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An Integrated QFD-TOPSIS Method for Prioritization of Major Lean Tools: A Case Study

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A B S T R A C T

Selecting the right lean tool is one of the most challenging tasks for decision-makers. This research represents an integration of two methods, Quality Function Deployment (QFD) and TOPSIS, to evaluate and prioritize the lean tools. The aim of this research is to propose an integrated QFD-TOPSIS method for finding and ranking the major wastes on a production floor and also prioritize lean tools for eliminating them. The proposed model consists of House Of Quality (HOQ) to identify major waste signs which transform them into seven wastes. A set of relative weights of the wastes were then determined which were input in the TOPSIS method to prioritize suitable lean tools.

Keywords: Quality function deployment, TOPSIS, HOQ, Lean tools, Waste.

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1. Introduction

The present pattern in industrial organizations has been the expanding accentuation of contending based on improving the features, diminishing time to showcase, cutting costs and furthermore including innovative points of interest. Competition has been rising to see the business transforming from the national to the worldwide dimension and client turning out to be more esteem cognizant and particular to the items that are being purchased. Being concerned about presenting new top-notch items at inexpensive costs, these above-mentioned constraints compel industrial associations to search for new methodologies and techniques for upgrading consumer loyalty, control expenses, amplify benefits, and lift their intensity, while being in a position to acquaint revolutionary item improvements with the marketplace quicker. Their capacity has been some portion of the accomplishment of distinguished associations for offering a vast array for merchandising and administrations of premium standard quicker and at moderate costs [1].

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Slimming costs shall support interest for items or resources, yet it could likewise have an effect on overall revenues in the event that they become unable to make at low expenses.

QFD is an extensive excellent system directed toward satisfying the client. The intent of employing QFD would be to integrate the voice of the client in the numerous stages of the item, system or process development cycle, and to presume if the necessary quality of client is being accomplished. Yoji Akao considered the father of QFD whose job has resulted in its very first execution in the Kobe Shipyard of Mitsubishi Heavy Industries in 1972. The West's curiosity about QFD was inspired by the reports on Toyota's accomplishments in its program between 1977 and 1984. The attainments included a drop in the growth cycle by one third, with a decrease in product development costs by 61 percent, and the virtual removal of rust associated guarantee issues [2]. The HOQ's classical construction is shown in ***Figure 1***.

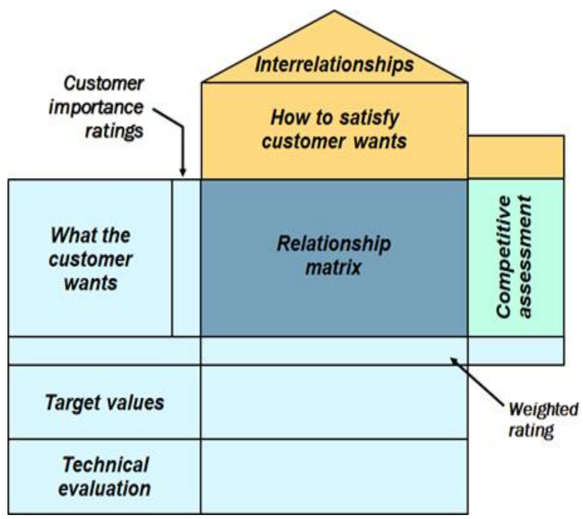


Figure 1. House of Quality (HOQ).

TOPSIS, first developed by Hwang and Yoon [3], is a multi-criteria decision-making tool. It's a process of compensatory aggregation that contrasts a pair of options by identifying weights for each standard, normalizing scores for each standard, and calculating the geometric space between each choice and the perfect choice that's the best score in every criterion. A premise of TOPSIS is the standards that will be monotonically rising or diminishing. Normalization is generally called the criteria or parameters of incongruous measurements in multi-criteria issues.

Compensatory techniques such as TOPSIS make it possible for trade-offs involving standards, in which a bad outcome in one criterion can be neglected with a fantastic result in a different standard. This gives a more realistic kind of modelling compared to non-compensatory procedures, including or excluding other options depending on difficult cut-offs. TOPSIS ponders the shortest Euclidean distance from the ideal solution to have a compound of the best performance values displayed by a candidate-alternative for each of the criteria [1]. Headings are capitalized; all major headings are flushed with the left margin in bold in 12 point fonts. Do not put a period after the text of the heading. Leave one line above a major heading and one line clear below before start of the next paragraph or second-level heading. The whole paper should be written in the "Times New Roman" font. The whole paper should be written in 12 point fonts. Every paragraph should be justified. Line spacing at paragraphs should be 1.15 cm and please leave one line space between two paragraphs.

