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Evaluation of Cost-Increasing Wastes in Manufacturing Enterprises Using Integrated AHP-DEMATEL Methods

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ABSTRACT

Particularly in highly competitive business environments, ensuring efficiency and productivity in production processes is of great importance for enterprises to achieve their goals. From this perspective, identifying and eliminating wastes that lead to inefficiency in processes is critically important for businesses. This study aims to identify cost-increasing wastes in manufacturing enterprises, assign weights to them, and determine their levels of influence. In this context, six main criteria identified through an extensive literature review were analyzed using the AHP (Analytic Hierarchy Process) and DEMATEL methods after obtaining expert opinions. The findings obtained from the AHP analysis revealed that overproduction was the most important waste encountered in production processes. Increased waiting times and unnecessary transportation activities followed this criterion, whereas unnecessary movement had the lowest priority weight. The DEMATEL results showed that unnecessary transportation activities were the most significant affecting factor, while unnecessary movement was the most significant affected factor.

Keywords: Production, Waste, Lean Production, Multi-Criteria Decision Making, AHP, DEMATEL

1. INTRODUCTION

The objective of enterprises is to deliver products that meet customer expectations in terms of quality, speed, timeliness, and low cost. Cost elements arising from waste, particularly in production processes, create pressure on product prices. As a result of this pressure, enterprises face many adverse consequences, ranging from reduced competitiveness to declines in sales and market share. Eliminating these problems is closely related to ensuring that production processes operate smoothly and efficiently. All forms of waste and activities that do not add any real value to the final product should be reduced or, where possible, eliminated in order to lower production costs (Fitriadi & Wijayanti, 2024).

Among the wastes encountered in production processes, production-related wastes occupy a prominent place. Producing goods with more raw materials than necessary, although the same output could be achieved with less, increases raw material waste. This leads to inefficient use of raw materials in enterprises and raises costs (Ardhyani et al., 2023). In addition, overproduction also constitutes an important source of waste, as production beyond demand leads to inventory accumulation.

Another significant category of waste in production processes is waiting-related waste. In particular, faulty production planning increases machine idle times and causes delays in processes. This may lead to losses of both time and labor for enterprises. In addition, approval waiting times arising from regulatory requirements and delays in correspondence are other developments that generate waste (Godswill et al., 2023; Aziz & Hafez, 2013: 681). Breakdowns or part replacements caused by untimely maintenance and repair of machines may stop processes or cause idle time, thereby interrupting production (Watts et al., 2023; Yorke & Bodek, 2005: 163). On the other hand, under-ordering, over-ordering, or incorrect ordering resulting from inadequate communication with suppliers also appear as supply-related wastes (Gavilan & Bernold, 1994).

It is also possible to state that wastes arising from unnecessary transportation have negative effects on production processes. Problems in material flow lead to the unnecessary transportation of materials and equipment between processes. As unnecessary transportation increases, problems such as labor loss and time loss emerge (Çanakçıoğlu, 2019: 274). In addition, poor in-plant layout planning that forces machines to be relocated continuously not only disrupts processes but also causes machine failures. Likewise, the constant movement of employees within the factory due to poor planning leads to excessive fatigue and time loss (Al-Aomar, 2012: 107; Polat & Ballard, 2003: 321).

Wastes arising from poor inventory management are also among the wastes encountered in production processes. Defective products resulting from faulty production planning lead to substantial financial losses and costs (Bajjou et al., 2017: 174). In addition, storage needs arising from unnecessary inventories due to physical inadequacies constitute another source of waste for enterprises. High storage costs force enterprises to dispose of excess inventories at low prices, which in turn increases costs (Aziz & Hafez, 2013: 684).

Errors caused particularly by inexperienced and unskilled employees make process improvement necessary and lead to the repetition of processes. Likewise, problems resulting from mistakes overlooked during the quality control stage also impose high costs on enterprises (Ansah et al., 2016: 786). In addition, occupational accidents arising from inadequate occupational safety reduce employees' morale and motivation and lower their performance. Furthermore, insurance payments, hospital expenses, and compensation resulting from increasing occupational accidents create significant costs for enterprises (Bajjou et al., 2017: 174).

