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Ergonomic personnel-task scheduling problem: A medium voltage insurance production application

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Abstract

Companies tend to use their labor force more effectively and balanced with the effect of increasing labor costs. Companies want to use their personnel as efficiently as possible to minimize costs. Ergonomics is a crucial method proposed to increase the productivity of employees. Therefore, ergonomically regulating the working conditions of workers is more than a necessity for companies. The problem of assigning workers to the tasks is defined as ergonomic personnel scheduling problems according to the objectives such as reducing the ergonomic risk of the worker, reducing the cycle time, and considering the technological constraints of the tasks. In this study, the ergonomic personnel scheduling problem for a medium voltage fuse manufacturing company is discussed. According to the firm's data, it is aimed to balance the ergonomic risks of the workers. REBA method was used to measure the ergonomic risks of tasks, and the goal programming method was used to solve the problem. With the proposed model, in addition to more effective and efficient use of the firm's workforce, ergonomic personnel scheduling has ensured that the ergonomic risks of the tasks assigned to the workers are as equal as possible.

1. Introduction

The goal of each producer is to make a maximum profit at minimum cost. Manufacturers are trying to increase their profits by reducing both material costs and process costs in this competitive market environment (Kaçmaz et al., 2019). One of the production planning activities for this purpose is labor planning. In labor planning, parameters such as duration of work, shift times, and ergonomic elements are taken into consideration to reduce the damage and difficulty of the worker due to the work (Bedir et al., 2017).

Production planning is the organization of activities to use the resources and labor required for meeting the demands with maximum efficiency and minimum cost. Production planning includes demand forecasts, capacity planning, material, and stock management. Worker and machine capacities are an important constraint in the formation of the main production plan and schedules. Another significant limitation is ergonomics (Otto and Scholl, 2013).

Ergonomics is the process of natural and technical research and development of humans' harmony with machines and the environment by examining human physical and psychological characteristics (Polat et al., 2017). The values obtained through observations and measurements reveal the ergonomic risk factor. Tasks with a high-risk factor are organized ergonomically. The physical structures of the worker and the work must be compatible. Work rotation to improve work compliance is an organizational strategy that is increasingly used in production systems. Work rotation prevents musculoskeletal disorders, relieves stress, increases job satisfaction and morale. As a result, productivity and employee engagement increases in the production system (Otto and Scholl, 2013). At the same time, the company gains a qualified and motivated workforce. In order to prevent musculoskeletal disorders caused by fatigue accumulation, personnel should be assigned to appropriate tasks, i.e., personnel-task scheduling should be made taking into account ergonomic factors (Wongwien and Nanthavanij, 2012a).

When decision-makers want to address many decision problems, they want more than one goal to be accomplished. For the solution of such multi-objective problems, methods to solve the problem are used to optimize more than one objective (Louly, 2013). Multi-criteria decision-making methods are frequently used in solving multi-objective problems. The goal programming method is also a powerful method developed by Charnes and Cooper (1977). In goal programming, target values are determined for the aims to be achieved, and deviation variables are added to the relevant constraints. In the objective function, more than one objective is combined by optimizing these deviation variables. Which goal is more important varies according to the problems addressed. The solution method in goal programming differs according to the importance level and priority of the goals.

In this study, the ergonomic personnel-task scheduling problem is discussed. In a factory that produces medium voltage fuse, the REBA method is used to determine the ergonomic risk of tasks. A goal programming model was proposed to minimize the total ergonomic risk scores of the personnel in the problem. In the model, considering the fatigue and loss of motivation of the workers, the maximum number of tasks that can be assigned to personnel is limited. A more efficient, more ergonomic, and minimum vacancy assignment was achieved than the current assignment schedule.

This paper is organized as follows. After the introduction, the literature reviews about the problem and solution method are given. In Section 3, the personnel-task scheduling problem is described, and the proposed goal programming model is given. The REBA method is presented in Section 4. A case study relating medium voltage fuse production and the suggested model results for the case study are given in Section 5. Finally, conclusion and future researches are carried in the last section.

2. Literature Review

The Personnel-task scheduling problem has been addressed with different names in the literature. These problems can be listed as follows: employee scheduling (Ağralı et al., 2017; Al-Yakoob and Sherali, 2007; Brezulianu et al., 2009; Drezet and Billaut, 2008; Parisio and Jones, 2015), shift scheduling (Al-Yakoob and Sherali, 2007), (Bhulai et al., 2008; Boyer et al., 2014; Brunner et al., 2007; Omar et al., 2015; Salvagnin and Walsh, 2012; Solos et al., 2016; Topaloğlu, 2009), personnel-task scheduling (Hojati, 2018; Krishnamoorthy et al., 2012; Lapègue et al., 2013; Omar et al., 2015; Prot et al., 2015; Smet et al., 2014) workforce scheduling (Cuevas et al., 2016; Fırat and Hurkens, 2012; Günther and Nissen, 2010; Laesanklang et al., 2015; Liao et al., 2013; Valls et al., 2009), staff scheduling (Cuevas et al., 2016; Günther and Nissen, 2010; Laesanklang et al., 2015; Rocha et al., 2014; Soukour et al., 2012). Table 1 summarizes the literature studies for the personnel-task scheduling problem. In addition to the use of exact methods such as mathematical programming and branch and bound algorithm, many heuristic methods (genetic algorithm, tabu search, particle swarm, etc.) are used to solve the personnel-task scheduling problem. According to the task area of the personnel in the problem, the personnel-task scheduling problem has found various application areas. These can be listed as many service systems such as health systems, shopping centers, call centers, and many production systems such as vehicle production, glass production, and telecommunication sector. In this study, a company operated in the electric and electronic industry is considered as a case study to demonstrate the proposed model.