2. Literature Review

Rawabdeh [4] has developed a collaborative QFD approach to eliminate waste in a shop floor. Three consecutive HOQ were built to identify major wastes and their causes in a production floor, and finally proposed suitable waste elimination tools. In the first house, major waste signs were transformed into seven basic wastes found on a shop floor and those wastes were prioritized according to their relative weight. The second house was built with input from the first house, the seven wastes, and transformed into main causes of the wastes. The causes were classified and prioritized similarly. Finally, a third house was built to find out suitable waste elimination tools where input was the major cause and output was prioritized by lean tools. Pang et al. [5] suggested a revolutionary integrated QFD model and TOPSIS method in the performance selection of manufacturing for the quality of product design. For achieving their desired aim, they used the QFD model for obtaining the absolute weight criteria of EDRs and developed the HOQ for dealing with uncertain information of various types. To analyze the decision process of design quality of product design, the TOPSIS method was used. The result obtained from best alternative through aggregate analysis of the result.

QFD method was united with TOPSIS methodology and its representation was suggested [1]. A case study of finding the supplier with better representation was emerged with considering nine factors, eight disparate criteria, and cost factor. Non-dimensional selection index was used for finding the desired objectives. It was Saaty's 9-point scale for transforming subjective criteria and getting judgmental values. A novel hybrid representation was suggested for supplier selection based on confederate Multiple Criteria Decision Method (MCDM) in the IT area and applied to a private bank on Iran as a case study [6]. QFD and TOPSIS method integrated and obtained the model used regarding opinions of employers on supplier qualification of information technology to the technical requirement in banks. Kavosi et al. [7] suggested a QFD-TOPSIS model for designing television in a company of Iran. The model incorporated cost and environmental factors in QFD using the TOPSIS method.

Hojjati and Anvary [8] proposed an integrated algorithm simultaneously MCDM method and Borda method to evaluate assets and ranking of the major lean tools featuring attributes including lead time, defect, cost, and value. The integrated two methods were SAW and TOPSIS. The results of scores of lean tools for different criteria were dissimilar. For decreasing lead time, the ranking was as follows: Continuous flow, pull system, set up reduction cellular manufacturing, and TPM. For other attributes, the ranking was also divergent. The ultimate highest ranking of the lean tools was continuous flow, pull system, six sigma, TPM, set up reduction, and levelling.

A combined QFD-TOPSIS model was suggested by Karimi et al. [9], which was applied in an industry of designing products according to customer requirements. It was a case study in Sum Service Company. Design requirements were established with QFD and TOPSIS were derived from calculating relative importance. Mohanraj et al. [10] suggested a method of prioritization of waste and lean tools using QFD. The current map and future was designed. Inventory, waiting, defect, and transport waste were identified and Kanban, SPF, QCO, and kaizen were the selected lean tools.

Nikjo et al. [11] considered an approach based on WeFA framework and MCDM methods in Multiple Attribute Group Decision Making (MAGDM) problems for the challenge of best player selection where important criteria and experts' vote is received by using WeFA. For determining the weight of each criterion, AHP is used. For weighting to Decision-Makers (DMs) and ranking of alternatives, the extended TOPSIS and its application in MAGDM are applied. Based on TOPSIS, Hosseinzadeh Lotfi et al. [12] put forward a method for ranking efficient DMUs. The criteria of ranking efficient DMUs is the difference between the distance of the center of gravity of all efficient DMUs to the ideal point and the anti-ideal point after and before deleting efficient DMUs one by one. Rahpeyma et al. [13] described how selection of supplier is a multi-index problem which affects the whole supply chain efficiency in both manufacturing and service industries. This article aims to integrate two well-known techniques considering the importance of selecting effective suppliers. These two techniques include QFD and TOPSIS in order to evaluate suppliers and rank them based on their merits. A multicriteria approach to prioritize dispatching according to the availability of resources was proposed by Osorio-Gómez et al. [14]. The risks associated with this decision has also been considered in prioritization criteria. In order to prioritize, the multicriteria model uses fuzzy QFD and TOPSIS.

