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A Model for Measurement and Calculation Waste in Production Flow Layout Using Fuzzy Logic

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Abstract

One of the issues of reducing waste and therefore increasing productivity in manufacturing enterprises is to endow with smooth and good production layout. Organizations can make production flow layouts productive by following up lean thinking model, thereby producing final products with minimal waste. The purpose of the research is to provide a model to aid industry managers' decision-making process with choosing between the most appropriate production flow layout patterns with respect to the amount of waste in production units; hence the idea is taken care of by considering criteria of inventory level, transport, lead time and product quality. In order to evaluate and choose layouts based on the forgoing criteria, a fuzzy inference system was employed. The system input is rating of each layout of production flow for each criterion, which was obtained by AHP method, and its output is the amount of waste of each layout of production flow. In order to simulate the proposed fuzzy inference system, Matlab software was utilized. In the end, a product layout with a quantitative difference compared to group (cell) layout, took up the least amount of waste and was considered as the most suitable of lean production flow layout for the study firm.

Keywords:

Waste, Product Layout, Process Layout, Group Technology (cellular), Fuzzy Inference Systems

1 Introduction

Lean Production System is one the most advanced management and control system which is at the top of the top manufacturing systems in terms of integrity and impressing other comprehensive management plans. Lean production which is known by the name of Toyota System means more production with less time, space, human effort, and equipment and material costs. In Lean production, the main goal is minimizing total wastes and damages as well as maximizing equipment utilization, human resources and funds [1]. Eliminating waste is the simplest most general description that can be provided in relation to Lean production, because all the definitions, descriptions and models that have been provided regarding Lean production share the same idea. But what is waste? In the simplest expression, it is called any activity (of human or machine) which attracts source consumers but does not manufacture value (or does not produce an appropriate value compared to the used source). Ohno describes wastes as follows: Defective products, overproduction of unnecessary goods, unnecessary transportation of products, materials and components, expecting labor for supplies or for the realization of activity in the upstream flow of goods awaiting further processing or consumption at a distance, unnecessary processing, and unnecessary movement of labor [2]. Womack et al. add two more issues to the mentioned seven which are: Goods and services that do not respond to the needs of consumers, equipment and facilities that are not used optimally [3]. According to Blake and Hunter waste refers to anything that does not result in adding value but the consumer will pay for it. According to Black and Hunter, the creators of Lean production wave (the Japanese) believed in two infrastructural principles, one, that all wastes must be eliminated in industry and two, that the main fund of the organizations is manpower [4]. In Suzaki and Cochran point of view waste includes the following cases: Producing too much: waste through too much or too early of a production; Defects: waste due to defects in the production thereby increasing the cost of rework or disposing of the product; Transport: wastes through the multiple and unnecessary movement of materials and components. Unemployed labor: material waste due to waiting for the workers; Inventory: waste due to the additional costs associated with excess inventory, as well as management of space, materials, additional people associated with this excess inventory; Movement: The waste through unnecessary movement of labor; Process: waste through unnecessary process steps [5,6]. Given the mentioned instances, one of the issues that can be very effective and determinant in reducing or removing waste in a production system is the layout of the facility in a manufacturing unit. The layout of the manufacturing industry is at an acceptable level productivity when it is able to reduce or eliminate waste in their production units. Therefore, the matter of a layout might as well be considered as a strategic issue which has a significant effect on the production system performance [7]. Thus, organizations can utilize their production flow layout by taking the approach of Lean thinking. There are four basic layouts (pattern of production flow layout): Product layout, process layout, fixed position layout, group (cell) layout [8,9,10].

Given the fact that the three product layout, process layout and arrangement of a group (cell) layouts are mainly used the manufacturing of the product, thus we will investigate them in relation to the existing waste in a production system.

