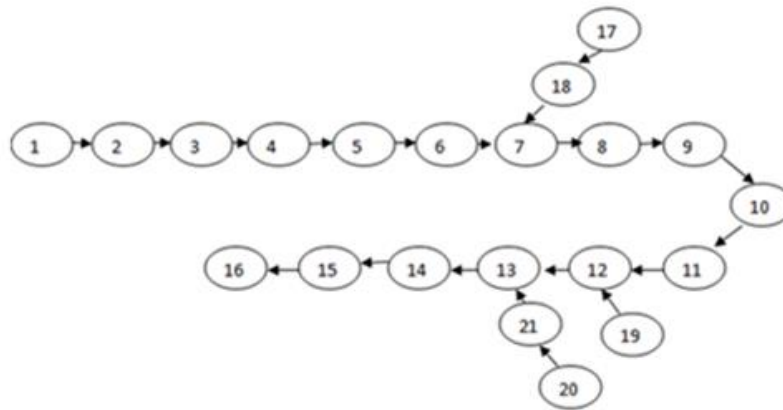


Figure 2. Precedence Diagram of Oven Assembly Line

Table 2. Data of Oven Assembly Line

No	Task	Time (seconds)	REBA Score
1	Top and bottom resistance and hinge counter	221.4	3
2	Isolating	78	10
3	Assembly of back sheet	48	6
4	U-galvanized fixing sheet	65.4	8
5	Assembly of turbo fan protection sheet	48	6
6	Fitting turbo fan	54	6
7	Pressing panel and wire grid	98.4	11
8	Putting cooler fan	42	4
9	Assembly of kable group and control	216	9
10	Grounding	54	9
11	Assembly of cable group to klemens	72.6	7
12	Pressing of cooler fan and rear protection	125.4	5
13	Assembly of oven door	90.6	6
14	Cleaning	42	7
15	Glass protection carton and stickers	30	7
16	Packing	196.2	8
17	Panel preparation	51	3
18	Kable grouping and preparation of control panel	199.8	4
19	Ftting mains cable to oven backing sheet	68.4	4
20	Oven outer glass preparation	31.8	3
21	Oven door preparation	231.6	10

The cycle time of the oven assembly line consisting of 21 tasks is 432 seconds and The REBA scores of the tasks range from 3 to 11. Assembly line balancing was carried out using the LOTT without considering the

REBA scores of the tasks, and the results are given in Table 3.

The results obtained from LOTT, the number of stations we found as 6 stations for given a cycle time, 432 seconds. Except for the last station, the idle time values of the stations vary from 13.2 to 202.2 seconds and the REBA scores range between 15 and 33. While

the worker at the fourth station is working on a low risk score, the worker at the third station is exposed to the physical strain, approximately two times. More clearly, worker at the third station is under much more risk than the worker at the fourth station.

Table 3. Solution of LOTT

Station	Task No	Task Time	REBA Score	Station		Difference	
				Time	REBA	Time	REBA
1	1	221.4	3	418.8	20	13.2	7
	2	78.0	10				
	19	68.4	4				
	17	51.0	3				
2	18	199.8	4	415.2	30	16.8	3
	3	48.0	6				
	4	65.4	8				
	5	48.0	6				
	6	54.0	6				
3	7	98.4	11	410.4	33	21.6	6
	8	42.0	4				
	9	216.0	9				
	10	54.0	9				
4	11	72.6	7	229.8	15	202.2	12
	12	125.4	5				
	20	31.8	3				
5	21	231.6	10	394.2	30	37.8	3
	13	90.6	6				
	14	42.0	7				
	15	30.0	7				
6	16	196.2	8	196.2	8	235.8	19
TOTAL				2,064.6	136	527.4	50

For this solution, risk parameters are determined as follows:

Total REBA score of tasks = 136

Average REBA score, $ERS = 136/6 = 22.67 \sim 23$

The stations will be targeted with a maximum REBA score of

$$ERS_{max} = 1.20 \overline{ERS} = \sim 27$$

The performance of the solution using the LOTT;

Time performance from Equation [2];

$$TP = \frac{|432-418.8|+|432-415.2|+|432-410.4|+|432-229.8|+|432-394.2|+|432-196.2|}{6 \cdot 432}$$

$$TP = \frac{527.4}{2592}$$

$$TP = 20.35\%$$

Ergonomic risk performance from Equation [3];

$$ERP = \frac{|27-20|+|27-30|+|27-33|+|27-15|+|27-30|+|27-8|}{6 \cdot 27} = \frac{50}{162}$$

$$ERP = 30.86\%$$

From Equation [4];

Total performance = 25.61%

The oven assembly line was solved with the developed model under the restriction of REBA (27) and the results are given in Table 4.