In the literature, they considered the ergonomic constraints, Wongwien and Nanthavanij (2012a) study aimed at not exceeding the allowed ergonomic risk limit by assigning heterogeneous workers to the jobs according to the personnel requirements of the tasks to be performed. In their study, Wongwien and Nanthavanij (2012b) assigned workstations to keep workers' daily noise risk within a permitted limit. Otto and Scholl (2013) established effective work rotation programs that offset ergonomic risks for workers in the automobile industry. In their study, Bektur and Hasgül (2013) formed a restaurant chart by taking into consideration seniority levels, skills, personal preferences, and business demands of the employees. Dewi and Septiana (2015) discussed the problem of assigning workers to a logistics company. They measured their physical and mental workloads. Polat et al. (2018) established a balancing model for ergonomic constraints for Type 2 simple assembly lines. They used the REBA method to calculate the physical workload at the stations. Mengoni et al. (2017) presented a methodology that evaluates ergonomic factors and safety factors. They also considered efficiency. They used the simulation method. Polat et al. (2017) discussed workers in a furniture factory in Denizli. They examined the image records of thirty-two workers and made measurements. They used the REBA method. As a result, it was determined that approximately 60% of workers were working at risk for the musculoskeletal system. In this study, the REBA method is used to take into account the ergonomic risks in the personnel task scheduling problem.

Table 1. Literature review studies for personnel-task scheduling

Problem	Literature	Solution Method	Application Area
Employee scheduling	Al-Yakoob and Sherali (2007)	KT	Gas Station
	Parisio and Jones (2015)	SP	Retail Outlet
	Brezulianu et.al (2009)	GA	Shopping Center
	Ağralı et.el. (2017)	MIP	Service Industries
	Drezet and Billaut (2008)	TS	Intelligence Technology
Shift Scheduling	Al-Yakoob and Sherali(2007)	MIP	Work Center
	Bhulaiet.al. (2008)	İM	Call Center
	Brunner et.al. (2009)	IP	Healthcare System
	Topaloglu (2009)	MOP	Healthcare System
	Salvagnin and Walsh (2012)	MP/CP	-
	Solos et.al. (2016)	HS	Truck Production
	Boyer et.al. (2014)	BPA	-
	Omar et.al. (2015)	SP	Emergency Departments
Personnel-task Scheduling	Smet et.al. (2014)	HS	-
	Krishnamoorthy et.al. (2012)	LR	-
	Lapègue et.al. (2013)	CP	-
	Protet.al. (2015)	TPM	-
	Hojati (2018)	GH	-
Workforce Scheduling	Valls et.al. (2009)	GA	Service Center
	Fırat and Hurkens (2012)	MIP	-
	Liao et.al. (2013)	SP	Call Center
	Laesanklang et.al. (2015)	DC	-
	Cuevas et.al. (2016)	MIP	-
Staff Scheduling	Zolfaghariet.al. (2009)	GA	Retail Sector
	Louly (2013)	GP	Call Centers
	Günther and Nissen (2010)	PS	-
	Rocha (2014)	CH	Glass Industry
	Soukour et.al. (2012)	HS	Security Service

MIP: Mixed Integer Programming, SP: Stochastic Programming, GA: Genetic Algorithm, TS: Tabu Search, IM: Iterative Method, IP: Integer Programming, MOP: Multi-Objective Programming, MP: Mathematical Programming, CP: Constraint Programming, HS: Heuristic Search, BPA:

Branch and Price Algorithm, LR: Lagrangian Relaxation, TPM: Two-phase Method, GH: Greedy Heuristic, DC: Decomposition, GP: Goal Programming, PS: Particle Swarm, CH: Constructive Heuristic

In the literature, the following studies that use goal programming in solving the personnel task scheduling problem can be given as an example. Eren and Varlı (2017) propose a model with goal programming to meet the number of employees needed for each shift and to make a distribution in a balanced and fair manner. In their model, five different goal constraints are considered. A goal programming model is developed by Ozcan et al. (2017) to increase the performance of employees and the worker requirements. A case study about a large-scale hydroelectric power plant is carried out by using real data. Azaiez and Sharif (2017) consider the solving of nurse scheduling problem by using goal programming. Their model objectives are related to unnecessary overtime costs while considering hospital specific goals and nurse preferences. A multi-objective goal programming model that optimizes seniority levels of staff in a restaurant is proposed by Bektur and Hasgul (2013). Ozder et al. (2017) develop a goal programming model to provide the best possible cleaning service for a university hospital. In order to assign the invigilator to the exams in the Faculty of Engineering of Kirikkale University, Varlı et al. (2017) use to goal programming, and 74 research assistants are assigned to 741 exams by considering the requirements of all departments. However, a goal programming model is proposed to optimize the REBA scores and to obtain the optimal personnel-task assignments in this study.

Based on the literature studies mentioned above, the contributions of this study to the literature can be given as follows: Although the personnel task scheduling problem is handled extensively in the literature, considering ergonomic risks was also considered for the first time in this study. Ergonomic risks are obtained by using the REBA method. A goal programming model is proposed to find the optimum personnel-task assignment, in which the obtained REBA scores are considered as goals. Also, the model is tested with real data collected from a company that produces a medium voltage fuse.