Product layout is known by names such as flow-line layout, assembly line layout and production layout. In a product layout, the machines and workstations are arranged according to the sequence of operations. The product layout is used by different factories, such as assembly plants, that manufacture either a single item or a few items in large quantities. Process layout is known by names such as job shop layout and functional layout. In a process layout, all operations of the same type are grouped together. For example, all milling machines are placed together in one department; all drilling machines are placed together in another and so on. This layout is used by factories that manufacture different types of products or jobs in small quantities, where each job has a different sequence of operations from any other. Group technology layout is sometimes called cellular layout. In a group layout, dissimilar machines are grouped and placed in work centers called cells that are used to process families of products that have some common characteristics with similar requirements [8,9,10].

2 Literature review

The investigation through books and articles regarding Lean production indicates that there have been a great number of articles written and published regarding the subject since 1990 which itself is the result of wide researches taken place about the matter. But the remarkable thing is that there has not been done much work on the topic of Lean Layout. For example, the studies of [11], [12], [13], [14], [15], [16], [17], [18] can be pointed which were on the subject of improving layout pattern of facilities using Lean production concepts. Da Silva and Cardoza studied the analysis of different types of layout in Lean production point of view [19]. De Carlo et al. did separate designs, using SLP, the Lean and experimental methods to design the layout of a production line (low capacity) and investigated each method with a case study in terms of transportation, costs and utilization. The results show the advantage of Lean manufacturing method compared to other methods [20]. Finally Pulkurte and his colleagues used Lean principles, analysis and improvement of ergonomic layout of the facility to study cycle time reduction on the assembly line of a manufacturing unit. They mainly put their focus on assembly line to increase productivity by identifying and eliminating non value-added activities as well as changes to work stations, improve the alignment by eliminating motion (unnecessary) of operators, content reduction through analysis of operators (using REBA) [21].

Given that selecting the type of layout in a production line is quite important and strategic and its determinant role in reducing (removing) the existing waste in a production system, the necessity of a strong technique which can evaluate the production line layout and assist the decision maker in such strategic decision, is pretty obvious. Since the decision on layout type is with the expert knowledge or reasoning people and this subjective comes along with judgments, vague information and language variables in most production process evaluations, therefore, a well-known approach to decision-making based on vague information is fuzzy logic. Fuzzy logic is able to formulate many of the concepts, variables and systems mathematically which are inaccurate and ambiguous and provide groundwork for reasoning, inference, control and decision-making under uncertainty conditions. Therefore a good field was prepared for using the fuzzy logic; in this paper, in order to increase the objectivity and effectiveness the fuzzy decision-making inference system has been used as a fuzzy decision model for better decision making. The reason behind using the Fuzzy Inference System between different types of procedures is that this method is intelligent. By intelligent, it is meant that is has a human-like behavior and it considers all the rules defined for it simultaneously and this is what man does daily. The proposed fuzzy inference system inputs are rated each of Layouts in the criteria that have been obtained using the AHP technique. This system gets the inputs and after applying some rules on them it emission the output the same amount of waste produced during each of the production flow layout. To simulate fuzzy inference system Matlab software has been used which is an appropriate environment for simulating such systems.

3 Research Method

Using approximation and the effective analysis of system behavior approximately is a new approach in system analysis. A fuzzy system is a system which's input data is done on the loose (fuzzy), system processing is done approximately (fuzzy) and system decision making is also done in fuzzy condition. There are different approaches for modeling the input data of the system, processing and evolving into a decision and one of them is using fuzzy rules with an if-then structure. A fuzzy inference system is composed of four main sections: 1) One fuzzifier that converts input variables numeric values to a fuzzy set. 2) The fuzzy rule base which is the set of if-then rules. 3) Fuzzy inference engine that converts inputs into outputs with a series of actions. 4) defuzzifier maker which converts the fuzzy output into a crisp number. Figure 1 shows the steps of a fuzzy inference system (fuzzifier and defuzzifier systems) [22].

