ENTHUSIASTIC
INTERNATIONAL JOURNAL OF APPLIED STATISTICS AND DATA SCIENCE
Volume 3, Issue 2, October 2023, pp. 212-221

A Mathematical Model for Determining the Facility Layout Plan of a Plastic Injection Factory

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ARTICLE INFO

Keywords
Facility layout planning
GAMS
Mathematical model
Optimization

ABSTRACT

In this study, a mathematical model has been developed to make the facility layout planning of the annex building, which is being built right next to the old building of a factory that produces plastic parts. Some or all parts of the departments, such as injection machines, semi-finished products, product, raw material warehouses, molding room, and paint shop in the old building of the factory can be moved to the new building. Nevertheless, some cannot be moved. Since injection machines use cranes for electricity, plumbing, and mold transport, relocation is very costly. Different layouts are proposed with the developed mathematical model for seven scenarios that allow and do not allow partitions of the departments. The proposed layout plans were compared in terms of the total carrying costs of the products and the carrying costs of the sections. In this way, the factory has been presented with a significant cost reduction opportunity.

1. Introduction

In facility planning, determining the most efficient layout plays a pivotal role in optimizing interunit transportation, regardless of the industry. Although our model universally applies to any sector where facility planning is paramount, our study zeroes in on the plastic injection factory. The rationale behind this decision stems from two main factors. First, we intended to address a tangible, real-world problem and produce actionable outcomes. The plastic injection factory presented itself as an apt setting given the current context and its unique challenges and opportunities. Second, a thorough review of the existing literature highlighted a palpable gap in specific applications tailored for the plastic injection sector. The paucity of analogous studies further motivated us to embark on this endeavor. Thus, in pursuit of originality and in response to the literature gap, we meticulously crafted a mathematical model to optimize the facility layout of the plastic injection factory. This study discusses the facility layout problem of an injection factory located in Eskisehir. The factory is expanding its area, and a new facility is being built adjacent to the existing facility. As a result, the facility plan of the factory needs to be rearranged to reduce interunit transportation.

Facility planning stands as a critical factor in determining the efficiency and profitability of manufacturing units. This study is instigated by the palpable challenges faced by a plastic injection company in Eskisehir. The company, grappling with the limitations of its current infrastructure, is at a juncture where spatial constraints, enhanced production capacities, and inefficient transportation

p-ISSN 2798-253X
e-ISSN 2798-3153

within its existing building impede its optimal functionality. Such constraints not only curb efficiency but also affect ergonomics and the working conditions of employees, in turn impacting profitability and workflow.

Recognizing these challenges, the core aim of our research is to develop a new layout plan. This plan is informed by the current interunit relations and transportation volumes, and endeavors to address identified bottlenecks using a mathematical model. The application of the quadratic assignment method within this model facilitates the strategic positioning of units in appropriate areas. Our primary metric of success and contribution is the reduction in transportation volumes, as this has cascading benefits from improved worker conditions to heightened profitability.

While the immediate need for this study arose from spatial constraints and transportation bottlenecks, its implications extend to the holistic functioning of the facility. A well-devised layout will serve both to optimize the existing facility and provide a blueprint for any subsequent.

To enhance the accuracy and applicability of our model, we have considered the feedback and requirements of all operational units within the company. Notwithstanding the initial successes of our model, we acknowledge areas of potential improvement. For instance, a more granulated analysis, where injection machines are individually evaluated rather than grouped, might yield superior results. Furthermore, aligning the model's cost parameters more closely with on-ground realities can make allocations more precise and desirable.

For endeavors of this nature, it's imperative to adopt a comprehensive approach: thorough observations, a review of preceding studies, and meticulous research to determine appropriate methodologies and constraints. Our study, while tailored for a plastic injection company, has broader applications. The developed mathematical model, with minor customizations, can be deployed across various manufacturing domains, emphasizing its universality and adaptability.