3. Personnel Task Scheduling Problem and Goal Programming Model

The personnel task scheduling problem determines which personnel will perform which task according to a particular purpose (Kaçmaz et al., 2019). Ergonomic personnel scheduling also takes into account the ergonomic risk conditions of the tasks and aims to minimize the risk level (Bedir et al., 2017).

In the proposed goal programming model, the aim is to minimize the deviations from the determined ergonomic risk level. The ergonomic risk levels of the tasks were also determined by the REBA method. Assumptions of the model are defined as the daily working time of the company is 510 minutes, the maximum number of tasks to be assigned is 6 to prevent the performance of the workers, each personnel qualified and can perform each job, task times are deterministic, tasks cannot be divided, technological constraints are taken into account, the number of staff required to perform a task is known, REBA scores are calculated for each task and REBA scores are known. The proposed goal programming model for the personnel scheduling problem is as follows.

Indices

i: Personnel

j: Task

Parameters

P: Total number of personnel

T: Total number of tasks

R_J: REBA score of the task j

A_J: REBA A score of the task j

B_J: REBA B score of the task j

W: Daily working hours

$\overline{T}$: The maximum number of tasks that can be assigned to each personnel

P_J: Number of personnel required for the task j

t_J= Duration of task j.

Decision variables

$$x_{iJ}: \begin{cases} 1, & staff\ i\ assign\ to\ task\ j \\ 0, & \text{otherwise} \end{cases}$$

d_{i1}^{-}: Negative deviation from the targeted REBA score

d_{i1}^{+}: Positive deviation from the targeted REBA score

d_{i2}^{-}: Negative deviation from the targeted REBA A score

d_{i2}^{+}: Positive deviation from the targeted REBA A score
d_{i3}^{+}: Positive deviation from the targeted REBA B score
d_{i3}^{-}: Negative deviation from the targeted REBA B score

The proposed goal programming model for solving the problem is as follows:

$$Min \sum_{i=1}^{P} (d_{i1}^{+} + d_{i2}^{+} + d_{i3}^{+}) \quad (1)$$

Constraints:

$$\sum_{J=1}^{T} x_{iJ} \leq \bar{T} i = 1, \ldots, P \quad (2)$$

$$\sum_{J=1}^{T} x_{iJ} \cdot t_J \leq W i = 1, \ldots, P \quad (3)$$

$$\sum_{i=1}^{P} x_{iJ} \leq P_J J = 1, \ldots, T \quad (4)$$

Goal Constraints:

$$\sum_{J=1}^{T} R_J \cdot t_J \cdot x_{iJ} + d_{i1}^{-} - d_{i1}^{+} = \sum_{J=1}^{T} 7 \cdot x_{iJ} \cdot t_J i = 1, \ldots, P \quad (5)$$

$$\sum_{J=1}^{T} A_J \cdot t_J \cdot x_{iJ} + d_{i2}^{-} - d_{i2}^{+} = \sum_{J=1}^{T} 5 \cdot x_{iJ} \cdot t_J i = 1, \ldots, P \quad (6)$$

$$\sum_{J=1}^{T} B_J \cdot t_J \cdot x_{iJ} + d_{i3}^{-} - d_{i3}^{+} = \sum_{J=1}^{T} 5 \cdot x_{iJ} \cdot t_J i = 1, \ldots, P \quad (7)$$

$$x_{iJ} \in \{0,1\}, R_J, d_i^{-}, d_i^{+} \geq \ \ i = 1, \ldots, P J = 1, \ldots, T \quad (8)$$

In this model, Eq. (1) refers to the objective function that aims to minimize the REBA scores of tasks assigned to personnel. The maximum number of tasks that can be assigned to each staff expressed by Eq. (2). Eq. (3) ensures that no worker is assigned more than the daily working hours. The number of personnel required to perform each task is guaranteed by Eq. (4). Eq. (5) is a goal constraint, and each staff is expected to have 7 REBA scores. Eq. (6) is a goal constraint, and each staff is expected to have 5 REBA A score. Eq. (7) is a goal constraint, and each staff is expected to have 5 REBA B scores. Eq. (8) defines the type of decision variables.

4. REBA Method

The REBA method was developed by Hignett and McAtamney (2000) to assess body postures. It is an effective method for assessing risks in manual tasks. By using the REBA method, static movements can be evaluated as well as dynamic changes. Thus, risks related to the body posture of the employee can be widely evaluated by the REBA method. The calculation of a job's REBA score consists of 4 steps (Figure 1):

Step 1: Observing the Task

While the employee performs the task, body posture, equipment usage, the suitability of the equipment used for the employee, working environment, general workplace environment, etc. are observed.

Step 2: Select Posture

After the tasks have been evaluated, it is decided which REBA score will be calculated according to which posture for which task. In decision making, the most common and long-lasting posture that requires the most muscle activity or strength can be chosen. A posture is chosen by taking into account postures involving one or more of these situations.

Step 3: Posture Scoring

Group A score is obtained by evaluating the body, neck, and leg positions and is selected a score from Table A given in the Appendix section. Group B score is obtained by evaluating the positions of the upper arms, forearms, and wrists and is selected from Table B, given in the Appendix section.

Step 4: Processing Points

The score calculated for the load is added to the group A score. Score A is obtained from Table A. Grip score is added to Group B score, and Score B is obtained from Table B. Score A and score B are combined using the "General Scoring Matrix" and score C is obtained from Table C given in Appendix. Then, the REBA score is obtained by adding the movement score from Table D, if any, to Score C. Finally, the general REBA score is obtained, and we can evaluate the ergonomic risk by using the risk evaluation table (Table E) given in the appendix.

