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Research Article

A goal programming approach for the facility layout problem with ergonomic constraint

Aylin ADEM[1,*], Esra Duygu DURMAZ[1], Ramazan ŞAHİN[1], Metin DAĞDEVİREN[1]

[1]Department of Industrial Engineering, Gazi University, Ankara, 06560, Türkiye

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ABSTRACT

In facility layout problems, ergonomic issues are generally not considered in the first place; instead, traditional layout aspects are taken into account. However, with the developing technology, legal responsibilities, and awareness of both the public and private sector to ergonomic issues, ergonomic concerns in designing any production area are getting more attention. The aim of this paper is to find an optimal single row facility layout arrangement taking into account both ergonomic and traditional layout aspects. The considered ergonomic feature is the noise exposure. If one worker exposures continuous high level of noise, temporary or permanent hearing loss may occur, which is not desired in the working life. To show the effect of noise exposure on layout, a mathematical model with noise constraint was developed. Moreover, a goal programming model which takes noise exposure, closeness ratings and material flow aspects as objectives was proposed. Traditional Analytical Hierarchy Process was utilized to gain the weights of the objectives. The applicability of the model was demonstrated by the solution of a hypothetical problem. The proposed models were tested and validated on different conditions to find out the effect of noise exposure.

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INTRODUCTION

With the developing technology, legal responsibilities, and awareness of both the public and private sector to ergonomic issues, ergonomic concerns in designing any production area are getting more attention. It is therefore not surprising that ergonomics are integrated into many work operations. The effect of ergonomics can also not to be ignored in the planning of facility layout, which is one of the most effective strategic decisions on the productivity of companies.

Facility layout is the physical arrangement and coordination of production vehicles, workstations, handling equipment, storage areas and all production areas in a limited space to increase production efficiency. Companies have to minimize their costs to maintain their competitive advantage in challenging market conditions. Facility layout has a high impact on the material handling and production

***Corresponding author.**
*E-mail address: aylinadem@gazi.edu.tr

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costs of enterprises. 20% to 50% of the total production cost is related to the transportation of work pieces. If the departments are better placed within the facility, a reduction in the transportation of material will occur and a 10% to 30% improvement in production costs will be achieved [1]. An efficient design of a facility provides companies low flow time and lateness, high safety and ergonomic conditions, besides the low material handling cost. For this reason, the appropriate arrangement of facility layout is of great importance for the company and it is a problem that must be carefully considered. Hence, facility layout problems, as practical and theoretical, have been studied by researchers [2-7]. For more information about FLPs, we refer to review paper [8].

A special type of facility layout, called as Single Row Facility Layout, is handled in the current study. Single Row Facility Layout Problem (SRFLP) can be defined as arranging machines on a straight line. It is one of the most common types of design used in cellular and flexible manufacturing systems for many reasons such as its effectiveness, simplicity, efficient flow structure, suitability for the arrangement of departments in different ways, having short flow distances, easy design of material handling systems [9]. SRFLP was first proposed by Simmons [10]. Since then, problem has been studied by researchers with exact solution approaches [11-15] and heuristic algorithms [16-22]. We refer to the review paper [23] for further details about SRFLP. Although the facility layout planning is generally aimed at minimizing material handling costs, it may also have different objectives such as maximizing the closeness ratings of machines, minimizing the material handling equipment, ensuring adjacency requirements, and effective usage of facility area. However, considering only traditional factors when designing facilities may cause improper layouts in terms of worker's health and safety.

It is known that all kinds of hazards that workers are exposed to in production environments, where they mostly spend their time directly, reduce work efficiency of employees. Therefore, just as ergonomic criteria are taken into account in operational activities such as personnel scheduling [24], the same situation is true for facility planning activities. In fact, from the point of view of facility planning, using ergonomics as a design principle will eliminate the possible future occupational health and safety issues.