Sobhanallahi et al. [15] suggested a different model by using a hybrid QFD-TOPSIS solution in MCDM methods for helping the selection of suppliers in the IT department of financial organizations. Finding the most related criteria is the first goal of the provided model. The second goal is to offer an optimized solution to the supplier selection problem. Torgul et al. [16] present an integrated AHP-QFD-TOPSIS methodology for the supplier selection problem. Firstly, priority ratings of the supplier’s customer requirements are ascertained using AHP. Next, QFD is used to establish a relationship matrix which identifies the degree of relationship between customer requirements and supplier selection criteria along with calculating the importance weights of evaluation criteria. Finally, to rank alternative supplier, the TOPSIS is used for optimal selection. The research of Pramanik et al. [17] was completed with a goal to develop a quantitative approach with integrated AHP-QFD methodology and this approach handles the conflicts between different decision-makers along with measuring the performance of the suppliers in order to select a resilient supplier that effects the manufacturing system. Büyüközkan et al. [18] proposed an integrated GDM technique based on the 2-type linguistic model along with QFD and TOPSIS method which was applied to a green warehouse selection problem. Cho et al. [19] investigated the feasibility of QFD-TOPSIS in presenting user preferences for multiple alternatives, such as construction techniques, products, systems, and design solutions.

3. Methodology

To identify major wastes on the shop floor, a thorough investigation was done on three different manufacturing industries in Bangladesh at the beginning of this research. By observing and after several sessions of discussion with the experts from those organizations, 15 major waste signs were identified as crucial. These signs, afterwards, were converted to seven wastes using scientific approaches. The QFD and TOPSIS method were used in the research to identify major wastes and prioritizing suitable waste elimination tools. The HOQ was built to establish the relation between waste signs and seven major wastes and the relative weights of all seven wastes were obtained. After that, the integration with the TOPSIS method was done to prioritize the lean tools which are suitable to eliminate those wastes.

3.1. Integrated QFD-TOPSIS Model

The integrated model of QFD and TOPSIS plays an innovative role in our research. The proposed model is shown in ***Figure 2***.

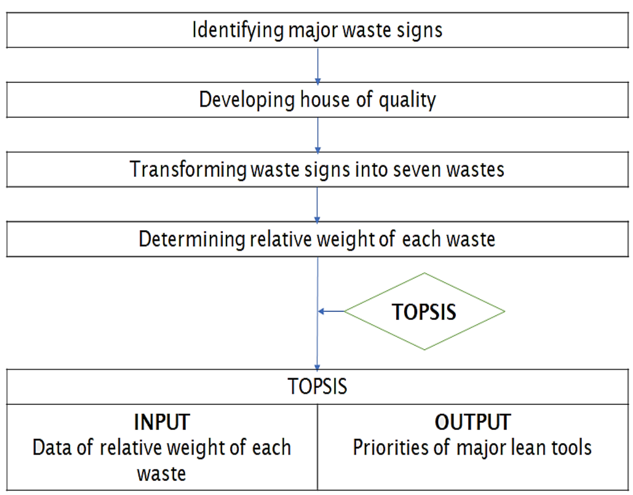
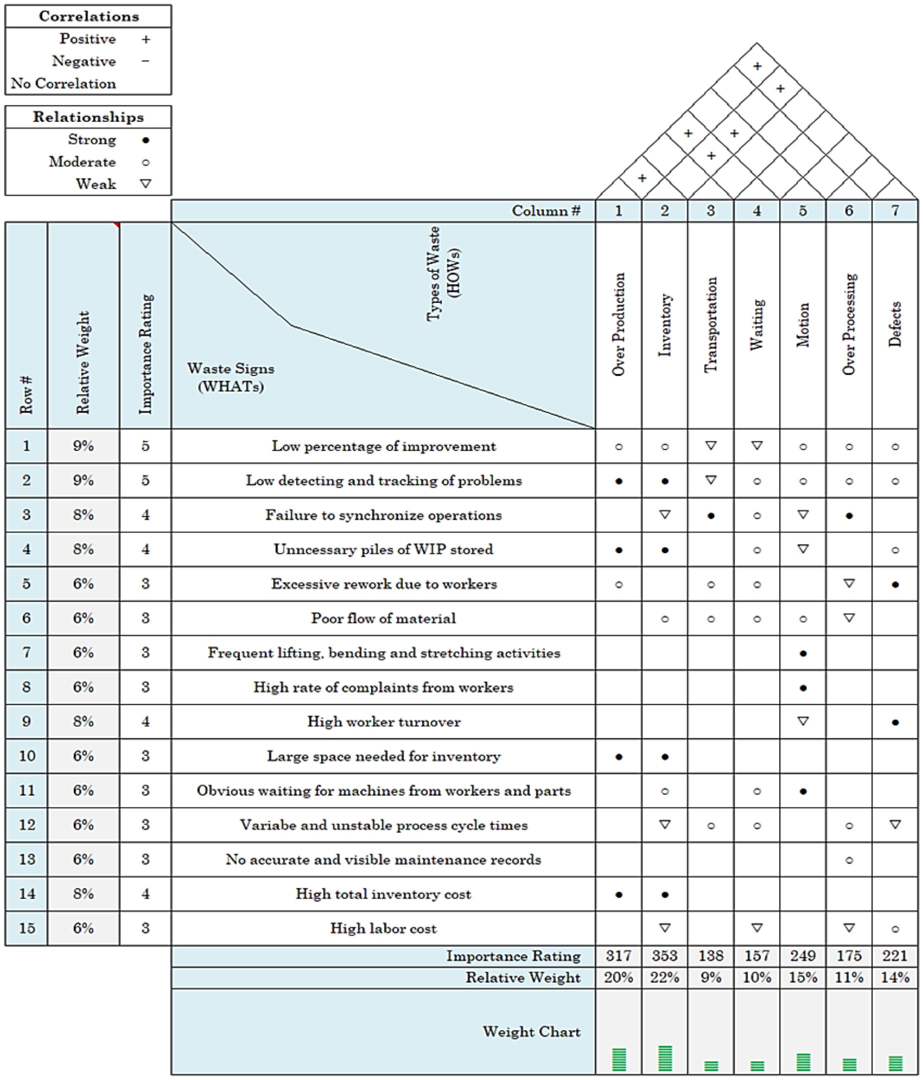