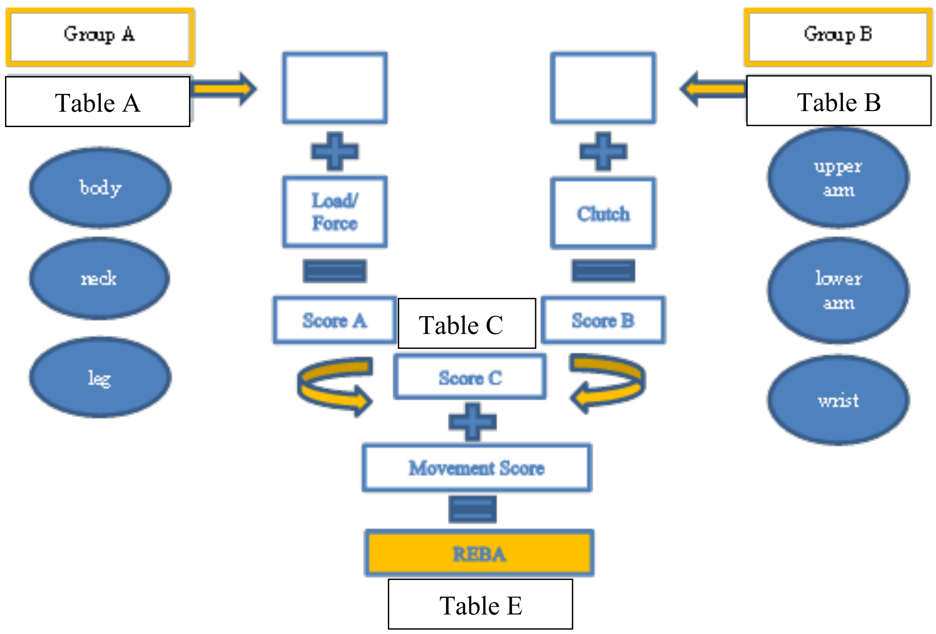

Figure 1. REBA Method Scoring Stages

In the REBA method, the score tables that will be used to calculate the score of a task are given in the appendix. In the REBA method, the score tables that will be used to calculate the score of a task are given in the appendix. More information and sample applications can be found in Hignett and McAtamney's (2000) study. Research and publication ethics were followed in this study.

5. Case Study

5.1 Medium Voltage Fuse Production

Current limiting fuses are the protection elements that melt the heat energy generated by the fault current and cut off the large short-circuit currents flowing from the fault circuit and at the same time prevent the re-jumps by separating. The function of the fuses is to protect the medium voltage switchgear from dynamic and thermal effects caused by short circuit currents greater than the minimum cut-off current of the fuse.

Figure 2. Medium voltage fuse production flow chart

There are five main processes in the production of medium voltage fuses (Figure 2). These processes consist of sludge preparation, firing, cutting, semi-finished product manufacturing, and assembly sections. There are a total of 12 workers and 43 jobs in the facility. The workers must be assigned to different departments in the production process to ensure the coordination of the works without interruption. At this stage, the determination of which work will be done by which worker appears to be a problem for the enterprise. For the distribution of these tasks to the personnel, the daily required labor force amounts for each task are calculated (Table 2).

Table 2. Durations of tasks and number of required personnel to perform the related task

	Task #	Tasks	Duration	# of required personnel
Mud preparation	1	Weighing mud raw material	90	2
	2	Mill Filling	30	4
	3	Mill water filling	30	1
	4	Mud sieving	120	1
	5	Mud into the tank	30	1
	6	Press unloading	30	2
	7	Weighing glaze raw material	15	1
	8	Glaze mill filling	15	2
	9	Glaze sieving	15	1
	10	Glaze standardization and coloring	60	2
	11	External body shaping	191	2
	12	Carrier Forming	202	2
Sintering	13	External body retouching	45	2
	14	External body glazing	45	2
	15	Kiln loading	55	3
	16	Kiln unloading	30	4
Cutting	17	External body cutting	195	1
	18	Carrier cutting	28	1
	19	External body grooving	155	1
	20	Carrier grooving	51	1
	21	External body quality control	155	1
	22	Carrier quality control	51	1
Intermediate Product	23	Contact head cutting	66	2
	24	Contact head forming	133	1
	25	Contact head grooving	133	1
	26	Bow Winding	166	1
	27	Comb pressing	33	2
	28	Perforated lid pressing	20	1
	29	Sand finisher pressing	20	1
	30	End cap pressing	20	1
	31	Inserting a comb	130	1
	32	Making display element	400	1
Assembly	33	Melting line winding	253	1
	34	Contact head plastering	253	1
	35	Carrier interlacing	166	1
	36	Display element assembly	253	1
	37	Comp interlacing	66	1
	38	Perforated lid plastering	100	1
	39	Sandblasting	33	1
	40	Sand cover assembly	66	1
	41	Final Cover Plastering	66	1
	42	Labeling and Packaging	233	1
	43	Packing and Stacking	19	1

5.2 Model Results

In this study, the REBA method was used to calculate the ergonomic risk scores of the tasks. The REBA method deals with the body movements of personnel. Each task was examined with the REBA method, and risk scores are calculated by utilizing the managers' experience. REBA A, REBA B, and total REBA scores for each task are given in Table 3.