While facility layout planning has drawn great attention of researchers, there have been limited studies on layout problems which focus on the ergonomic aspects. In these studies, generally the risks in the working environment and human factors are handled via multi-criteria decision making approaches. More specifically, ergonomic aspects of layouts are considered during comparisons of layout alternatives. Brooks [25] carried out a research on the ergonomic principles of office design by using checklist approach. Azadeh and Moradi [26] integrated fuzzy simulation, fuzzy data envelopment analysis and fuzzy Analytical Hierarchy Process (AHP) for facility layout with ergonomic issues. Tompkins, White [1] included human factor risk as one of the criteria for evaluation of different design alternatives. Moatari-Kazerouni, Chinniah [27] studied Occupational Health and Safety (OHS) parameters in designing step of a facility layout. They proposed a four-step solution approach to the problem. Li, Tan [28] proposed a mathematical model for a dynamic facility layout problem and used artificial bee colony algorithm with the objectives of minimizing material handling cost and reconstruction cost, minimizing the physical and mental risks, maximizing area utilization rate. Hammad, Akbarnezhad [29] offered a new multi-objective mixed integer nonlinear programming model that optimizes site layout and minimizes material handling costs and noise pollution. Abad [30] employed simulation-based approach considering Rapid Upper Limb Assessment (RULA) in facility layout. Suhardi, Juwita [31] used the systematic layout planning considering the muscle pain of workers to design the layout in a sewing department and evaluated alternative layouts by using a simulation software. Ferjani, Pierreval [32] considered fatigue factor that is affected by noise exposure, long walking distance and manipulation of heavy parts in designing facilities. They utilized a simulation model that is based on a fuzzy logic engine. Vadivel and Sequeira [33] proposed the AHP, Technique For Order Preference By Similarity To An Ideal Solution (TOPSIS) and fuzzy TOPSIS for selection facility layout design by taking into account ergonomic aspects.

Thus, as seen in the literature, there is no study that handles the noise exposure level in ergonomic facility layout on the basis of mathematical modelling and provides an optimal solution to this problem. To fulfil this gap in the literature, this paper proposes mathematical models that show the effect of noise exposure on the facility layout arrangement by using different scenarios. Although, it is not possible to express as a full ergonomic facility arrangement model that the basic SRFLP obtained with the constraint set we added; it can be easily said that the developed model will at least protect the employees in terms of industrial noise. In addition, a preliminary study was conducted on whether there is a trade-off between ergonomic and economic purposes within the scope of this study. Besides this, the SRFLP model aimed to minimize total flow distance and closeness rating scores. These three objectives were prioritized by decision maker with AHP method. The multi objective mathematical model was solved by using gained weights. This paper shows the balance between ergonomics and economic aims. The physical impact of industrial noise on employees is temporary or permanent hearing loss; it is also a source of psychological stress. Ignoring this factor during machine placement is an important deficiency in terms of employee health. By utilizing the proposed approach, company managers and occupational health professionals can consider both occupational health factors and economic aims in facility layouts.

This paper is organized as follows: After limited literature and general information about the study are given in Section 1, noise effect in facility layout is described in Section 2. The proposed mathematical models, illustrative examples and related details about results are presented in Section 3. A discussion is given in section 4 and finally section 5 presents concluding remarks and future research opportunities.

INDUSTRIAL NOISE EFFECT IN FACILITY LAYOUT

Noise as defined in general, is annoying sound that can inversely affect safety and performance of workers [34]. Noise affects negatively the performance of the workers with contributing his stress level continuously. Noise, humidity, high temperature, and vibration in the working environment are generally considered insignificant and normal details by managers. Nevertheless, these ergonomic elements, especially in the long run exposure, are really harmful on the workers' health both psychological and physiological. Because long working hours and negative conditions in the working environment affect the workers' health, there is a need to take drastic measures against these harmful effects.

In a working environment, if a worker exposure to excessive noise, specifically at levels of 90 dB and higher, can cause hearing loss. Such hearing loss is of two types. If hearing loss is caused by noise-damaged nerves in the inner ear or brain, it is called sensorineural hearing loss. Hearing loss due to damage to the outer or middle ear is called conductive hearing loss. The latter one is diagnosed by physicians by the means of a tuning fork placed on the bone behind the auricle of the ear for testing bone conduction [34].

Not all loud sounds are perceived as noise by people, but all sounds in the production environment are perceived as noise by employees. In addition to the effects of noise on the employee on hearing loss; the conducted studies also show that it has psychological effects such as distraction and loss of motivation. The psychological effects of industrial noise cause employees to be more vulnerable to work accidents due to distraction [35].

Actually, from an ergonomic point of view, the way followed to prevent harmful effects of risk parameters; is generally the case of preventing noise at its source, preventing between the receiver and the source, and finally using the measures to be taken on the person. However, in most cases, the values of some risk parameters cannot be reduced below a certain level, regardless of what precautions are taken in the production environment and the person. In such circumstances, it may be possible to protect employees with organizational methods from some ergonomic factors such as industrial noise in production environments.