Figure 2. Integrated QFD-TOPSIS model.

QFD was selected to identify and prioritize major wastes that occurred on a shop floor. For this purpose, a HOQ was built which is not quite conventional manufacturing-based. The modified HOQ consists of four segments: WHATs, HOWs, relationship matrix between WHATs and HOWs, and correlation matrix among HOWs. ***Figure 3*** shows the developed HOQ model for this study.



Row #	Relative Weight	Importance Rating	Waste Signs (WHATs)	1 Over Production	2 Inventory	3 Transportation	4 Waiting	5 Motion	6 Over Processing	7 Defects
1	9%	5	Low percentage of improvement	○	○	▽	▽	○	○	○
2	9%	5	Low detecting and tracking of problems	●	●	▽	○	○	○	○
3	8%	4	Failure to synchronize operations		▽	●	○	▽	●	
4	8%	4	Unncessary piles of WIP stored	●	●		○	▽		○
5	6%	3	Excessive rework due to workers	○		○	○		▽	●
6	6%	3	Poor flow of material		○	○	○	○	▽	
7	6%	3	Frequent lifting, bending and stretching activities					●		
8	6%	3	High rate of complaints from workers					●		
9	8%	4	High worker turnover					▽		●
10	6%	3	Large space needed for inventory	●	●					
11	6%	3	Obvious waiting for machines from workers and parts		○		○	●		
12	6%	3	Variabe and unstable process cycle times		▽	○	○		○	▽
13	6%	3	No accurate and visible maintenance records						○	
14	8%	4	High total inventory cost	●	●					
15	6%	3	High labor cost		▽		▽		▽	○
			Importance Rating	317	353	138	157	249	175	221
			Relative Weight	20%	22%	9%	10%	15%	11%	14%

Figure 3. HOQ model developed for this study.

Here, major waste signs were used as the WHATs and seven wastes (inventory, over production, transportation, waiting, motion, defects and over processing) were used as the HOWs. The relationship matrix between waste signs and wastes was defined as either strong (carries nine points and denoted by ●), medium (carries three points and denoted by ○) or weak (represented by ▽ and carries one point).

The correlation among the seven wastes was represented by "+" for positive relation, "-" for negative relation. The correlation between two wastes indicates the effect on each other while one of them is increased or reduced. For example, a reduction in overproduction will obviously reduce inventory waste. Blank cells represent unknown correlation.

The importance rating (C_i) of the WHATs (major waste signs) was obtained from expert opinion (personal communication). A survey was done to rate each waste signs on a scale of 1 (less important) to 5 (most important). The relationship matrix was also obtained from discussions with professionals, floor leaders, and experts.