Table 3. REBA scores of tasks

	Tasks	Group A			Group B			Load / Force	Grip	Movement	A score	B score	C score	REBA score
		Body	Neck	Leg	Upper Arm	Lower Arm	Wrist							
Mud preparation	Weighing mud raw material	4	2	3	5	2	2	3	1	2	10	9	14	14
	Mill Filling	4	3	4	5	2	3	3	1	3	12	9	15	15
	Mill water filling	2	1	1	1	1	1	0	0	0	2	1	1	1
	Mud sieving	1	1	1	1	1	1	0	0	0	1	1	1	1
	Mud into the tank	1	1	1	1	1	1	2	0	0	3	1	2	2
	Press unloading	3	3	3	4	2	2	3	2	3	10	8	15	15
	Weighing glaze raw material	4	2	4	5	2	2	3	1	3	11	9	15	15
	Glaze mill filling	4	3	3	1	2	3	3	1	3	11	4	14	14
	Glaze sieving	1	1	1	1	1	1	0	0	0	1	1	1	1
	Glaze standardization and coloring	2	2	1	2	2	1	3	2	1	6	4	8	8
	External body shaping	3	3	1	4	2	2	2	3	3	7	9	13	13
	Carrier Forming	3	3	1	4	2	2	2	3	3	7	9	13	13
Sinterin	External body retouching	2	2	1	3	2	3	2	0	3	5	5	9	9
	External body glazing	4	3	1	3	2	2	2	0	2	8	5	12	12
	Kiln loading	2	2	1	5	2	3	3	0	3	6	8	12	12
	Kiln unloading	2	2	1	5	2	3	3	0	3	6	8	12	12
Cutting	External body cutting	1	1	1	2	2	2	2	0	0	3	3	3	3
	Carrier cutting	1	1	1	2	2	2	2	0	0	3	3	3	3
	External body grooving	1	1	1	2	2	2	2	0	0	3	3	3	3
	Carrier grooving	1	1	1	2	2	2	2	0	0	3	3	3	3
	External body quality control	3	2	1	3	2	3	2	0	2	6	5	10	10
	Carrier quality control	3	2	1	3	2	3	2	0	2	6	5	10	10
Intermediate Product	Contact head cutting	4	2	1	2	2	2	0	0	1	5	3	5	5
	Contact head forming	2	2	1	2	1	2	0	0	0	3	2	3	3
	Contact head grooving	2	2	1	3	2	2	0	0	0	3	5	4	4
	Bow Winding	2	1	1	1	1	3	0	0	1	2	2	3	3
	Comb pressing	2	2	1	2	1	2	0	0	0	3	2	3	3
	Perforated lid pressing	2	2	1	2	1	2	0	0	0	3	2	3	3
	Sand finisher pressing	2	2	1	2	1	2	0	0	0	3	2	3	3
	End cap pressing	2	2	1	2	1	2	0	0	0	3	2	3	3
	Inserting a comb	2	1	1	1	2	3	0	0	1	2	3	3	3
	Making display element	1	3	1	1	2	2	0	0	0	3	2	3	3
Assembly	Melting line winding	1	1	1	1	1	2	1	2	2	2	4	5	5
	Contact head plastering	1	1	1	1	1	1	1	1	0	2	2	2	2
	Carrier interlacing	1	2	1	1	1	3	1	1	1	2	3	3	3
	Display element assembly	3	3	2	2	2	3	1	1	2	7	5	11	11
	Comp interlacing	1	2	2	1	1	3	1	1	1	3	3	4	4
	Perforated lid plastering	1	1	1	1	1	1	1	1	0	2	2	2	2
	Sandblasting	1	1	1	1	1	1	2	1	1	3	2	4	4
	Sand cover assembly	2	1	1	1	1	1	2	0	0	4	1	3	3
	Final Cover Plastering	1	1	1	1	1	1	2	0	0	3	1	2	2
	Labeling and Packaging	3	2	2	3	2	3	2	1	1	7	6	10	10
	Packing and Stacking	5	3	3	4	2	3	3	1	3	12	8	15	15

The firm currently does not pay attention to ergonomic conditions when assigning the tasks to the personnel. Therefore, it can be said that the staff has difficulty in terms of the ergonomic conditions while performing the tasks. The goal programming model was solved with the ILOG CPLEX Optimization program to optimize the ergonomic conditions and obtain the task assignment. The results are given in Table 4. According to the average REBA scores, there is a deviation from the target for only two of the workers (workers 9 and 12). Results have been achieved close to the targeted ergonomic risk value for other workers. In this way, personnel-task scheduling is obtained with lower ergonomic risk.

Furthermore, The total task times for each staff and complete assigned tasks to each person are reported in Table 4. According to the model results, a balanced task assignment is obtained between the idle time and the total number of tasks for each staff. Some of the staff (e.g., staff 2) performs more tasks in less full task time, while some of the staff (e.g., staff 5) performs fewer tasks in longer total task times. These are due to the balanced assignment of the REBA scores of the tasks by the model.

Table 5 shows the aggregate results obtained after the personnel task schedule has been prepared in all departments. According to the results, the total time spent on tasks is 5334 minutes. The average number of tasks assigned to personnel is 5. The average REBA score for staff is 7.25. Also, the REBA score is assigned to tasks in a balanced manner according to their ergonomic risks. According to the results obtained, a more appropriate personnel-task assignment is obtained in terms of worker health.