In addition to the disruptive effects of the noise on the person, this situation has negative consequences on financial attributes of companies. The health expenses of the employee and the compensation to be incurred when the worker becomes disabled are also serious issues to consider.

-In the case of the simultaneous operation of more than one machine with a distance between them, it is necessary to know the distances and the individual noise levels of the respective machines for calculating the total noise level occurring in the specified area.

The noise level at a point *r* th away from the noise source can be calculated using the following equation [34]: $L_p = L_s - 10\log(4\pi r^2) - 10$ where, L_p: the noise level at a point away from the noise source in decibels, L_s: the noise level at the source in decibels, *r*: the distance between the point and the noise source, in feet. This formulation was expressed with Eq. (9) in the mathematical model in Section 3.1.

This formulation allows the determination of the noise level that the noise source, which has a certain distance from a specified point, reaches the specified point. With the mathematical model proposed in this study, the noise levels that more than one noise source reaches the control point are calculated. After that, the equivalent noise level at the control point is calculated. It is tried to find a machine layout where this equivalent noise does not exceed 90 dB. For the daily noise limit, different limit values are taken in various countries (Ex: USA, Argentina: 90dB, UK: 85dB)[36]. This paper considers the 90 dB as threshold limit value for noise exposure. Based on the definition of the dB concept, when calculating the equivalent noise, a logarithmic summation is utilized to sum two or more dB units[36]. This calculation logic was shown in Eq. (10) in the mathematical model in Section 3.1.

PROPOSED MATHEMATICAL MODELS

In this section, a mathematical model with single objective and a weighted goal programming model are developed to analyze the impact of noise consideration in layout planning. The proposed mathematical models are based on the SRFLP model introduced by Love and Wong [15]. General assumptions of the models and detailed explanations about the examined production system are given as follows.

Assumptions of the proposed mathematical models:

- Machines are rectangular or square. Machine lengths in the x-axis are known and widths in the y-axis are ignored. Machine centroids are assumed to be aligned on a straight line.
- Materials are transported between centroids of machines and the distance they travel is calculated as rectilinear.
- Material flow between each pair of machines is known.
- The material flow is independent of product types and shows the total number of materials transported between machines. The term material represents all raw materials and work-in-process parts in various manufacturing stages.
- Clearances between machines are ignored.
- Identical machines are not allowed.

- Reverberation effect in noise consideration is ignored.

SRFLP model with noise consideration

In the SRFLP model, the objective is to minimize total flow distance. Total flow distance is the sum of weighted distances between each pair of machines. In this study, the weights are to be considered as the number of materials transported between each pair of machines. Assuming the unit transportation cost of all types of materials are the same and equals to 1 monetary unit, it can be said that total flow distance represents material handling cost. For ease of calculation, total flow distance is used instead of material handling cost in the proposed model. The general SRFLP model given by [15] is presented and explained as follows.

Indices and Parameters:

i, j: machines

D: number of machines

f_{ij}: material flow between *i* and *j* machines

h_i: length of machine *i*

M: big number

Decision Variables:

$$R_{ij} = \begin{cases} \text{distance between centroids of machine } i \text{ and machine } j, \text{ if } i \text{ is to the right of } j \\ 0, \quad \text{otherwise} \end{cases}$$

$$L_{ij} = \begin{cases} \text{distance between centroids of machine } i \text{ and machine } j, \text{ if } i \text{ is to the left of } j \\ 0, \quad \text{otherwise} \end{cases}$$

x_i: end point location of machine *i*

$$\alpha_{ij} = \begin{cases} 1, \quad \text{if machine } i \text{ is to the left of machine } j \\ 0, \quad \text{otherwise} \end{cases}$$