Increasing waste has led enterprises to seek new approaches, and at this point they have begun to benefit from lean production in order to identify and eliminate wastes arising from production, delays, waiting, and breakdowns in production processes (Rahman et al., 2013: 174). Lean production is an effective tool used in the manufacturing and service sectors to combat non-value-adding activities and waste (Nandakumar et al., 2020: 1217). Lean production aims to improve the performance and efficiency of the production system by eliminating waste in processes. At the same time, this perspective seeks to incorporate practices that enhance customer value into processes and to achieve quality at the source through continuous improvement in business processes (Sun, 2011: 160; Mundra & Mishra, 2020: 2156). Lean production accelerates lead times and enhances competitiveness by ensuring the most effective use of existing resources and by reducing inventory through the elimination of activities that do not create value in processes (Moldner et al., 2020: 233).

This study aims to identify the wastes that hinder enterprises from achieving the speed, quality, and cost advantages necessary to sustain their operations and to rank these wastes according to their weights. Within this scope, six main criteria related to waste, identified through the literature review and expert opinions, were analyzed using the AHP and DEMATEL methods. It is believed that the findings of the study will help decision-makers develop priority-based strategies in their decisions regarding the elimination of waste. In addition, given the limited number of studies in the literature that jointly employ the AHP and DEMATEL methods, this study occupies an important place.

2. LITERATURE REVIEW

This section presents several previous studies on wastes arising in production processes that constitute significant cost factors.

In their study, Ayçin and Özveri (2016) aimed to reduce waste and improve performance through lean production practices. Their findings, obtained using DEMATEL, one of the multi-criteria decision-making methods, indicated that product and process defects, excess inventory, and wastes arising from overproduction had high levels of importance. In their study, Rawabdeh (2005) developed a model related to wastes encountered in the workplace and used the survey method to examine the relationships among overproduction, processing, inventory, transportation, defective production, waiting, and unnecessary movement. Al-Aomar (2012), in his study investigating wastes in the construction sector, stated that production defects were among the most significant wastes.

Nassri et al. (2021) used the survey method in their study investigating labor waste. Their findings revealed that unnecessary movement, waiting, and indirect work led to the highest levels of labor waste. Salhieh et al. (2019) employed the Delphi method to identify and rank the seven deadly wastes encountered in a factory environment. Sternberg et al. (2013) investigated waste in motor carrier operations through qualitative and quantitative methods and emphasized the existence of supply-related wastes. Goshime et al. (2019), in their qualitative study aimed at eliminating wastes, highlighted the success of lean production in addressing space waste, material waste, and labor waste.

In a survey study conducted on 421 enterprises operating in India, Phogat and Gupta (2019) concluded that inventory waste was the greatest source of waste. They also found that processing waste, waste arising from breakdowns caused by insufficient maintenance, transportation waste, and unnecessary movement waste were equally important. Widodo et al. (2021), in their study aimed at identifying wastes in order to improve business processes, stated that labor-related wastes, in particular, create significant costs for enterprises.

Several studies conducted using the AHP (Analytic Hierarchy Process) method, which is also employed in the present study, are also mentioned here. Nguyen et al. (2018) utilized the AHP method to evaluate complexities arising in construction projects. Sequeira et al. (2021) used AHP to assess the decisions required for the redesign of production processes. Singh et al. (2020) employed AHP to evaluate green manufacturing parameters; Rangone (1996) used it to assess the overall performance of manufacturing departments; and Singh et al. (2019) used the AHP method to evaluate the determinants of sustainable manufacturing among Indian cement producers.

Sodhi et al. (2020) employed AHP to evaluate barriers to the implementation of waste management techniques in the Indian manufacturing sector; Singh and Kumar (2013) used it to measure the level of utilization of advanced technologies; and Kumar et al. (2020) benefited from AHP to weight the criteria necessary for the successful implementation of agile manufacturing.

3. METHOD

In this study, the AHP (Analytic Hierarchy Process) method was employed to weight the wastes arising in the production process, while the DEMATEL method was used to determine the levels of influence of these wastes.

3.1. Analytic Hierarchy Process (AHP)

Manufacturing enterprises face difficulties in identifying indicators with relatively high effects in terms of sustainability. Such weighting processes may become highly complex because they involve both tangible and intangible aspects. In addition, evaluations are based on different value judgments and scenarios (Heijungs et al., 2010: 425). For these reasons, the Multi-Criteria Decision-Making (MCDM) method is highly suitable for this and similar studies (Herva & Roca, 2013: 357).