Numerous studies have proposed diverse methods to address facility layout problems. a two-stage solution for the multi-story facility layout problem was proposed [1]. Another study suggested three novel layout alternatives for a business in the İzmir Organized Industrial Zone, effectively reducing daily transport distances [2]. A study also aimed to reduce material handling costs in an automotive subsidiary by redesigning its factory layout using ARENA for modeling the current system and LayOPT for devising a new layout [3]. endeavored to streamline sheet metal processes in steel door production by exploring alternative factory layouts using Vip-Planopt 10 software [4]. A study researched the P-median problem to minimize average weighted distance and suggested increasing warehouse numbers [5]. Another study has analyzed the layout of military facilities, achieving an 8.64% cost reduction [6]. A study in 2021 utilized the LayOPT program, focusing on patient movement to address hospital inefficiencies [7]. Then, a study sought to optimize the internal logistics of a relocating steel forging company using Proximity Matrix" and "Milk-run" [8]. Then, a study focused on minimizing total costs by determining the best facility placements with a heuristic method [9]. A study improved intracellular machine layouts to address production inefficiencies [10]. Then, another study focused on reducing transportation costs and prioritizing personnel safety in military facility layouts [11]. A comprehensive book on production management and systems has also been published [12]. Another study proposed alternative layouts to minimize transportation costs by focusing on flow efficiency [13]. Then, an innovative approach using the tabu search method for the facility layout problem has also been introduced [14]. A study has developed two alternative layouts for a manufacturing facility [15]. Meanwhile, another study aimed to optimize inventory classification using ABC analysis and the Analytic Network Process (ANP) [16]. Last, in [17], cost-driven layouts were compared with those considering additional criteria. While these studies share the goal of reducing transportation and costs, their methods vary based on facility needs and complexity. This research draws inspiration from Turanoğlu's 2012 study on the Quadratic Assignment Problem.

2. Method

In this study, the process of obtaining the data, the methods used, and the mathematical model are examined in detail under this title.

2.1. Data

To solve the problem of facility planning; It is necessary to collect information such as process flow diagrams, materials used, units, and relations between them from the manufacturing departments of the company whose facility planning will be made. Material flow tables were created according to the parts determined as a result of the ABC analysis made with the information which were production quantity, sales quantity, and selling price. After the analysis of the obtained information, the basic plan was decided, and the product flow pattern was determined. It is necessary to ensure the comfort and safety of the employees, to allocate sufficient space for the necessary materials and equipment, and to place the workstations in a way that ensures easy maintenance. With good workplace planning, this problem is solved by optimizing material handling. During the study, the applicability of the plan could be ensured by considering that every work done had a cost. A plan involving a cost the company could not afford was not viable. Product flowchart is presented in Fig. 1.

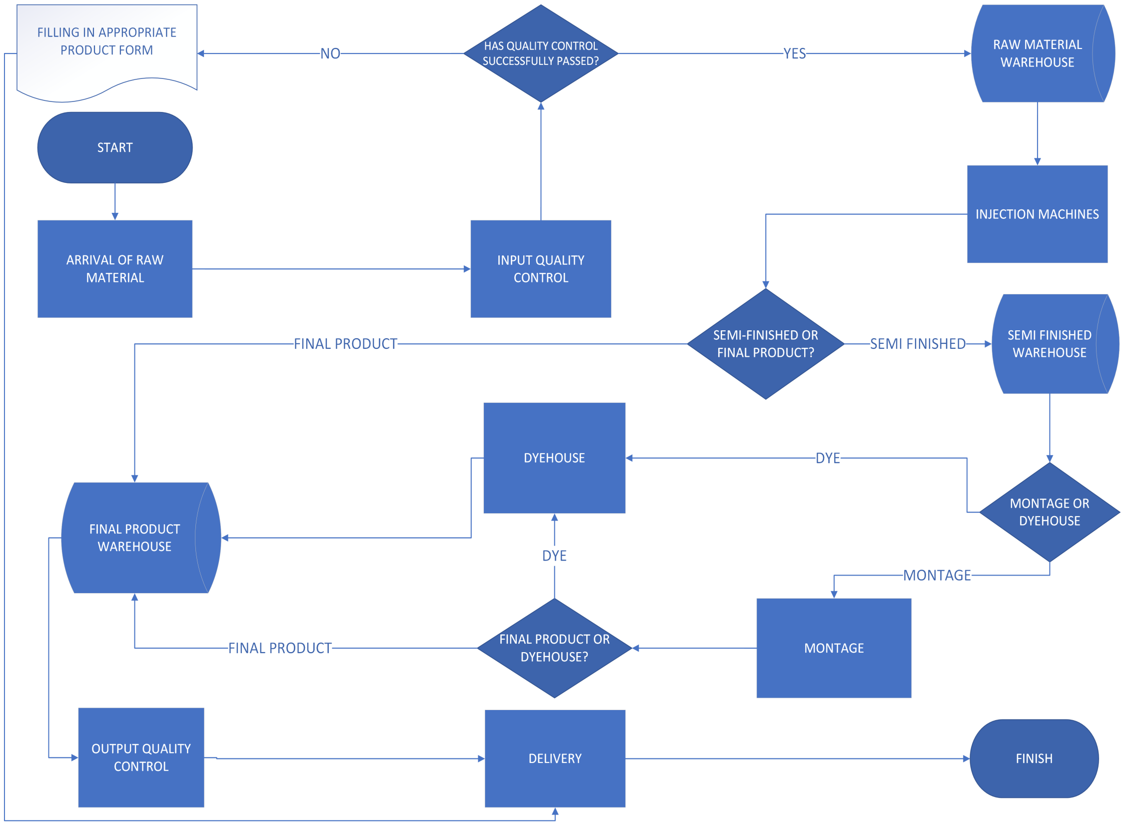


Fig. 1 Product flowchart.