$$\min \sum_{i=1}^{D-1} \sum_{j=i+1}^{D} f_{ij} * (R_{ij} + L_{ij}) \tag{1}$$

subject to

$$R_{ij} - L_{ij} = x_i - x_j + 0.5 * (h_j - h_i) \tag{2}$$

$$x_i - x_j + M * \alpha_{ij} \geq h_i \tag{3}$$

$$x_j - x_i + M * (1 - \alpha_{ij}) \geq h_j \tag{4}$$

$$h_i \leq x_i \leq \sum_{i=1}^{D} h_i \tag{5}$$

$$\alpha_{ij} \in \{0,1\} \qquad \forall i, j \tag{6}$$

$$R_{ij}, L_{ij} \geq 0 \qquad \forall i, j \tag{7}$$

$$x_i \geq 0 \qquad \forall i \tag{8}$$

Eq. (1) is the objective function which aims to minimize total flow distance. Eq. (2) finds the rectilinear distances between machines. Eq. (3) and Eq. (4) fix the location of machines and eliminate machine overlapping. Eq. (5) ensures that all machines are located within the determined facility area which is specified by summing the lengths of all machines. Eq. (6) presents the type of decision variable. Eq. (7) and Eq. (8) are non-negativity constraints. As explained in Introduction section, this paper considers the noise exposure aspect in mathematical layout planning modelling for the first time. Therefore, the reaction of this basic SRFLP model to the noise parameter is investigated on an example problem. Assume that, in a company manufacturing industrial products, a work unit of six machines is required to be redesigned. Moreover, it is desired to use a point in the area close to the production unit. This point is allocated for a computerized control system (CCS) which controls the automated machines. At the same time, the total noise level of these machines on the worker in this control unit is taken into consideration. The data employed in this study were taken from a data set in the related literature [37]. Material flow matrix is given in Table 1. The noise data of machines are randomly generated by the authors via Mersennie-Twister Algorithm using MS Excel and shown in Table 2. The CCS is placed vertically aligned with the last machine in the sequence. The machine lengths are five feet and the vertical length between the centroids of the machines and the CCS is three feet. Developed models were solved by using LINGO 17.0.

Table 1. Material flow between machines

	1	2	3	4	5	6
1	-	4	6	2	4	4
2	4	-	4	2	2	8
3	6	4	-	2	2	6
4	2	2	2	-	6	2
5	4	2	2	6	-	10
6	4	8	6	2	10	-

Table 2. Noise levels of machines (in dB)

Machines	Machine1	Machine2	Machine3	Machine4	Machine5	Machine6
Noise Level	95	100	90	125	105	110

SRFLP model is employed in three different scenarios to figure out the noise effect in layout configuration and objective function value. First of all, the SRFLP model given above and represented by Model-1 in Table 3 is performed. The noise exposure in CCS of the obtained layout is calculated using Eq. (9) and Eq. (10) and presented in fourth column in Table 3. Eq. (9) and Eq. (10) calculate the total noise level when machines work simultaneously.

$$e_i = n_i - 10\log\left(4\pi t_i^2\right) - 10 \qquad \forall i \tag{9}$$

$$E = 10\log\left[\sum_{i=1}^{D} 10^{0,1e_i}\right] \tag{10}$$

where,

n_i: noise level of machine i (dB)

e_i: distance based equivalent noise level of machine i at determined point

t_i: Euclidian distance between centroids of machine i and determined point

E: total noise exposure value at determined point (dB)

Model-2 is the model which aims only to minimize total noise exposure without considering the total flow distance. The objective function of Model-1 is changed with Eq. (11) in Model-2. This model utilizes Eq. (2) -(9) as constraints and Eq. (12) and Eq. (13) as additional nonnegativity expressions. The total flow distance of the obtained layout is calculated and given in second column in related row in Table 3.

$$\min\ 10\log\left[\sum_{i=1}^{D} 10^{0,1e_i}\right] \tag{11}$$

$$t_i \geq 0 \qquad \forall i \tag{12}$$

$$e_i \geq 0 \qquad \forall i \tag{13}$$

Finally, Model-3 takes the noise effect into account as a constraint. This model uses the Eq. 1 as objective function and Eq. (2) - (10) and Eq. (12) - (14) as constraints. Eq. (14) restricts the total noise exposure within the permissible level.

$$E \leq 90 \text{ dB} \tag{14}$$

Table 3 summarizes the obtained layouts, flow distances and noise exposure values of these three models.

When no restriction is made to the noise in the model (Model-1), the total noise exposure level on the worker is above the permissible noise level is 90 dB. The results of the Model-2 imply that there can be a trade-off between ergonomic aspects and flow distance. This model puts the machine with the lowest noise level (Machine3) as close as possible to the CCS. At the same time, Machine4 which has the highest noise level is placed to the furthest location to the CCS. The results of Model-3 reveal that when ergonomic consideration is included in the model, total noise exposure of worker decreases. Although, the total flow distance values of Model-1 and Model-3 are the same, it can be seen clearly, the noise parameter plays a role on the machine sequence and, Machine1 and Machine3 are positioned closer to the CCS.