The AHP method is one of the methods used to weight criteria. Based on psychological and mathematical foundations, the AHP method involves the hierarchical comparison of criteria and their related sub-criteria (Saaty, 2001). Successfully used in solving many decision-making problems, the AHP method has important advantages in terms of ease of application, repeatability, support for expert judgment, consistency of results, and the modeling of complex problems (Narasimhan, 1983).

The mathematical procedures applied within the scope of AHP are followed as shown below (Uludağ & Doğan, 2021: 288–289):

Stage 1:

Let $a_1, a_2, a_3, \ldots, a_n$ denote the decision criteria; let $w_1, w_2, w_3, \cdots, w_n$ denote the weights of the criteria; and let $i, j = 1,2, \ldots, n \text{ and } \forall i, j \in A$. The pairwise comparison matrix represented by A is given in Equation (1.1).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ 1/a_{1j} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ 1/a_{1n} & \cdots & 1/a_{in} & \cdots & a_{nn} \end{bmatrix}, \quad i, j = 1, \ldots, n. \qquad \textbf{(1.1)}$$

Stage 2:

The main problem in the Analytic Hierarchy Process is the calculation of the value $a_{ij} \cong w_i / w_j$. The weight matrix represented by W is shown in Equation (1.2).

$$w_1 \ldots w_j \ldots w_n$$

$$W = \begin{array}{c} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{array} \begin{bmatrix} w_1/w_1 & \dots & w_1/w_j & \dots & w_1/w_n \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \dots & w_i/w_j & \dots & w_i/w_n \\ \vdots & & \vdots & & \vdots \\ w_n/w_1 & \dots & w_n/w_j & \dots & w_n/w_n \end{bmatrix} \quad \textbf{(1.2)}$$

Stage 3:

Multiplying the pairwise comparison matrix A by the weight vector W is equal to multiplying the eigenvalue of A by the weight vector W. If the eigenvalue of A is n, then w is the associated eigenvector. This relationship is shown in Equation (1.3).

$$\begin{array}{c|ccccc} & A_1 & \dots & A_j & \dots & A_n \\ \hline A_1 & w_1/w_1 & \dots & w_1/w_j & \dots & w_1/w_n \\ \vdots & \vdots & & \vdots & & \vdots \\ A_j & w_i/w_1 & \dots & w_i/w_j & \dots & w_i/w_j \\ \vdots & \vdots & & \vdots & & \vdots \\ A_n & w_n/w_1 & \dots & w_n/w_j & \dots & w_n/w_n \end{array} \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix}, \ (i,j = 1,2,\dots,n). \quad \textbf{(1.3)}$$

Stage 4:

According to the AHP method, while the formula shown in Equation (1.3) provides an advantage for the solution, it also requires a broader analytical perspective. In the matrix $A = (a_{ij})$, where $i,j = 1,2,\dots,n$, e $a_{ij} = w_i/w_j$. Matrix A is a consistent matrix with positive entries throughout, satisfying the reciprocity principle, and for $i,j,k = 1,2,\dots,n$, it is consistent due to the equality a_{ij}=1/a_{ij}. The formula shown in Equation (1.4) is used to calculate the eigenvector W; that is, the Perron vector of matrix A is computed (Uludağ & Doğan, 2021: 291).

$$Aw = \lambda_{max} w, \quad w_i = \frac{\sum_j^n a_{ij} w_j}{\lambda_{max}}, \quad (\forall i = 1,2,\dots,n) \quad \textbf{(1.4)}$$

Stage 5:

After calculating the eigenvector W, it is necessary to determine whether matrix A is consistent. matrisinin The consistency of the matrix is assessed at the end of the process. According to the AHP method, in order for the inconsistency in matrix A to be detected by means of the $\lambda_{max} - n$ criterion, matrix A must satisfy the equality $\lambda_{max} = n$ in order to be consistent. Therefore, in a positive and reciprocal matrix A, $\lambda_{max} \geq n$. In the next step of the method, two measures are used: the Consistency Index (C.I.), shown in Equation (1.5), and the Consistency Ratio (C.R.), shown in Equation (1.6).

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad \textbf{(1.5)}$$

$$CR = CI/RI \quad \textbf{(1.6)}$$

To calculate the CR shown in Equation (1.6), the Random Consistency Index (R.I.) values are used. These values are presented in Table 1.

Table 1. Random Index (R.I.)

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.52	0.89	1.11	1.25	1.40	1.45	1.45	1.49

Within the scope of the study, the consistency ratios of the criteria used were found to be < 0.10. A consistency ratio, namely C.R., equal to or less than 0.10 indicates that the judgments are consistent. Otherwise, the decision-makers need to revise their pairwise comparisons (Uludağ & Doğan, 2021).