ABC analysis includes:

a. The annual use of each material used in the departments should be determined.
b. The last unit cost of annual usage should be determined for each material used in the departments.
c. Materials should be listed and categorized according to their annual consumption amounts, from the costliest to the least costly, as the total amount, from the largest to the smallest.

The route information of these parts and how many boxes of products are transported within the facility in a year were defined in the model by applying these steps and selecting the parts that makeup 80% of the factory's profit.

Table 1. ABC Analysis

Stock Code	Product Name	Quantity In the Box	Produce Amount Per Year	Number Of Box Carried Per Year	Product Weight	Runner Weight	Waste Per.	Max. Box Cap.	Number Of Box Per Year	Waste Per.	Runner (Box/Year)	Waste+ Runner
1	PRODUCT 1	500	76,120	152	5	2	0.015	43.75	9	0	2.609828571	3
2	PRODUCT 2	3,000	15,795	5	1.66666667	1	0.015	43.75	1	0	0.180512229	0
3	PRODUCT 3	500	12,875	26	2.66666667	1	0.015	43.75	1	0	0.294277943	0
4	PRODUCT 4	500	7,652	15	1	1	0.015	43.75	0	0	0.131182971	0
5	PRODUCT 5	1,000	6,315	6	0.66666667	1	0.015	43.75	0	0	0.072171429	0
6	PRODUCT 6	6	1,610	268	120		0.015	43.75	4	0	0	0
7	PRODUCT 7	3.5	631	180	120		0.015	43.75	2	0	0	0
8	PRODUCT 8	3.5	702	201	113.333333	12	0.015	43.75	2	0	0.184649257	0
9	PRODUCT 9	6	1,540	257	350	23	0.015	43.75	12	0	0.792205714	1
10	PRODUCT 10	4	2,084	521	120.666667	5	0.015	43.75	6	0	0.214398514	0
11	PRODUCT 11	4.5	3,951	878	163333333		0.015	43.75	2	0	0	0
12	PRODUCT 12	4	999	250	316.666667		0.015	43.75	7	0	0	0
13	PRODUCT 13	5	1,775	355	37.3333333	5	0.015	43.75	2	0	0.202825143	0

The route information of 13 parts was obtained by performing ABC analysis in the Table 1. A material flow table between units was created to be used in the model. Since this information was confidential, the data had been changed and added to the table.

2.2. Proposed Mathematical Model

Mathematical modeling aims to find a solution to the problem in many ways by expressing a problem mathematically. By evaluating this result, a conclusion is reached in line with its applicability. The proposed mathematical model is explained under this title.

The proposed mathematical model is established based on Quadratic Assignment Problem (QAP). In the QAP, there are equal numbers of candidate areas and units. While the distances between each area and the flow amounts between each unit are determined, the assignment of units to the areas is realized by minimizing the total transportation cost. At the end of the assignment, a unit is established in each candidate area and no candidate area, and the unit remain uncovered.

General Algebraic Modeling System (GAMS) is a high-level programming language for obtaining the best solution for a mathematically specified model in the computer environment. It enables us to find the solution to complex models easily with methods such as linear programming and nonlinear programming. The problem whose mathematical model is coded in GAMS and solved. The model has elements like variables, parameters, tables, and equations. Below is the code that enables the necessary assignments to be made by considering the transportation and one-time costs of the facility planning problem, whose mathematical model is established.

Indices:

$i,m \quad : Unit\ Index\ (i,m = 1,2,\dots,18)$

$j,n \quad : Area\ Index\ (j,n = 1,2,\dots,18)$

Parameters:

B_{ij} : Cost incurred table in case of relocation unit *i* to unit *j*
C_{ij} : Cost incurred table in case of relocation machine *i* to machine *j*
α_{im} : Material flow table from unit *i* to unit *m*
β_{jn} : Distance table from area *j* to area *n*
T_{ij} : Cost per unit moved from unit *i* to area *j*

Decision Variables:
x_{ij} : 1 if unit i is assigned to area j,0 otherwise.