The results obtained from the proposed model Show that, except for the last station, the idle times of the stations are between 13.2 and 120 seconds and the REBA scores range from 20 to 27. The worker at fourth station increased to 22, and the risk score of the worker at third station decreased from 33 to 27. On the assembly line, the risk difference has dropped from 12 to 7, and the difference between the physical strains of the workers at the stations has dropped to an acceptable level.

Performance Criteria of LOTT Under Ergonomic Risk:

Time performance;

$$TP = \frac{|432-418.8|+|432-393|+|432-384|+|432-312|+|432-330.6|+|432-226.2|}{6 \cdot 432}$$

$$TP = \frac{527.4}{2592}$$

$$TP = 20.35\%$$

Ergonomic risk performance;

$$ERP = \frac{|27-20|+|27-27|+|27-27|+|27-22|+|27-25|+|27-15|}{6 \cdot 27} = \frac{26}{162}$$

$$ERP = 16.05\%$$

Total performance = 18.20%

Table 4. LOTT Under Ergonomic Risk

Station	Task No	Task Time	REBA Score	Station		Difference	
				Time	REBA	Time	REBA
1	1	221.4	3	418.8	20	13.2	7
	2	78	10				
	19	68.4	4				
	17	51	3				
2	18	199.8	4	393	27	39	0
	3	48	6				
	4	65.4	8				
	5	48	6				
	20	31.8	3				
3	21	231.6	10	384	27	48	0
	6	54	6				
	7	98.4	11				
4	8	42	4	312	22	120	5
	9	216	9				
	10	54	9				
5	11	72.6	7	330.6	25	101.4	2
	12	125.4	5				
	13	90.6	6				
	14	42	7				
6	15	30	7	226.2	15	205.8	12
	16	196.2	8				
TOTAL						527.4	26

In the LOTT solution, time performance was 20.35%, REBA performance was 30.86% and total performance was 25.61%. In the REBA restricted model, the time performance was not changed, but the REBA performance decreased by 16.05% and therefore the total performance decreased to 18.20%. Obviously, although the developed model did not change the idle time, the ergonomic risk decreased significantly and a more balanced assembly line in terms of ergonomic risk between the stations was achieved.

6. Discussion

In this study, in the assembly line balancing, in addition to priority constraints and cycle time constraints, the development of a new model that takes into account the level of ergonomic risk is considered. Furthermore, in order to compare the proposed model with the conventional assembly line balancing, a performance criterion consisting of the combination of the duration and the ergonomic risk score is defined. The developed model is applied to the oven assembly line of a company. In the assembly line, the task times were measured, priorities were constructed, and ergonomic risk levels were calculated by using the REBA method.

The developed method was applied on an assembly line and compared according to the determined performance criteria. According to this; in the assembly line, when the REBA constraints are

considered, the balancing delay (20.35%) doesn't change, however, the deviations from the determined risk (REBA) score have been greatly reduced from 30.86% to 16.05% and there is no station above the acceptable (maximum) risk score (27).

When ergonomic risk levels are considered, it is seen that the risk levels of the stations are more balanced and the risk level is not exceeded. To respond demand quickly, companies want to receive as many output as possible, and only make adjustments based on their processing time. However, this idea is a short-term idea, ergonomic risks should be given importance and considered in every problem. With the developed method, a line balancing method is applied by adding ergonomic conditions and desired results are obtained in terms of ergonomic improvement.

Each extra station come together with new and noteworthy investment in technology, equipment and increasing variable costs on behalf of a manufacturer. To handle such a process, a company must make a mindful assessment of advantages of decline in ergonomic risks that one or more extra stations can make. However, there are some essential problems in accordance with the assembly line workers who expose to above-average ergonomic risks and some occupational diseases, such as carpal tunnel, muscular pains in the various regions of the body like the back, neck, shoulder, arms and wrists.

For future research, the developed model using a classical method should be improved for better performance measures. Once the model has been applied, relatively empty stations can be filled in by applying displacement operations /between tasks. Maybe with less station number the line can be balanced also still do not exceed risk limits. In this study, REBA method was used to assess the ergonomic risk level. As a further work, we plan to apply other risk assessment methods such as OWAS, OCRA and QEC.

Conflict of Interest

No conflict of interest was declared by the authors.

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