3.2. DEMATEL Method

DEMATEL Method is one of the most effective methods, which can be used to analyze direct and indirect relations between the components of a system according to their types and importance degrees (Geng & Chu, 2012). DEMATEL Method, which is one of the most important and most frequently used multi-criteria decision-making techniques, is a systematic method making use of expert evaluations that may be obtained in clear numerical values to develop a series of relationship matrices (Maduekwe & Oke, 2021). DEMATEL is a comprehensive method for constructing and analyzing a structural model that has causal relations between complex factors. It allows administrators to divide the related variables into cause-effect groups to understand the causal relations between the variables better (Jalal & Shoar, 2017).

The DEMATEL Method is mostly used for decision-making qualifications based on the pairwise comparison. The different steps in the DEMATEL Method are as follows (Wu & Chang, 2015; Nilashi et al., 2015)

Step 1: Creating the Direct Relationship Matrix (D)

$$D= \begin{bmatrix} d_{11} & d_{1j} & \dots & d_{1s} \\ d_{i1} & d_{ij} & \dots & d_{is} \\ \vdots & \vdots & \dots & \vdots \\ d_{s1} & d_{sj} & \dots & d_{ss} \end{bmatrix} \text{(i,j=1,2…,s)}$$

At this stage, a Direct Relationship Matrix is created based on expert opinions. Here, the factors are compared in pairs with an effect ranging between 0 and 4. DM1, DM2, and DM3 represent decision-makers. The first stage is completed by taking the arithmetic averages of the answers given by all the decision-makers to form the Direct Relationship Matrix. 0 means no effect, and 4 shows a high effect level.

Step 2: Normalization of the Decision Matrix

$$n = \frac{1}{max \sum_{j=1}^{s} dij} \text{,(i, j=1,2,.. s)} \qquad \tilde{D} = n(.)D$$

At this stage, the direct relation matrix shown with *D* is normalized, and the normalized direct relation matrix shown with $\tilde{D}$ is created.

Step 3: Creating the Total Relationship Matrix

$$T = \tilde{D}(I - \tilde{D})^{-1}$$

The Total Relationship Matrix represented with T is created in this step.

Step 4: Creating the Cause and Effect Matrix

$$V = \left[\sum_{j=1}^{s} t_{ij}\right]_{sx1} \qquad Y = \left[\sum_{j=1}^{s} t_{ij}\right]_{1xs} \qquad \propto = \frac{\sum_{i=1}^{s}\sum_{j=1}^{s}[t_{ij}]}{s}$$

Calculating the alpha (threshold value) is performed at this stage where vector values are also found to draw the diagram, which also shows the interaction between the system elements. The X vector represents the sum of the lines in the total relationship matrix, and the Y vector represents the sum of the columns. The horizontal axis vector (V+Y), which shows how important the criteria are, is also calculated at this stage. Similarly, the vertical axis vector (V-Y) is calculated and determined according to the threshold value. If the effect of this vector is positive, it indicates that the criterion is included in the affecting group (cause), whereas if it is negative, it indicates that the criterion is included in the affected group (effect). The (V+Y, V−Y) dataset is used to construct the impact-relation diagram (Uludağ & Doğan, 2021: 331).

Step 5: Obtaining the Internal Dependency Matrix and the diagram showing the effect relationship

$$V_i + Y_i, \qquad V_i - Y_i \qquad C_i = \sqrt{((V_i + Y_i)^2 + (V_i - Y_i)^2)}$$

At this stage, the weight coefficients of the criteria, i.e. C_i values are calculated by using the relevant formula.

Step 6: Determination of criterion weights

$$w_i = \frac{C_i}{\sum_{i=1}^{s} C_i}$$

In the final step, criteria weights obtained by using the formula are normalized with the relevant formula. In this way, the weight of each factor, i.e. the w_i values are calculated.

4. APPLICATION

This section of the study first identifies the wastes encountered in production processes. In this context, an extensive literature review was conducted, and expert opinions were consulted to determine the wastes to be used in the study. Accordingly, six waste criteria representing these wastes were identified and presented in Table 2.