Constraints:

$$\sum_{j=1}^{18} x_{ij} = 1 \qquad \forall i \qquad (1)$$

$$\sum_{i=1}^{18} x_{ij} = 1 \qquad \forall j \qquad (2)$$

$$x_{ij} \in \{0,1\} \qquad \forall i,j \qquad (3)$$

Objective function,

$$min\, z = \sum_{i=1}^{18}\sum_{j=1}^{18}\left(B_{ij} + C_{ij}\right) x_{ij} + \sum_{i=1}^{18}\sum_{j=1}^{18}\sum_{m\neq i}^{18}\sum_{n\neq j}^{18}\left(\alpha_{im}\,\beta_{jn}\,x_{ij}\,x_{mn}\right) T_{ij}. \qquad (4)$$

Constraint (1) ensures that each unit is always assigned to a field. Constraint (2) ensures that each field is assigned to a unit. Constraint (3) is for determining the decision variables type. The objective function (4) is the sum of the one-off costs that must be incurred if the unit is moved to another area and the values obtained by multiplying the material flow table and the distance table for each area and unit.

The areas seen in Fig. 2 are defined as the places where the units will be assigned. According to the constraints set in the developed mathematical model, the units to be assigned to the fields are as follows:

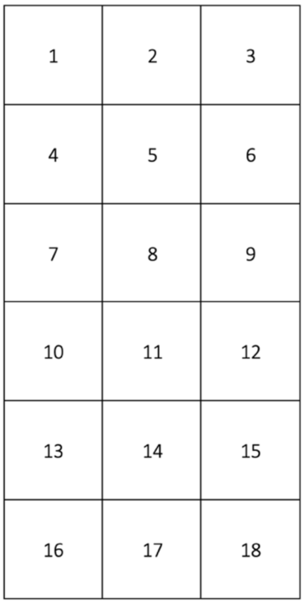


Fig. 2 Area layout defined to the model.

a. Raw material warehouse
b. Input output quality control
c. Molding
d. Recycle
e. Dyehouse
f. Montage
g. Office
h. Injection machine groups (E1)
i. Injection machine groups (E2)
j. Injection machine groups (E3)
k. Injection machine groups (E4)
l. Injection machine groups (E5)
m. Injection machine groups (E6)

n. Delivery
o. Special need
p. Semi-product warehouse
q. Empty space
r. Final product warehouse

DELIVERY	INPUT OUPUT QUALITY CONTROL	RECYCLE
WAREHOUSE	EMPTY SPACE	E2
EMPTY SPACE	E1	E3
DYEHOUSE	MOLDING	E4
MONTAGE	E6	E5
SPECIAL NEED	OFFICE	MOLDING

Fig. 3 Current layout.

OFFICE	E3	MOLDING
DELIVERY	E5	E1
INPUT OUTPUT QUALITY CONTROL	WAREHOUSE	DYEHOUSE
E4	MONTAGE	E6
SPECIAL NEED	E2	RECYCLE

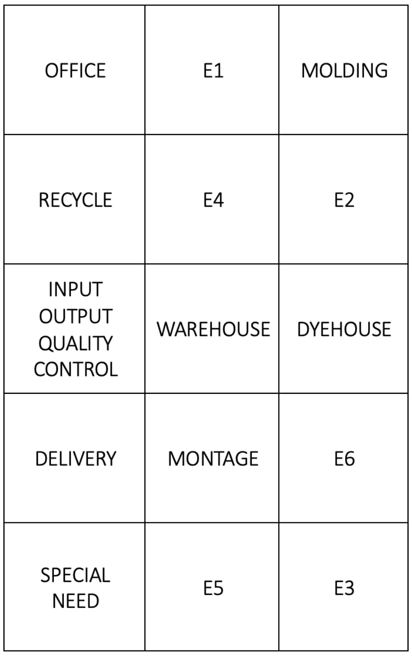
Fig. 4 Layout for Scenario 1.

3. Results and Discussion

In our results and discussion section, several scenarios are presented, each grounded in specific criteria rooted in both practical and theoretical considerations. First, our criteria were meticulously shaped to align with the operational policies of the Plastic Injection factory under study. This real-world alignment was further enhanced by referencing established criteria in facility layout literature. A crucial aspect of our methodology involved optimizing material flow, evidenced by our strategic placement of high-interaction units closer to the facility's core. This practical approach was further refined by integrating constraints tailored to address potential operational challenges, which, it should be noted, can vary based on specific company dynamics. Modifications across scenarios were informed by these principles, and our designation of the 'optimal scenario' stands as a synthesis of these methodological considerations.