Goal Programming Model

In this section, SRFLP is handled as a multi-objective problem in order to make it more suitable for real life and a weighted goal programming model is developed. In this goal programming model, the noise exposure value, which was a constraint in the previous single-objective model, is considered as a criterion that should be minimized. The first objective of goal programming model is the same as previously established model. The second objective is to minimize total closeness rating scores, which is a qualitative criterion. The closeness rating values of machines are numerical values that present the evaluation of required closeness between machines; e.g. bigger value means the necessity to assign the machines closer [38]. The total closeness rating score is obtained by summing the weighted distances by using c_{ij} parameters. This formulation uses the closeness ratings between each pair of machines as weights, similar to total flow distance. The last objective of the model is minimizing total noise exposure of a determined point in working area. The indices, parameters and decision variables are the same with the models in previous section. Additionally, a new parameter is defined as c_{ij}: closeness ratings between i and j machines.

$$\min\ w_1 d_1^+ + w_2 d_2^+ + w_3 d_3^+ \tag{15}$$

subject to

$$R_{ij} - L_{ij} = x_i - x_j + 0.5*(h_j - h_i) \tag{16}$$

$$x_i - x_j + M*\alpha_{ij} \geq h_i \tag{17}$$

Table 3. Obtained layout, flow distance and noise exposure

Models	Obtained Layout	Total Flow Distance	Total Noise Exposure(dB)
Model-1	1-3-2-6-5-4	600	94.49
Model-2	4-6-5-2-1-3	670	76.54
Model-3	4-5-6-2-3-1	600	76.77

$$x_j - x_i + M*(1-\alpha_{ij}) \geq h_j \quad (18)$$

$$h_i \leq x_i \leq \sum_{i=1}^{D} h_i \quad (19)$$

$$e_i = n_i - 10\log\left(4\pi t_i^2\right) - 10 \quad (20)$$

$$E = 10\log\left[\sum_{i=1}^{D} 10^{0,1e_i}\right] \quad (21)$$

$$\sum_{i=1}^{D\text{-}1}\sum_{j=i+1}^{D} f_{ij}*(R_{ij}+L_{ij}) + d_1^- - d_1^+ = goal_1 \quad (22)$$

$$\sum_{i=1}^{D\text{-}1}\sum_{j=i+1}^{D} c_{ij}*(R_{ij}+L_{ij}) + d_2^- - d_2^+ = goal_2 \quad (23)$$

$$E + d_3^- - d_3^+ = goal_3 \quad (24)$$

$$\alpha_{ij} \in \{0,1\} \qquad \forall i,j \quad (25)$$

$$R_{ij}, L_{ij} \geq 0 \qquad \forall i,j \quad (26)$$

$$x_i \geq 0 \qquad \forall i \quad (27)$$

$$t_i \geq 0 \qquad \forall i \quad (28)$$

$$e_i \geq 0 \qquad \forall i \quad (29)$$

Eq. (15) is written for aiming to minimize positive deviations from each objective. Eq. (16) to Eq. (21) is the same as the previous mathematical model. Eq. (22), Eq. (23) and Eq. (24) are the soft constraints of mathematical model. These constraints are related to total flow distance, total closeness rating score and total noise exposure, respectively. Eq. (25) presents the type of decision variable. Eq. (26) -(29) are non-negativity constraints.

When gaining weights of the objectives, AHP is employed because of its frequent use in the literature and proof of its validity. The readers who want to learn more information about AHP technique and its application area can be benefitted from Dagdeviren [39].

The importance degree which is provided in Table 4 is utilized in conducting pairwise comparisons of the goals. The compromised decision matrix which was agreed all experts is given in Table 5. This matrix shows the compromised expert evaluations about the goals. The utilized version of the AHP technique in this paper is the traditional one, which is proposed by Saaty [40] with 1-9 scale. To measure whether the decision-maker is consistent when making comparisons between criteria, the Consistency Ratio must be calculated. In this calculation, random index numbers are used depending on the number of n criteria. If the value found as a result of the calculations is below 0.10, it is concluded that the comparison matrix created is consistent. Otherwise, the decision matrix should be rearranged [40]. The consistency ratio of the compromised decision matrix is calculated lower than 0.1, this matrix is consistent and does not need to be re-arranged.

After constructing the decision matrix, the normalized matrix is obtained by dividing each column value by the corresponding column sum (Table 6). The arithmetic average of each row of the normalized decision matrix is calculated (Table 7). These obtained values are the percentage importance weights for each criterion [41].