Table 2. Criteria Used in the Study

Criteria	**Sources**
Defective Production	Aziz and Hafez (2013); Ansah et al. (2016); Al-Aomar (2012); Bajjou et al. (2017); Polat and Ballard (2003); Ayçin and Özveri (2016); Rawabdeh (2005); Gavilan and Bernold (1994)
Inventory Errors	
Increased Waiting Times	
Overproduction	
Unnecessary Transportation Activities	
Unnecessary Movement	

After determining the waste criteria to be used in the study, a decision-making group consisting of three individuals from academia and industry was formed. At this stage, the decision-makers were asked to compare the identified indicators and score them on a scale from 0 to 10. The main criteria used in the study were coded as follows: *Overproduction (C1)*, *Increased Waiting Times (C2)*, *Unnecessary Transportation Activities (C3)*, *Inventory Errors (C4)*, *Unnecessary Movement (C5)*, *and Defective Production (C6)*.

The findings related to the AHP method are presented below:

Within the scope of the study, the weights of the main criteria were first calculated, followed by the weights of the sub-criteria associated with each main criterion. To calculate the weights of the main criteria and sub-criteria, the opinions of three experts were obtained, and these decision-makers were denoted as DM1, DM2, and DM3. The arithmetic mean of the opinions of each decision-maker was then calculated. The tables regarding the criterion weights are presented below.

Table 3. Initial Matrix for the Main Criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
C1	1.00	3.00	6.00	3.00	5.00	2.00
C2	0.39	1.00	5.00	4.00	5.00	2.00
C3	0.18	0.19	1.00	6.00	4.00	5.00
C4	0.39	0.28	0.19	1.00	2.00	5.00
C5	0.19	0.21	0.24	0.65	1.00	1.33
C6	0.65	0.65	0.20	0.21	0.83	1.00
Total	2.80	5.33	12.63	14.86	17.83	16.33

Table 4. Normalized Decision Matrix for the Main Criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
C1	0.36	1.07	2.14	1.07	1.79	0.71
C2	0.14	0.36	1.79	1.43	1.79	0.71
C3	0.06	0.07	0.36	2.14	1.43	1.79
C4	0.14	0.10	0.07	0.36	0.71	1.79
C5	0.07	0.08	0.09	0.23	0.36	0.48
C6	0.23	0.23	0.07	0.08	0.30	0.36

Table 5. Priority Vector for the Main Criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**w**	a.w.
C1	0.05	0.14	0.27	0.14	0.23	0.09	0.43	4.723
C2	0.02	0.05	0.23	0.18	0.23	0.09	0.37	3.564
C3	0.01	0.01	0.05	0.27	0.18	0.23	0.35	2.309
C4	0.02	0.01	0.01	0.05	0.09	0.23	0.19	1.054
C5	0.01	0.01	0.01	0.03	0.05	0.06	0.08	0.541
C6	0.03	0.03	0.01	0.01	0.04	0.05	0.08	0.765

The λmax values of each main criterion and sub-criterion were calculated. As required by the method, the consistency index (CI) and consistency ratio (CR) were also calculated for each main criterion and for the sub-criteria associated with each main criterion, and these were found to be below the threshold value of 0.10. The criterion weights were then determined and interpreted according to their order of importance.

Table 6. Calculation of the λmax Coefficient

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**w**	a.w.	**d**
C1	0.05	0.14	0.27	0.14	0.23	0.09	0.43	4.723	10.983
C2	0.02	0.05	0.23	0.18	0.23	0.09	0.37	3.564	9.633
C3	0.01	0.01	0.05	0.27	0.18	0.23	0.35	2.309	6.597
C4	0.02	0.01	0.01	0.05	0.09	0.23	0.19	1.054	5.547
C5	0.01	0.01	0.01	0.03	0.05	0.06	0.08	0.541	6.768
C6	0.03	0.03	0.01	0.01	0.04	0.05	0.08	0.765	9.562
								λmax=	1.364

Accordingly, the main criteria related to the wastes encountered in production processes were ranked as C1 > C2 > C3 > C4 > C5 > C6. Based on the AHP weights, it was concluded that the most significant waste was Overproduction.