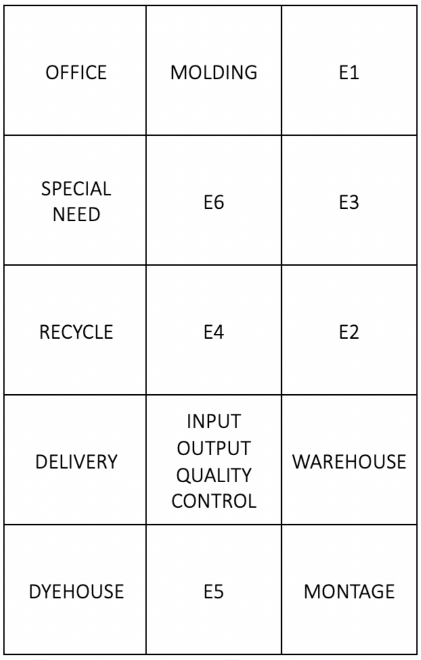
In this section, considering different constraint groups to the existing layout of the enterprise, what different suggestions can be presented is examined. In this direction, first, the objective function value was calculated for the existing layout plan of the factory. Afterward, seven different scenarios (alternatives) were proposed considering different constraint groups. Each is explained separately below, and the corresponding objective function values were calculated by solving the mathematical models with the CPLEX solver of the GAMS.

First, the objective function value for the existing layout of the factory in Fig. 3 was calculated at 7,696,812. Scenario 1 represents the layout obtained using the proposed mathematical model. The obtained layout plan for Scenario 1 is given in Fig. 4. The objective function value is calculated as 3,066,081. In Scenario 2, injection machines should be located in the same section as the crane line. Hence, these constraints were added to the proposed mathematical model. The layout obtained by Scenario 2 is given in Fig. 5. The objective function value for this scenario was 3,150,009. In Scenario 3, the molding room must be on the crane line for the molds to be transported by crane. In this case, the layout in Fig. 6 was formed. The objective function value for this scenario was 3,397,668. In Scenario 4, considering the case that the warehouse was not in the middle of the enterprise in the proposed mathematical model, the layout in Fig. 7 was obtained. The objective function value was calculated as 3,951,207 for this scenario. In Scenario 5, the layout that occurs when more than one warehouse is added to the proposed mathematical model is shown in Fig. 8. In this case, the objective function was calculated as 2,933,505. In Scenario 6, the constraints, injection machines, and molding room should be on the crane line, has been added to the proposed mathematical model. This layout is shown in Fig. 9. The objective function is 2,805,210 for this scenario. For Scenario 7, the layout in Fig. 10 was obtained according to the situation that the raw material warehouse, shipment, and final product warehouse are on the left side of the layout. The objective function value is obtained as 2,866,210.



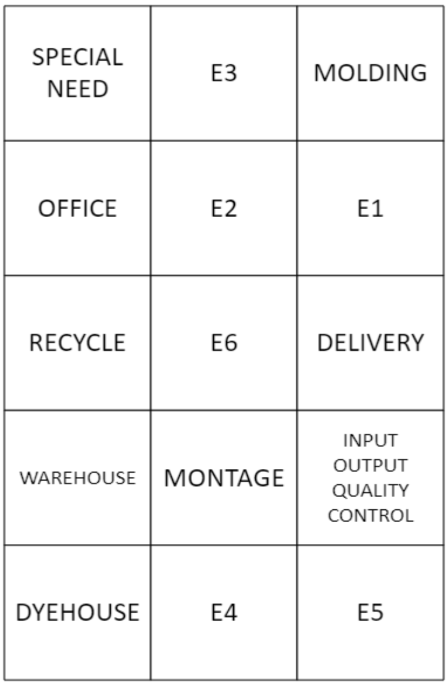
OFFICE	E1	MOLDING
RECYCLE	E4	E2
INPUT OUTPUT QUALITY CONTROL	WAREHOUSE	DYEHOUSE
DELIVERY	MONTAGE	E6
SPECIAL NEED	E5	E3

Fig. 5 Layout for Scenario 2.