The relative weight of each waste sign (WHATs) was calculated using, $R_w = \frac{C_i}{\sum_i^{15} C_i} \times 100\%$. After obtaining data from experts, the relationship matrix was constructed and the importance rating of each waste (HOWs) was determined using the following formula:

$$IR_j = 100 \times \sum_{i=1}^{15} (R_w \times R_{ij}).$$

Where R_{ij} = weight assigned to the relationship matrix.

The relative weight of each waste was then calculated using, $w_j = \frac{IR_j}{\sum_{j=1}^{7} IR_j} \times 100\%$.

The steps in the general TOPSIS method are described as follows:

Step 1. Create a standardized decision matrix. The concept of decision matrix can be expressed as

$$A = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ g_{ml} & g_{ml} & \cdots & g_{mn} \end{bmatrix}.$$

Here, g_{mn} denotes the m_{th} alternative for the n_{th} attribute. And the standardized or normalized decision matrix can be computed by

$$r_{mn} = \frac{g_{mn}}{(\sum_{m=1}^{n} g_{mn}^2)^{1/2}}.$$

Step 2. Find the weighted standardized matrix. At first, the weight w_j of seven wastes were developed from QFD. Later, the weighted normalized matrix can be generated from

$$\tilde{V} = [v_{ij}]_{m \times n}.$$

Where $v_{ij} = r_{ij}(\cdot)w_j$; $\sum_{j=1}^{n} w_j = 1;\ i = 1, 2, \dots, m; j = 1, 2, \dots, n.$

Step 3. Find the ideal and anti-ideal solution. The ideal solution can be generated from

$$V^* = \max\{v_1^*, v_2^*, \dots, v_j^*\};\ j = 1, 2, \dots, n.$$

Similarly, the anti-ideal solution can be obtained from

$$V^- = \min\{v_1^*, v_2^*, \dots, v_j^*\};\ j = 1, 2, \dots, n.$$

Step 4. Develop distances between each alternative. Distance from ideal solution can be computed by

$$d_i^* = [\sum_{i=1}^{n}(v_{ij} - v_j^*)^2]^{1/2}.$$

And the distance from anti-ideal solution can be obtained from

$$d_i^- = [\sum_{i=1}^{n}(v_{ij} - v_j^*)^2]^{1/2}.$$

Step 5. Calculate the closeness coefficient by

$$C_i^* = \frac{d_i^-}{d_i^* + d_i^-}.$$

Step 6. Rank the alternatives from the preference order of closeness coefficient found in ***Step 5***.

3.2. Data Collection

Data were collected mainly from discussions and interviews with experts and professionals. To develop the HOQ, importance rating of each waste sign was collected using

$$\text{Importance rating of each waste sign} = \frac{\text{Sum of importance of each waste sign for all experts}}{\text{Total number of experts participated in the interview}}.$$

The weight of the relationship matrix was also obtained by the same procedure. The importance rating and relative weight (w_j) of each seven waste were determined afterwards.

Table 1. Relative weight (w j) of seven wastes.

Waste	Relative Weight (%)	Weight (w_j)
Over Production	20%	0.20
Inventory	22%	0.22
Transportation	9%	0.09
Waiting	10%	0.10
Motion	15%	0.15
Over Processing	11%	0.11
Defects	14%	0.14

To start with the TOPSIS method, a decision matrix had to be constructed. At first, seven lean tools were selected as alternatives for this method. These seven tools are Kanban, 5S, Quick Changeover, Total Productive Maintenance, Single Piece Flow, Kaizen, and Cellular Manufacturing. These are the most popular and most effective waste elimination tools for this study. Data were collected as how significantly a particular lean tool can eliminate each seven waste and then a decision matrix was constructed as follows. Semi-structured questionnaires were set up for the interview with experts and professionals. They were asked to rate the importance of each lean tool prior to removing seven major wastes.

Table 2. Decision matrix for TOPSIS method.

Major Wastes	Major Lean Tools						
	Kanban	5S	QCO	TPM	SPF	Kaizen	Cellular Manufacturing
Over Production	8.33	7.33	5.33	2.33	1.33	5.67	6.33
Inventory	8.33	3	5.67	1	8	4.33	7.67
Transportation	7.67	4.33	2	2	5.33	3	2.33
Waiting	8.67	6.67	4.67	3.33	7.67	6.33	5.67
Motion	2.33	4.33	5.33	8	7	3.67	3.67
Over Processing	7.33	5.33	3.67	1.67	3.67	3.67	4.67
Defects	5.33	3.33	4.33	3.67	2.33	7.67	2.33

4. Results

After all necessary observations and calculations, wastes and lean tools were prioritized according to their relative weight and importance. The identified and prioritized crucial wastes that are most common in manufacturing industries in Bangladesh are shown in ***Table 3***.