Table 4. Importance scale

Importance Degree	Definition
1	Equal
3	Medium importance
5	High importance
7	Very high importance
9	Absolute importance
2,4,6,8	Intermediate values

Table 5. The compromised decision matrix

	Total closeness rating	Total flow distance	Total noise exposure
Total closeness rating	1	1/2	1/3
Total flow distance	2	1	1/2
Total noise exposure	3	2	1

Table 6. Normalized Matrix

	Total closeness rating	Total flow distance	Total noise exposure
Total closeness rating	0.167	0.143	0.182
Total flow distance	0.333	0.286	0.273
Total noise exposure	0.500	0.571	0.545

Table 7. The weights of objectives

Objectives	Weights
Total closeness rating	0.16
Total flow distance	0.30
Total noise exposure	0.54

To integrate all of the objectives in a non-biased way, a normalization procedure is utilized. In order to ensure that the objectives have the same level of impact on the final layout, it is necessary to normalize the objectives [16]. The required minimum values for normalization procedure are obtained by solving the mathematical model with related single objective. In determining the maximum value of an objective, the method given by Malakooti [42] is used. According to this method, the value of one objective function will only be as bad as the value that will appear when the other objective function is optimized. The objective functions of Model-A, Model-B and Model-C are the minimizing total flow distance, minimizing total closeness rating score and minimizing total noise exposure, respectively. In each model, other values which are not objectives are also calculated and saved in the related column as shown in Table 8. Finally, the minimum values of objectives are Min_flow, Min_rating and Min_noise and the maximum values are max {Flow-B, Flow-C}, max {Rating-A, Rating-C}, max {Noise-A, Noise-B}.

After these operations, Eq. 22-24 are updated with Eq. 30-32.

$$(\sum_{i=1}^{D\text{-}1}\sum_{j=i+1}^{D} f_{ij} * (R_{ij}+L_{ij}) - \text{Min\_flow}) / (\max\{\text{Flow-B, Flow-C}\} - \text{Min\_flow}) + d_1^- - d_1^+ = 0 \tag{30}$$

Table 9. Closeness rating values between machines

	1	2	3	4	5	6
1	-	5	3	2	6	4
2	5	-	5	2	6	2
3	3	5	-	1	2	1
4	2	2	1	-	2	2
5	6	6	2	2	-	6
6	4	2	1	2	6	-

$$(\sum_{i=1}^{D\text{-}1}\sum_{j=i+1}^{D} c_{ij} * (R_{ij}+L_{ij}) - \text{Min\_rating}) / (\max\{\text{Rating-A, Rating-C}\} - \text{Min\_rating}) + d_2^- - d_2^+ = 0 \tag{31}$$

$$(E - \text{Min\_noise}) / \max\{\text{Noise A-Noise B}\}\text{-Min\_noise} + d_3^- - d_3^+ = 0 \tag{32}$$

The proposed goal programming model was implemented on the example problem in Section 3.1 by using the obtained weights. Closeness rating values of this example is shown in Table 9 [37].

Table 10 shows calculated values for normalization of the given example. Table 10 clearly indicates that the objectives have conflicting nature. The final machine sequence obtained by solving the goal programming model is shown in Figure 1. In this layout, the machines are located on a straight line in order of Machine 4, Machine 5, Machine 6, Machine 2, Machine 1 and Machine 3. The CCS unit is aligned with the centre point on the x-axis of the last machine (Machine3) in the sequence. The results and deviation values of objectives are summarized in Table 11.

For the total flow distance objective, the deviation value is obtained as 0.00. Thus, the flow distance of the final machine layout is 600. The deviation value of the second objective is found as 0.58. This situation indicates that the target value for this objective could not be satisfied.

Table 8. Data for normalization

	Total flow distance	Total closeness rating score	Total noise exposure
Model-A	Min_flow	Rating-A	Noise-A
Model-B	Flow-B	Min_rating	Noise-B
Model-C	Flow-C	Rating-C	Min_noise

Table 10. Data for normalization of the example

	Total flow distance	Total closeness rating score	Total noise exposure
Model-A	600	540	94.49
Model-B	690	445	94.51
Model-C	670	465	76.54