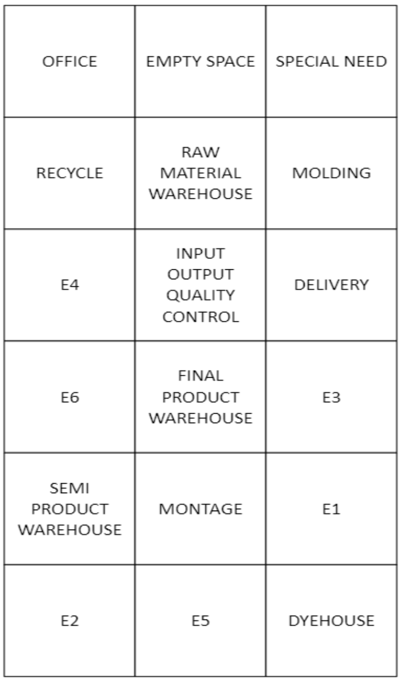
OFFICE	MOLDING	E1
SPECIAL NEED	E6	E3
RECYCLE	E4	E2
DELIVERY	INPUT OUTPUT QUALITY CONTROL	WAREHOUSE
DYEHOUSE	E5	MONTAGE

Fig. 6 Layout for Scenario 3.



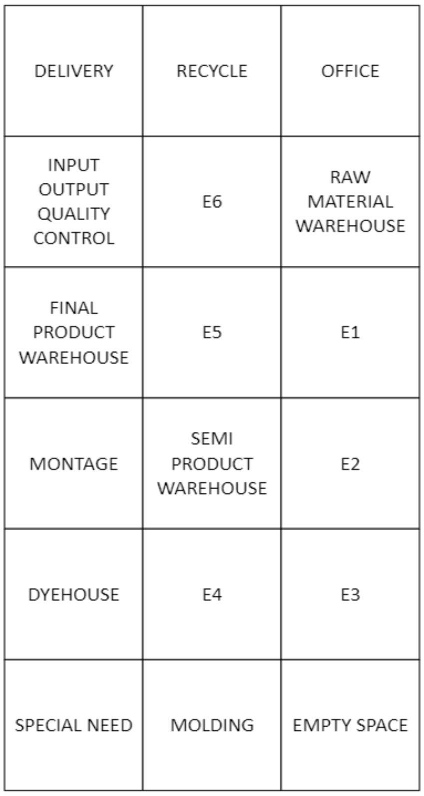
SPECIAL NEED	E3	MOLDING
OFFICE	E2	E1
RECYCLE	E6	DELIVERY
WAREHOUSE	MONTAGE	INPUT OUTPUT QUALITY CONTROL
DYEHOUSE	E4	E5

Fig. 7 Layout for Scenario 4.



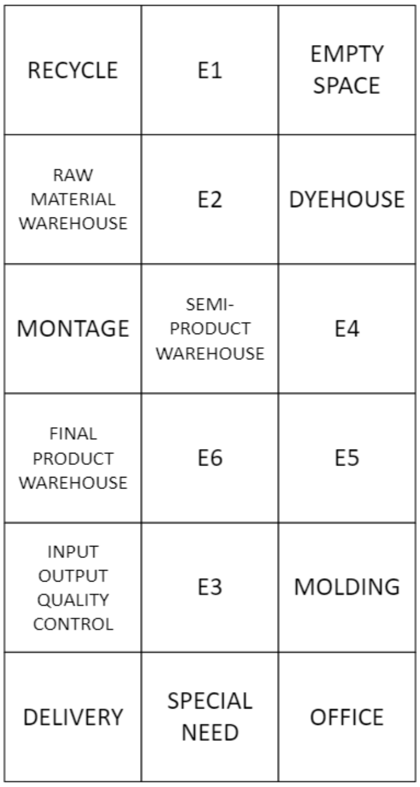
OFFICE	EMPTY SPACE	SPECIAL NEED
RECYCLE	RAW MATERIAL WAREHOUSE	MOLDING
E4	INPUT OUTPUT QUALITY CONTROL	DELIVERY
E6	FINAL PRODUCT WAREHOUSE	E3
SEMI PRODUCT WAREHOUSE	MONTAGE	E1
E2	E5	DYEHOUSE

Fig. 8. Layout for Scenario 5.



DELIVERY	RECYCLE	OFFICE
INPUT OUTPUT QUALITY CONTROL	E6	RAW MATERIAL WAREHOUSE
FINAL PRODUCT WAREHOUSE	E5	E1
MONTAGE	SEMI PRODUCT WAREHOUSE	E2
DYEHOUSE	E4	E3
SPECIAL NEED	MOLDING	EMPTY SPACE

Fig. 9 Layout for Scenario 6.



RECYCLE	E1	EMPTY SPACE
RAW MATERIAL WAREHOUSE	E2	DYEHOUSE
MONTAGE	SEMI-PRODUCT WAREHOUSE	E4
FINAL PRODUCT WAREHOUSE	E6	E5
INPUT OUTPUT QUALITY CONTROL	E3	MOLDING
DELIVERY	SPECIAL NEED	OFFICE

Fig. 10 Layout for Scenario 7.