When the results were evaluated, the productivity of the company is increased. The predetermined task assignments result that job motivation increases significantly. In the company, a basic procedure has been established for task assignment and scheduling. In addition, the flexible and predetermined number of personnel enables rapid response to sudden production changes. Considering these advantages, it can be said that the proposed model is a practical approach to solve the personnel task scheduling problem.

In addition to the numerical advantages of the proposed mathematical model and approach, it has many benefits in terms of implementation for the company. A new perspective is brought to the company in terms of scientific problem-solving. Thanks to the developed model, the company is provided to easily follow the model changes. The results obtained from the model could be presented periodically at management meetings, and archived by reporting. Company's interpretation and analysis possibilities have been developed with simple statistical analysis on model parameters and results.

Table 4. Personnel scheduling performance results

Personnel	1	2	3	4	5	6	7	8	9	10	11	12
Total tasks times	358	228	498	509	429	489	444	458	530	509	447	435
Total tasks number	5	6	4	6	3	4	6	5	5	5	6	6
Average REBA score	7.09	7.54	7.19	5.54	7.43	7.18	7.18	7.07	8.14	7.08	7.13	8.48

6. Conclusion and Discussion

In this study, personnel scheduling problem in a factory producing medium voltage fuse is discussed. In the solution of the problem, especially the ergonomic constraints, the number of products determined by the planning department, the working hours, and the maximum amount of work a person can perform are considered. Ergonomic conditions are taken into account in the proposed goal programming model, and tasks are assigned to the personnel. As a result of the model, both technical requirements were provided, and an ergonomic working schedule was prepared for the workers. It is possible to develop the proposed model and solution approach in various ways. A study in which the task times are considered stochastic will be remarkable. A model considered the personnel skills can be developed as a future study. Also, the heuristic or meta-heuristic approaches can be used in large-scale problems, especially in case studies where the number of staff and the number of tasks are high. The model solution becomes complicated and time-consuming.

Table 5. The final assignment of personnel task scheduling

	Task #	Task	1	2	3	4	5	6	7	8	9	10	11	12	REBA
Mud preparation	1	Weighing mud raw material							1	1					14
	2	Mill Filling	1			1				1			1		15
	3	Mill water filling												1	1
	4	Mud sieving										1			1
	5	Mud into the tank		1											2
	6	Press unloading	1			1									15
	7	Weighing glaze raw material				1									15
	8	Glaze mill filling			1	1									14
	9	Glaze sleving	1												1
	10	Glaze standardization and coloring		1							1				8
	11	External body shaping						1				1			13
	12	Carrier Forming									1			1	13
Sintering	13	External body retouching							1				1		9
	14	External body glazing									1	1			12
	15	Kiln loading		1					1	1					12
	16	Kiln unloading	1	1			1			1					12
Cutting	17	External body cutting									1				3
	18	Carrier cutting									1				3
	19	External body grooving							1						3
	20	Carrier grooving											1		3
	21	External body quality control											1		10
	22	Carrier quality control												1	10
Intermediate Product	23	Contact head cutting						1						1	5
	24	Contact head forming										1			3
	25	Contact head grooving											1		4
	26	Bow Winding						1							3
	27	Comb pressing		1									1		3
	28	Perforated lid pressing												1	3
	29	Sand finisher pressing										1			3
	30	End cap pressing		1											3
	31	Inserting a comb			1										3
	32	Making display element				1									3
Assembly	33	Melting line winding	1												5
	34	Contact head plastering								1					2
	35	Carrier interlacing					1								3
	36	Display element assembly			1										11
	37	Comp interlacing							1						4
	38	Perforated lid plastering			1										2
	39	Sandblasting							1						4
	40	Sand cover assembly						1							3
	41	Final Cover Plastering												1	2
	42	Labeling and Packaging					1								10
	43	Packing and Stacking				1									15

Appendix

In this section, the tables required to select the Group A (Table A) and Group B (Table B) scores of the REBA method given in Figure 1 are given. Table C shows the general scoring matrix by comparing Group A and Group B scores. Finally, the table where the general REBA score will be interpreted is also reported.

Table A. Scores for the body, neck and leg positions

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	5	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B. Scores for the upper arms, forearms and wrists

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C. General scoring matrix

Score A (score form table A +load/force score)	Table C											
	Score B, (table B value + coupling score)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	11	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table D. Movement scores

+1	1 or more body parts are held longer than a minute (static)
+1	Repeated small range actions (more than 4x per minute)
+1	Action causes rapid large range change in postures or unstable base

Table E. REBA general scoring

1 = Negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate & implement change
11+ = very high risk, implement change

Legal/special permission

None was required as the current work system was established by the authors in a newly installed experimental facility.

Contribution of Researchers

Hacı Mehmet Alakaş contributed to establish the mathematical model, evaluate the ergonomic risk of tasks and write the manuscript draft. Mehmet Pınarbaşı contributed to the followings in the study: Collection of data and analysis of results. İsmet Sönmez prepared a literature review, obtaining the solution of the mathematical model and writing the manuscript. Ahmet Yüksel contributed to literature review, obtaining the solution of the mathematical model and writing the manuscript.

Conflict of Interest

The authors declared that there is no conflict of interest.