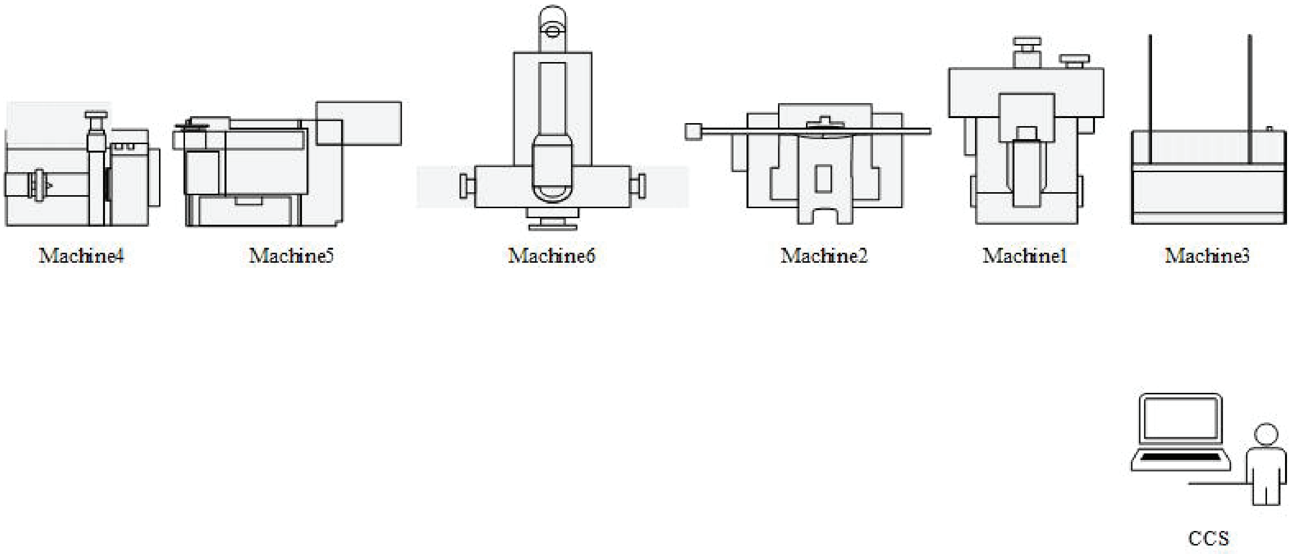

Figure 1. Final machine layout.

Table 11. Deviations and results

Objective	Deviation	Result	Computational time (s)
Total flow distance	0.00	600	44.48
Total closeness rating	0.58	500	
Total noise exposure	0.0053	76.63	

Similarly, the deviation value is calculated as 0.0053 for the total noise exposure objective. This means that the objective's target value could not met. Since these objectives are soft constraints of the goal programming model there may be deviations from the target values.

To show the reaction of the developed model, the model was solved for different sized data sets. The obtained machines' sequences and computational times are given in Table 12. The material flow and closeness rating scores were taken from [37]. For the 2 problems with 6 machines and 8 machines, 3 different noise level sets with different averages were generated. Model-A, Model-B and Model-C were solved to obtain goal values of objectives and normalization processes were repeated for all problems.

For example, Problem 2 with 6 machines has noise levels; 120,100,115,125,110,100, respectively as seen in Table 12. After conducting the solution process of the goal programming model for this problem, the obtained machine sequence is 4-3-1-5-6-2 and the computational time is 74.11 seconds. Table 12 implies that as the problem size grows, the solution time increases.

Basic SRFLP is an NP-hard problem [16]. In this study, the complexity of the problem increased even more because new constraints and decision variables were added to the

Table 12. Obtained layouts and computational times of different data sets

Pr.	Number of machines	Noise levels of machines	Obtained machine sequence	Computational time (s)
1	6	95-100-90-125-105-110	4-5-6-2-1-3	44.48
2	6	120-100-115-125-110-100	4-3-1-5-6-2	74.11
3	6	85-95-80-90-105-100	4-5-6-2-1-3	53.6
4	8	125-95-100-90 -110-85-100-105	1-2-7-5-8-6-3-4	848.41
5	8	125-115-120-100-110-100-95-115	2-1-3-8-5-7-6-4	2568.93
6	8	90-80-95-100-95-85-105-100	3-4-8-6-7-5-1-2	3068.64

Table 13. Basic sensitivity analysis for objective weights

	Scenario 1		Scenario 2		Scenario 3	
Objectives	**weights**	**deviations**	**weights**	**deviations**	**weights**	**deviations**
Total flow distance	0.005	0.77	0.005	1	0.99	0
Closeness rating score	0.005	0.21	0.99	0	0.005	0.58
Noise exposure	0.99	0.000045	0.005	0.0059	0.005	0.0053

model. Therefore, larger problems could not be solved optimally in reasonable computational times.