Table 7. Direct-Relation Matrix

Direct-Relation Matrix						
	C1	C2	C3	C4	C5	C6
C1	1.000	2.667	5.667	2.667	5.333	1.667
C2	0.389	1.000	5.333	3.667	5.000	1.667
C3	0.178	0.189	1.000	5.667	4.333	5.333
C4	0.389	0.278	0.178	1.000	1.667	5.000
C5	0.189	0.206	0.233	0.667	1.000	1.333
C6	0.667	0.667	0.200	0.206	0.833	1.000

At this stage, the direct-relation matrix obtained as a result of the decision-makers' comparison of the factors was first constructed. The scoring in the pairwise comparison scale was used to compare the factors. In this context, three decision-makers compared the criteria. Subsequently, the arithmetic mean of the responses provided by each decision-maker was calculated, and the direct-relation matrix was established.

Table 8. Determination of the Row Sums and Column Sums of the Direct-Relation Matrix and the Maximum Value

Determination of the Row Sums and Column Sums of the Direct-Relation Matrix and the Maximum Value							
	C1	C2	C3	C4	C5	C6	Total
C1	0.000	2.667	5.667	2.667	5.333	1.667	**18.000**
C2	0.389	0.000	5.333	3.667	5.000	1.667	16.056
C3	0.178	0.189	0.000	5.667	4.333	5.333	15.700

C4	0.389	0.278	0.178	0.000	1.667	5.000	7.511
C5	0.189	0.206	0.233	0.667	0.000	1.333	2.628
C6	0.667	0.667	0.200	0.206	0.833	0.000	2.572
Total	1.811	4.006	11.611	12.872	**17.167**	15.000	62.467

At this stage, the values in the direct-relation matrix were normalized, and the normalized direct-relation matrix was obtained. For this process, Formula [2] presented in Step 2 was applied. In order to calculate the normalized values, the row and column totals of the direct-relation matrix were calculated, and the maximum value among them was identified. This maximum value was used in the normalization process (17.167).

Table 9. Normalized Direct-Relation Matrix

Normalized Direct-Relation Matrix						
	C1	C2	C3	C4	C5	C6
C1	0.000	0.155	0.330	0.155	0.311	0.097
C2	0.023	0.000	0.311	0.214	0.291	0.097
C3	0.010	0.011	0.000	0.330	0.252	0.311
C4	0.023	0.016	0.010	0.000	0.097	0.291
C5	0.011	0.012	0.014	0.039	0.000	0.078
C6	0.039	0.039	0.012	0.012	0.049	0.000

In Step 3, Formula [3] was applied to construct the Total-Relation Matrix. In the formula, the term "total" is represented by T. The Total-Relation Matrix obtained by applying the required stages is presented in Table 10.

Table 10. Total-Relation Matrix

Total-Relation Matrix						
	C1	C2	C3	C4	C5	C6
C1	0.000	0.030	**0.138**	**0.057**	**0.168**	**0.039**
C2	0.001	0.000	**0.110**	**0.079**	**0.135**	**0.035**
C3	0.000	0.001	0.000	**0.125**	**0.088**	**0.146**
C4	0.001	0.001	0.000	0.000	0.015	**0.097**
C5	0.000	0.000	0.000	0.002	0.000	0.008
C6	0.002	0.002	0.001	0.001	0.005	0.000
Total	0.004	0.033	0.250	0.264	0.410	0.326

In order to construct the Total-Relation Matrix, the inverse matrix obtained had to be multiplied by the normalized direct-relation matrix. The column sums of the Total-Relation Matrix were also calculated at this stage, since they would be used in the next step of the DEMATEL method to calculate the $\boldsymbol{Y}$ vector.

In Step 4, the relation diagram showing the interactions among the elements of the system was constructed. The row sums of the Total-Relation Matrix (the $\boldsymbol{V}$ vector) and the column sums (the Y vector) were calculated using Formula [4]. Then, the V and Y vectors were added to obtain the horizontal-axis vector $(V + Y)$, which indicates the degree of importance of the criterion. Similarly, the Y vector was subtracted from the V vector to obtain the vertical-axis vector $(V - Y$). A negative value of this vector indicates that the criterion belongs to the *affected* group, whereas a positive value indicates that it belongs to the *affecting* group (Uludağ & Doğan, 2021: 340). The $(V + Y, V - Y)$ dataset is used to construct the impact-relation diagram. In addition, the alpha (threshold) value was calculated at this stage, and in Table 11, values exceeding the $\propto$ value were indicated in bold. In order to eliminate minor effects in the dataset and draw the impact-relation diagram, the $\propto$ equation given in Formula [4] was applied ($\propto$**=0,036**).