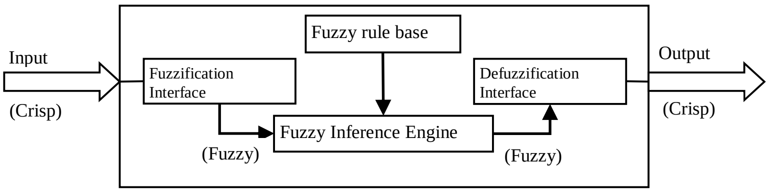


Fig. 1.fuzzifier and defuzzifier systems [22]

This study, in order to evaluate and select the alignment the production flow layout with the approach of waste elimination has implemented the proposed model in Alborz Cable Company. Since 37 of the experts and specialists with experience, have sufficient knowledge and information on the current production flow layout, therefore, because of the population limits, the opinions of all subjects have been investigated and the study is non-sampling. The model proposed in this study consists of three phases and eight steps (Fig. 2).

Phase 1

- Step 1: Identifying the criteria and sub-criteria for evaluation and selection of production flow layouts with waste elimination approach.
- Step 2: Weight estimating for each sub-standard using AHP techniques.

Phase 2

- Step 3: obtaining layout scores in each criterion according to the score given to each sub-criterion obtained from the second step.

Phase 3

- Step 4: The introduction of input and output variables and membership functions of the fuzzy system.
- Step 5: Creating a fuzzy rule base using the expert opinion.
- Step 6: Designing fuzzy Inference Engine.
- Step 7: Inference System simulation using MATLAB software.

Step 8: Selecting the production flow layout which has obtained the lowest amount of waste using the scores obtained in the third step, the simulation model of the seventh step, and obtains the waste of any of the production flow layouts.

Thus it can be said that this study is applicatory in terms of goal and descriptive-survey in terms of nature and method.

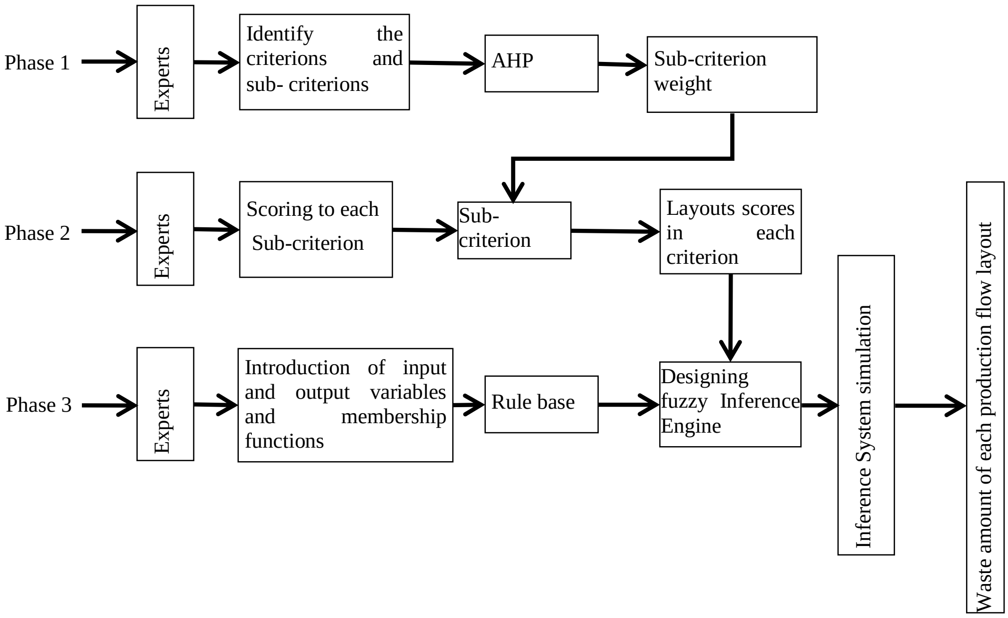


Fig. 2. Model Proposed

4 Implementing the Proposed Model

Phase 1

- Step 1 (Identify the criterions and sub- criterions)

According to the subject's literature, articles and also interviews with experts, criterions and sub-criterions effective on the process of choosing a production flow layout with a waste elimination approach were identified and selected (Table 1).