The obtained results are summarized in Table 2. This table consists of six columns. The first column is the current layout or scenario name. In the second column, there are the objective function values, the change of the objective function compared to the previous scenario (if there is a worsening, it is given with a minus sign), what it is compared to, the improvement percentage (negative values mean worsening) and the last explains features of the relevant scenario included. Scenarios can be divided into two groups: the first four scenarios in the first group and the others in the second. The most significant difference between these two groups is that there is one warehouse in the first group and three warehouses in the second group. As constraints were added to the model, the impact of these changes on the objective function and the changes in facility layout were examined, leading to the creation of new constraints. As seen from the table, the optimum scenario is six according to the objective function value. We can also see that transportation increases if there is only one warehouse. Of course, these scenarios can be expanded and are open to change for further analysis.

Table 2. Comparison of the Current Layout and the Scenarios

	Objective Function Value	Lagged Difference	Compared to	Improvement Percentage	Explanations
Current Layout	7,696,812	-	-	-	-
Scenario 1	3,066,081	-4,630,731	Current Layout	60%	with a single warehouse without adding other restrictions
Scenario 2	3,150,009	+83,928	Scenario 1	-2.7%	the restriction that injection machines must be on the same line as the crane line has been added.
Scenario 3	3,397,668	+247,659	Scenario 2	-7.8%	the restriction that the molding room must be on the same line as the crane line has been added.

	Objective Function Value	Lagged Difference	Compared to	Improvement Percentage	Explanations
Scenario 4	3,951,207	+553,539	Scenario 3	-16%	the warehouse should not be in the center of the layout restriction has been added.
Scenario 5	2,933,505	-1,017,702	Scenario4	25%	the warehouse was divided into three and added to the model as raw material warehouse, semi product warehouse and final product warehouse.
Scenario 6	2,805,210	-128,295	Scenario 5	4.3%	the restriction that the injection machines and molding room must be on the same line with the crane line has been added.
Scenario 7	2,866,210	+61,000	Scenario 6	-2.1%	the restriction that the raw material warehouse, shipping and final product warehouse should be located on the left side of the facility plan has been added.

4. Conclusion

Since the facility layout affects the costs directly, it is very important for a lot of companies. The fact that it is almost impossible to make changes in the design after the facility layout is implemented in real life, increases the importance of this design even more.

In this study, alternative layout plans for a plastic injection factory was produced. When the objective function values of the current layout and Scenario 1 were compared, an improvement of around 60% was occurred. The obtained results showed that the layout for Scenario 1 was significantly better than the current layout. Scenario 2, on the other hand, involved determining the location of the crane line according to Scenario 1. Changing the layout of Scenario 1, which has a location outside the crane line, is necessary to avoid infrastructure costs. In this case, there was a 2.7% deterioration in the objective function. It is observed that Scenario 2 places the warehouse in the middle because the warehouse transports are high, making it difficult for shipments or raw materials to arrival. The restriction that the warehouse was not in the middle had been added to Scenario 3. It resulted in a 7.8% deterioration in the objective function. In addition to Scenario 3, the molding room must be on the crane line. This constraint is important since the molds are taken to the injection machines by crane. When this constraint was added in Scenario 4, a 16% deterioration occurred in the objective function value. In Scenario 5, it is suggested to add three different types of warehouses to the facility since lean production is implemented in the factory as opposed to a single warehouse layout. These three types of warehouses have been added to the model because raw materials, semi-finished products, or finished products are stored in the warehouse after each process. When the model was run without any constraints, a 25% improvement was observed compared to Scenario 4. In Scenario 6, an improvement of 4.3% was observed in the objective function value when the constraint on the crane and molding room location was added to Scenario 5. This situation is due to the placement of units that do not have any transport with other units rather than the addition of constraints. In Scenario 7, the constraints of Scenario 6's raw material warehouse shipment and end product warehouse being on the left side of the building were added. This constraint was intended to ensure that the products coming to or leaving the facility were made from a single side of the facility. The objective function value deteriorated by 2.1% compared to Scenario 6. As a result of these Scenario trials, it is appropriate to choose Scenario 6 with the best objective function value when it comes to transports. However, if there is a raw material arrival or final product output from the left side of the facility for shipment, Scenario 7 gives the most suitable placement for what is desired. The aspect that is open to improvement in the study is that more is needed to reflect the reality arising from the equal areas brought by the quadratic assignment problem. A definite layout plan has yet to be established. The created plan can be implemented approximately.