Table 11. Mutual Influence Among Factors

Mutual Influence Among Factors								
Factors	V Vector	Y Vector	V+Y Vector	V-Y Vector	Effect Type	w	W	W %
C1	0.432	0.004	**0.436**	**0.428**	**Affecting**	**0.611**	0.191	19.1%
C2	0.360	0.033	**0.393**	**0.327**	**Affecting**	**0.511**	0.160	16.0%
C3	0.361	0.250	0.611	**0.111**	**Affecting**	**0.621**	0.195	19.5%
C4	0.114	0.264	0.378	-0.150	Affected	**0.407**	0.127	12.7%
C5	0.012	0.410	0.422	-0.398	Affected	**0.580**	0.182	18.2%
C6	0.009	0.326	0.335	-0.317	Affected	**0.461**	0.145	14.5%
					Total	3.191	1.000	100%

In Step 5, the impact-relation diagram was obtained by following the relevant procedure. Formula [5] was applied to carry out this stage. At the same time, in the next step (Step 6), the criterion weights needed to be determined, and the weights were calculated using Formula [6]. According to the information presented in Tables 10 and 11, the main affecting factor was identified as Unnecessary Transportation Activities, coded as C3, with a weight of w = 0.621. The second affecting factor was determined as Overproduction, coded as C1, with a weight of w = 0.611. The third affecting factor was identified as Increased Waiting Times, coded as C2, with a weight of w = 0.511. Accordingly, the ranking of the affecting factors was determined as C3 > C1 > C2.

When the affected factors are examined, they are ranked from the highest to the lowest according to their weight values (w) as follows: Unnecessary Movement, coded as C5 (w = 0.580), Defective Production, coded as C6 (w = 0.461), and Inventory Errors, coded as C4 (w = 0.407). Accordingly, the ranking of the affected factors is C5 > C6 > C4.

Table 12. Factor Weights

Code	Factors	w	Effect Type
C1	Overproduction	0.611	**Affecting**
C2	Increased Waiting Times	0.511	**Affecting**
C3	Unnecessary Transportation Activities	0.621	**Affecting**
C4	Inventory Errors	0.407	Affected
C5	Unnecessary Movement	0.580	Affected
C6	Defective Production	0.461	Affected

CONCLUSION AND RECOMMENDATIONS

This study identified the wastes frequently encountered in production processes that negatively affect enterprise performance. First, these wastes were weighted by using the AHP (Analytic Hierarchy Process) method, and then their levels of influence were determined by means of the DEMATEL method. Within the scope of the study, six main criteria representing waste were identified on the basis of the literature review and expert opinions. Accordingly, the numerous and structurally complex wastes encountered in enterprises were weighted and ranked according to their levels of importance. By identifying the most important and least important wastes in production processes, the study aimed to support decision-makers in developing strategies for waste reduction.

According to the AHP results, overproduction was identified as the most important waste among the main criteria. It was followed by increased waiting times and unnecessary transportation activities. In contrast, unnecessary movement was found to have the lowest priority weight among the waste criteria. These findings indicate that particular attention should be paid to production planning, process continuity, and material flow in order to reduce waste-related costs in manufacturing enterprises.

The wastes whose weights were determined were subsequently re-evaluated by using the DEMATEL method in order to examine the interactions among the factors. According to the DEMATEL findings, unnecessary transportation activities, overproduction, and increased waiting times were identified as affecting factors, whereas inventory errors, unnecessary movement, and defective production were determined to be affected factors. More specifically, unnecessary transportation activities emerged as the most prominent affecting factor, while unnecessary movement was identified as the most prominent affected factor. This result suggests that inefficient transportation flows may trigger other forms of waste across the system, whereas unnecessary movement is more likely to intensify as a consequence of the interactions among other waste factors.

The findings obtained in this study are partially consistent with the existing literature. In their DEMATEL-based study, Ayçin and Özveri (2016) found that product/process defects had the highest relationship level among the waste types, followed by excess inventory and overproduction. Their results also placed unnecessary transportation, unnecessary movement, and waiting in the lower part of the relation-level ranking. In this respect, the present study is similar in emphasizing the importance of defect-related and inventory-related wastes; however, it differs in the ordering of specific waste categories and in identifying unnecessary transportation activities as the most prominent affecting factor.

Based on the findings of this study, it is believed that enterprises will be able to recognize the relative importance of the wastes that increase costs and reduce competitiveness and performance, and to shape their strategies accordingly. In this way, waste can be addressed more effectively, and production processes can be managed in a more efficient and sustainable manner.

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