As the machine number increases due to the noise calculation formulas structure (i.e. distance-based calculation) ergonomic aims do not force the developed models as economic aims does. However, it is known that in large companies, due to the legal responsibilities ergonomic conditions are taken into account seriously [35]. Basic ergonomic issues like noise exposure are generally encountered in SMEs (Small and Medium Sized Enterprises) [43]. Therefore, considering small sized samples solution of the proposed models will be more distinctive in terms of the understanding the effect of noise exposure on the layout of the facility.

DISCUSSION

The conflict between ergonomic goals and economic goals, which is supported by the results of this study and is a generally accepted conclusion in the literature, requires that this situation should be considered as one of the critical management decisions. Obviously, a production environment can have multiple ergonomically risky features. Noise parameter is one of the most encountered ergonomic aspect of workplaces [35]. Actually, excessive noise exposure affects the employee's health and job satisfaction in a negative way [32]. The noise parameter, which has a negative effect on productivity in the workplace, employee health, and health expenditures, must be considered in conducting or planning every kind of production activity in terms of strategic management. There are direct costs of not paying attention to ergonomics in the production environment, but there are also some hidden costs that have not yet been clearly revealed [44]. Since finding the best result with limited resources points to a classical optimization problem, a mathematical modelling approach was employed in this study to find the ergonomic facility layout, different from the related literature.

To show the effect of changes of the objective weights, a basic sensitivity analysis was conducted, and the results are summarized in Table 13.

Obviously, in the different scenarios developed, and especially in the goal programming results, managers were shown how the layouts differ when economic and ergonomic purposes are considered separately or together when deciding on the facility layout (See Table 3 and Table 11).

In Scenario 1, strict ergonomic approach was considered. Thus, the deviation value of noise exposure was calculated lower than the base goal programming model. Although the weight of this objective was determined to be a large value, the deviation was not obtained as zero. In Scenario 2, the dominant objective was the closeness rating score, and the deviation value was zero. Although the weights changed, Scenario 3 had the same result as the base model.

Since the main aims of this paper are to make some deductions on the basis of noise exposure and to integrate the noise parameter into the facility planning models, interpretations of the noise-dominated scenario are important. When the other two objectives were dominant, the respective target values were achieved. However, no matter how much the weight of the total noise exposure objective is increased, the target value cannot be reached. This indicates that the noise objective is in conflict with the traditional facility layout objectives. It also demonstrates the critical importance of integrating ergonomic goals into facility planning approaches.

Since ergonomic measures have a reducing effect on health expenditures arising from work accidents in the future [45], it is predicted that the preparation of facility layout plans by paying attention to ergonomic features gives the managers strategic eligibility in terms of work efficiency, employee health, and health expenditures.

CONCLUSION

The well-being of human resources in production environments plays a critical role on the employees' efficiency and motivation. On the other hand, facility layout approaches by aiming to optimize some production activities of companies under certain conditions determine the machine locations in production environments. In this paper, a study on how to integrate the noise parameter, frequently encountered in production environments and known that long term health effect of it is permanent, to the SRFLP model. Therefore, new mathematical model variations were proposed that address both traditional facility layout goals and ergonomics-related purposes. In order to analyse the effects of the integration of noise parameter to the mathematical models appropriately, different scenarios were developed. The results of these scenarios showed that noise parameter which is one of the frequently encountered risk parameter in production environments can be integrated to facility layout problem and the proposed models produce reasonable results.

This study, which serves as a preliminary analysis of how to add a constraint on noise exposure to a basic facility layout model, will be shed light on future studies in this area. The fact that the human resources', which is difficult to manage motivational, feeling safe in the production environment have a serious effect on labor productivity. On the other hand, the philosophy of "prevention is cheaper than pay", which is effective in all occupational health and safety approaches, has also made ergonomic approaches more popular. The current paper attempts to shed light on the intersection of two different disciplines (ergonomics and facility layout).

Obviously, the current version of this paper is open to be improved. For further research, the reverberation effect which can be show differences according to the structure and the heights of the walls, proximity of the person to the noise source etc. can be considered in developing mathematical models. Moreover, it can be considered as different ergonomic attributes of production environment such as thermal comfort. Besides, in terms of facility layout design, multi-row or multi-floor facilities can be arranged under ergonomic constraints.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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