References

Ağralı, S, Taşkın, Z. C. & Ünal, A. T. (2017). Employee scheduling in service industries with flexible employee availability and demand. *Omega*, 66,159-169. https://doi.org/10.1016/j.omega.2016.03.001

Al-Yakoob, S. M. & Sherali, H. D. (2007). Mixed-integer programming models for an employee scheduling problem with multiple shifts and work locations. *Annals of Operations Research*, 155, 119–142. https://doi.org/10.1007/s10479-007-0210-4

Azaiez, M. N. & Al Sharif, S. S. (2005). A 0-1 Goal Programming Model for Nurse Scheduling. *Comput. Oper. Res.*, 32, 491–507. https://doi.org/10.1016/S0305-0548(03)00249-1

Bedir, N., Eren, T. & Dizdar, E.N. (2017). Ergonomik personel çizelgeleme ve parekende sektöründe bir uygulama. *Mühendislik Bilimleri ve Tasarım Dergisi*, 5(3), 5-10. https://doi.org/10.21923/jesd.331259

Bektur G, Hasgül S (2013) Kıdem seviyelerine göre işgücü çizelgeleme problemi: Hizmet sektöründe bir uygulama. Afyon Kocatepe Üniversitesi İİBF Dergisi 11(2):385-402

Bhulai, S., Koole, G. & Pot, A. (2008). Simple methods for shift scheduling in multiskill call centers. *Manufacturing & Service Operations Management*, 10(3), 411-420. https://doi.org/10.1287/msom.1070.0172

Boyer, V., Gendron, B. & Rousseau, L. M. (2014). A branch-and-price algorithm for the multi-activity multi-task shift scheduling problem. *Journal of Scheduling*, 17(2), 185-197. https://doi.org/10.1287/msom.1070.0172

Brezulianu, A., Fira, M. & Fira, L. (2009). A genetic algorithm approach for a constrained employee scheduling problem as applied to employees at mall type shops, *Proceedings of the 2009 International Conference on Hybrid Information Technology*, Dong Seoul University, Korea, ACM. https://doi.org/10.1145/1644993.1645085

Brunner, J.O., Bard J. F. & Kolisch, R. (2009). Flexible shift scheduling of physicians. *Health Care Management Science,* 12(3), 285-305. https://doi.org/10.1007/s10729-008-9095-2

Charnes, A. & Cooper, W. W. (1977). Goal programming and multiple objective optimizations: Part 1. *European journal of operational research*, 1(1), 39-54. https://doi.org/10.1016/S0377-2217(77)81007-2

Çöl, G. (2013). *Goal Programming Approach to Workforce Scheduling Problem with Different Seniority Levels (Master's Thesis).* Eskisehir Osmangazi University Fen Bilimleri Enstitüsü, Eskisehir.

Cuevas, R., Ferrer, J. C., Klapp, M. & Muñoz, J. C. (2016). A mixed integer programming approach to multi-skilled workforce scheduling. *Journal of Scheduling*, 19(1), 91-106. https://doi.org/10.1007/s10951-015-0450-0

Dewi, D. S. & Septiana, T. (2015). Workforce Scheduling Considering Physical and Mental Workload: A Case Study of Domestic Freight Forwarding. *Procedia Manufacturing*, 4, 445-453. https://doi.org/10.1016/j.promfg.2015.11.061

Drezet, L. E. & Billaut, J. C. (2008). Employee scheduling in an IT company. *Resource-Constrained Project Scheduling: Models, Algorithms, Extensions and Applications*, 243-255.

Eren, T. & Varli, E. (2017). Shift Scheduling Problems and A Case Study. *Int. J. Inform. Technol,* 10, 185–197.

Fırat, M. & Hurkens, C. A. J. (2012). An improved MIP-based approach for a multi-skill workforce scheduling problem. *Journal of Scheduling*, 15(3), 363-380. https://doi.org/10.1007/s10951-011-0245-x

Günther, M. & Nissen, V. (2010). Particle swarm optimization and an agent-based algorithm for a problem of staff scheduling. *European Conference on the Applications of Evolutionary Computation*, Springer-Heidelberg, Berlin. https://doi.org/10.1007/978-3-642-12242-2_46

Hignett, S. & Mcatamney, L. (2000). Rapid entire body assessment (REBA). *Applied ergonomics*, 31(2), 201-205. https://doi.org/10.1016/S0003-6870(99)00039-3

Hojati, M. (2018). A greedy heuristic for shift minimization personnel task scheduling problem. *Computers & Operations Research,* 100, 66-76. https://doi.org/10.1016/j.cor.2018.07.010

Kaçmaz, S. Ö., Alakaş, H. M. & Eren, T. (2019). Shift Scheduling with the Goal Programming Method: A Case Study in the Glass Industry. *Mathematics*, 7(6), 561-583. https://doi.org/10.1016/j.cor.2018.07.010

Krishnamoorthy, M., Ernst, A. T. & Baatar, D. (2012). Algorithms for large scale shift minimisation personnel task scheduling problems. *European Journal of Operational Research*, 219(1), 34-48. https://doi.org/10.1016/j.ejor.2011.11.034

Laesanklang, W., Pinheiro, R. L., Algethami, H. & Landa-Silva, D. (2015). Extended decomposition for mixed integer programming to solve a workforce scheduling and routing problem. *International Conference on Operations Research and Enterprise Systems*, Lisbon, Portugal. https://doi.org/10.1007/978-3-319-27680-9_12

Lapègue, T., Odile, B. M. & Damien, P. (2013). A constraint-based approach for the shift design personnel task scheduling problem with equity. *Computers & Operations Research,* 40(10), 2450-2465. https://doi.org/10.1016/j.cor.2013.04.005