Future studies can focus on transferring unrelated units. It is very difficult to find the best solution for NP-hard problems such as the facility layout problem. Better results can be obtained by solving the large-sized problems with heuristic methods. In addition, a model flow chart was created according to the data of the parts used in the ABC analysis and the routes of these parts. A better result can be achieved if more part data is added to the model.

References

[1] N.A. Türkmen and S.N. Oğulata, "Hastane İş Akış ve Yerleşim Değerlendirmesi," Master's thesis, Çukurova University, Adana, Turkey, 2008.

[2] O. Karadaş, "Tesis Yerleşim Planlaması ve Bir İşletmede Uygulanması," Master's thesis, Yaşar University, İzmir, Turkey, 2016.

[3] M. Yurdakul, S. Eşkin, and Y.T., İç, "Bir İmalat Sisteminin Yerleşim Düzeninin İyileştirilmesi," *TÜBAV Bilim,* vol. 2, no. 4, pp. 399–411, 2009.

[4] N. Koçak and A. Tüzemen, "Çelik Kapı Sektöründe Tesis Yerleşim Problemi: Bir Uygulama," *Journal of Business in the Digital Age*, vol. 2, no. 3, pp. 129–135, Dec. 2020, doi:10.46238/jobda.833062.

[5] İ. Durak and M.S. Yıldız, "P- Medyan Tesis Yeri Seçim Problemi: Bir Uygulama," *International Journal of Alanya Faculty of Business*, Vol. 7, no. 2, pp. 43–64, 2015.

[6] H.B. Ece, "A Mixed Linear Integer Model for Military Facility Layout Optimization Problem," Master's thesis, Middle East Technical University, Ankara, Turkey, 2015.

[7] H. Karateke and R. Şahin, "A Two-Stage Approach for the Multi-Floor Facility Layout Problem: Benders Decomposition Algorithm," *Journal of the Faculty of Engineering and Architecture of Gazi University*, vol. 36, no. 2, pp. 953–970, Mar. 2021, doi: 10.17341/gazimmfd.734297.

[8] R. Arslan, "Süreç Optimizasyonu: Tesis İçi Ürün Taşıma Operasyonunun Milk-Run ile Optimizasy*onu*," Master's thesis, Gebze Technical University, Gebze, Turkey, 2018.

[9] V. Yiğit, O. Türkbey, "Tesis Yerleşim Problemlerine Sezgisel Metotlarla Yaklaşım," *Journal of the Faculty of Engineering and Architecture of Gazi University*, vol. 18, no. 4, pp. 45–56, Apr. 2003.

[10] S. Kayserili, "Mobilya Sektöründe Faaliyet Gösteren Bir Firmada Tesis Yerleşimi Uygulaması," Master's thesis, Kırıkkale University, Kırıkkale, Turkey, 2017.

[11] M. Akça, "Çok Amaçlı Tesis Yerleşim Problemi: Matematiksel Model Tabanlı Sezgisel Yöntem ve Bir Uygulama," Master's thesis, Gazi University, Ankara, Turkey, 2017.

[12] S. Aydın, "*Üretim Yönetimi*," Anadolu University Open Education Faculty, Eskişehir, Turkey, 2018.

[13] O. Karadaş, "Tesis Yerleşim Planlaması ve Bir İşletmede Uygulanması," Master's thesis, Yaşar Üniversitesi, Izmir, Turkey, 2016.

[14] A.N. Adıgüzel, "Tesis Yerleşimi Düzenlenmesi Problemi İçin Bir Tabu Arama Sezgisel Algoritması," Master's thesis, İstanbul Üniversitesi Fen Bilimleri Enstitüsü, İstanbul, Turkey, 2012.

[15] B. Turanoğlu, "Fabrika İçi Yerleşim Düzeni ve Bir İşletmede Uygulaması," Master's thesis, Ataturk University, Erzurum, Turkey, 2012.

[16] M. Beğik, M. Hamurcu, and T. Eren, "Stok Kontrolde Abc Analizi Ve Analitik Ağ Süreci Yönteminin Isı Cihazları Firmasında Uygulanması," *Kırıkkale Üniversitesi Sosyal Bilimler Dergisi*, vol. 7, no. 1, pp. 197–216, 2017.

[17] M. Erdoğan, Ö.N. Bilişik, and Baraçlı "A Customer Satisfaction Model Based on Fuzzy TOPSIS and SERVQUAL Methods," *5th International Conference on Applied Operational Research - ICAOR'13*, 2013, pp.74–83.