Table 3. Observation 1.

Major Wastes	Relative Importance	Rank
Over Production	317	2
Inventory	353	1
Transportation	138	7
Waiting	157	6
Motion	249	3
Over Processing	175	5
Defects	221	4

The relative weight of each waste was determined as a percentage from the importance rating. A pie chart was demonstrated to visualize the percentages of the relative weight of each seven waste and illustrated in ***Figure 4***.

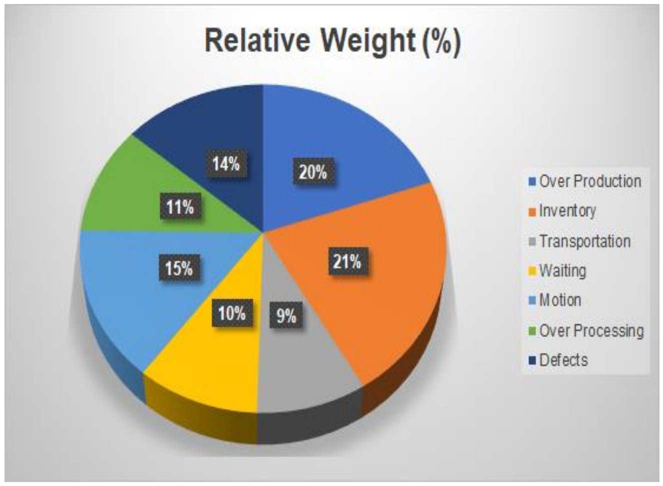


Figure 4. Pie chart of relative weight (%) of 7 waste.

The final prioritized lean tools are shown in ***Table 4***.

Table 4. Observation 2.

Lean Tools	Priority Order
Kanban	1
5S	6
QCO	5
TPM	7
SPF	4
Kaizen	3
Cellular Manufacturing	2

The result was generated from the calculation of the TOPSIS method where the input data was obtained from the QFD method. This integrated method is more reliable and logical in terms of scientific and statistical background. The model might be questioned for validation. For that purpose, the result was compared with the outcome of the TOPSIS method alone. In this integrated method, the relative weight of seven wastes was input in the TOPSIS method to create a weighted normalized decision matrix and then calculated. For the typical TOPSIS method, the weight of the wastes was gathered from interview sessions with professionals. The comparison between the integrated model and only the TOPSIS method was done and the Sum of Squared Errors (SSE) and Mean Squared Errors (MSE) were determined to validate the accuracy of the proposed model. The comparative analysis shown in ***Table 5*** found a sum squared error of only 0.006576 which proves the accuracy of the proposed integrated QFD-TOPSIS method. The calculated mean squared error also provides justification and validation of the model. The close consequents of SSE and MSE surely provide a logical explanation of the proposed hybrid model.

Table 5. SSE and MSE.

Lean Tools	Integrated QFD-TOPSIS Method	Only TOPSIS Method	SSE	MSE
Kanban	0.69	0.665		
5S	0.459	0.448		
QCO	0.487	0.444		
TPM	0.289	0.309		
SPF	0.509	0.488		
Kaizen	0.516	0.484		
Cellular Manufacturing	0.533	0.487		

5. Conclusions

The key goal of the study was to find and prioritize major wastes and waste elimination or to prioritize lean tools on a production floor. For that purpose, an integrated QFD-TOPSIS model was constructed. At first, significant waste signs were identified through interviews and on-field investigation. Then, those signs were converted into seven major wastes. These processes were done using the QFD approach. Then several lean tools were selected and ranked according to their importance or significance in eliminating previously mentioned wastes by TOPSIS method. SSE and MSE were determined which represented the accuracy of our developed hybrid QFD-TOPSIS model. It was found that inventory waste is the crucial one on the shop floor. Over production and motion are the next two high-ranked wastes found from the study. The Kanban or pull system was found to be the best tool to eliminate waste. Kanban is a scheduling system in lean philosophy and can achieve the goal of leanness and Just-In-Time (JIT) manufacturing. Cellular manufacturing is another major tool that can be implemented in order to eliminate wastes from a job shop. It can eliminate inventory wastes and waiting time on a production floor. The third-prioritized lean tool is Kaizen, which means continuous improvement. It increases worker morality and certainly reduces wastes from a production floor.

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