Liao, S., Van Delft, C. & Vial, J. P. (2013). Distributionally robust workforce scheduling in call centers with uncertain arrival rates. *Optimization Methods and Software*, 28(3), 501-522. https://doi.org/10.1080/10556788.2012.694166

Louly, M. A. O. (2013). A goal programming model for staff scheduling at a telecommunications center. *Journal of Mathematical Modelling and Algorithms in Operations Research*, 12(2), 167-178. https://doi.org/10.1007/s10852-012-9200-x

Mengoni, M, Matteucci, M. & Raponi, D. (2017). A multipath methodology to link ergonomics, safety, and efficiency in factories. *Procedia Manufacturing*, 11, 1311-1318. https://doi.org/10.1016/j.promfg.2017.07.259

Omar, E. R., Garaix, T., Augusto, V. & Xie, X. (2015). A stochastic optimization model for shift scheduling in emergency departments. *Health Care Management Science*, 18(3), 289-302. https://doi.org/10.1007/s10729-014-9300-4

Otto, A & Scholl, A. (2013). Reducing ergonomic risks by job rotation scheduling. *OR spectrum*, 35(3), 711-73. https://doi.org/10.1007/s00291-012-0291-6

Özcan, E. C., Varli, E. & Eren, T. (2017). Goal Programming Approach for Shift Scheduling Problems in Hydroelectric Power Plants. *J. Inf. Technol*, 10, 363–370.

Özder, E. H., Varli, E. & Eren, T. (2017). A Model Suggestion for Cleaning Staff Scheduling Problem with Goal Programming Approach. *Karadeniz J. Sci.*, 7, 114–127.

Parisio, A. & Jones, C. N. (2015). A two-stage stochastic programming approach to employee scheduling in retail outlets with uncertain demand. *Omega*, 53, 97-103. https://doi.org/10.1016/j.omega.2015.01.003

Polat, O., Mutlu, Ö., Çakanel, H., Doğan, O., Özçetin, E. & Şen, E. (2017). Working Posture Analyses of Workers with Reba Method in a Furnıture Factory. *Journal of Engineering Sciences and Design*, 5, 263-268. https://doi.org/10.21923/jesd.41742

Polat, O., Mutlu, Ö. & Özgormus, E. (2018). A Mathematical Model For Assembly Line Balancing Problem Type 2 Under Ergonomic Workload Constraint. *The Ergonomics Open Journal*, 11(1), 1-10. https://doi.org/10.2174/1875934301811010001

Prot, D., Lapègue, T. & Bellenguez-Morineau, O. (2015). A two-phase method for the shift design and personnel task scheduling problem with equity objective. *International Journal of Production Research*, 53(24), 7286-7298. https://doi.org/10.1080/00207543.2015.1037023

Rocha, M., Oliveira, J. F. & Carravilla, M. A. (2014). A constructive heuristic for staff scheduling in the glass industry. *Annals of Operations Research*, 217(1), 463-478. https://doi.org/10.1007/s10479-013-1525-y

Salvagnin, D. & Walsh, T. (2012). A hybrid MIP/CP approach for multi-activity shift scheduling. *International Conference on Principles, and practice of constraint programming*. Springer-Heidelberg, Berlin. https://doi.org/10.1007/978-3-642-33558-7_46

Smet, P., Wauters, T., Mihaylov, M. & Berghe, G. V. (2014). The shift minimisation personnel task scheduling problem: A new hybrid approach and computational insights. *Omega*, 46, 64-73. https://doi.org/10.1016/j.omega.2014.02.003

Solos, L. P., Tassopoulos, I. X. & Beligiannis, G. N. (2016). Optimizing shift scheduling for tank trucks using an effective stochastic variable neighbourhood approach. *Int. J. Artif. Intell.,* 14(1), 1-26.

Soukour, A. A., Devendeville, L., Lucet, C. & Moukrim, A. (2012). Staff scheduling in airport security service. *IFAC Proceedings Volumes*, 45(6), 1413-1418. https://doi.org/10.3182/20120523-3-RO-2023.00169

Topaloglu, S. (2009). A shift scheduling model for employees with different seniority levels and an application in healthcare. *European Journal of Operational Research*, 198(3), 943-957. https://doi.org/10.1016/j.ejor.2008.10.032

Valls, V., Pérez, A. & Quintanilla, S. (2009). Skilled workforce scheduling in service centers. *European Journal of Operational Research*, 193(3), 791-804. https://doi.org/10.1016/j.ejor.2007.11.008

Varli, E., Alagas, H. M., Eren, T. & Özder, E. H. (2017). Goal Programming Solution of the Examiner Assignment Problem. *Bilge Int. J. Sci. Technol. Res.*, 1, 105–118.

Wongwien, T. & Nanthavanij, S. (2012a). Ergonomic workforce scheduling under complex worker limitation and task requirements: Mathematical model and approximation procedure. *Songklanakarin Journal of Science and Technology*, 34(5), 541-549.

Wongwien, T. & Nanthavanij, S. (2012b). Ergonomic Workforce Scheduling for Noisy Workstations with Single or Multiple Workers per Workstation. *International Journal of the Computer, the Internet and Management*, 20(3), 34-39.

Zolfaghari, S., Quan, V., El-Bouri, A. & Khashayardoust, M. (2009). Application of a genetic algorithm to staff scheduling in retail sector. *International Journal of Industrial and Systems Engineering*, 5(1), 20-47. https://doi.org/10.1504/IJISE.2010.029755