Table 1: criterions and sub- criterions lean production flow layout

Criteria	Sub-Criteria	Adapted from 1	2	3	4	5	6
Inventory Level		√		√			√
	Batch Size	√			√		√
	Overproduction	√			√	√	
	Work in Process(WIP)	√			√		
Lead Time		√				√	√
	Cycle Time	√	√		√		
	Queue Time				√		
	Setup time	√			√		√
Transport		√		√	√		√
	Material Handling	√			√		
	Movement of Workers	√			√		
	Distance between Workstation				√		
Quality		√		√		√	√
	Specialization of Workers				√		√
	Advanced Equipment				√		√
	Control Loop						√

1. [2]; [3]; [5]; [6]; 2. [21]; 3. [19]; 4. [23]; [24]; 5. [25]; 6. [26].

- Step 2 (sub-criterion weight estimation)

The sub-criterions of each criterion have been obtained according to the experts' opinions, questionnaire, coupled comparison and the weight of each criterion using the AHP technique. Table 2 shows criterions, sub-criterions and the weight of each that has been used in production flow layouts evaluation (using the waste elimination approach). It should be noted, that the incompatibility parameters which are designed to show the reliability of the questionnaire, have also been presented in this table.

Table 2: Weight and incompatibility rate of each criterion and sub- criterion

Inventory Level			Lead Time			Transport			Quality		
Batch Size	Overproduction	Work in Process (WIP)	Cycle Time	Queue Time	Setup time	Material Handling	Movement of Workers	Distance between Workstation	Specialization of Workers	Advanced Equipment	Control Loop
0.717	0.195	0.088	0.687	0.127	0.186	0.364	0.099	0.537	0.649	0.072	0.279
I.R. = 0.09			I.R. = 0.09			I.R. = 0.09			I.R. = 0.06		

Phase 2

- Step 3 (Obtaining layouts scores in each criterion)

Layouts scores in each criterion have been obtained according to the score given (by experts) and Equation 1. In this equation, "CS" is the score of each criterion, "SCS" the score given to each sub-criterion, "W" the weight of each criterion and in the number of each criterion's sub-criterions.

$$CS = \sum_{i=1}^{n} SCS_i \times W_i \qquad (1)$$

First, in this step, with the help of experts, a score between 1- 9 has been given to production line layout. Table 3 represents the scores given to production flow layouts sub-criterion by the experts. Then, the score of each criterion which has been obtained according to the equation 1 and table 3 has been showed in table 4. These scores are the inputs of the built model.

Table 3: The scores given to production flow layouts sub-criterion by the experts

	Inventory Level			Lead Time			Transport			Quality		
	Batch Size	Overproduction	Work in Process (WIP)	Cycle Time	Queue Time	Setup time	Material Handling	Movement of Workers	Distance between Workstation	Specialization of Workers	Advanced Equipment	Control Loop
Product Layout	4	7	2	2	3	3	3	4	3	2	9	8
Process Layout	4	7	9	9	7	8	9	7	5	7	1	3
Group Technology Layout	4	6	3	3	2	2	2	3	2	5	5	1

Table 4: The score of each criterion according to the equation 1 and table 3

	Inventory Level	Lead Time	Transport	Quality
Product Layout	4.409	2.313	3.099	4.178
Process Layout	5.025	8.56	6.654	5.452
Group Technology Layout	4.302	2.687	2.099	3.844

Phase 3

- Step 4 (the introduction of input and output variables and membership functions of the fuzzy system)

According to researches and studies, in this fuzzy system, 4 criterions effective on the waste amount in production flow layouts, have been used as input variables.

The proposed fuzzy inference system input variables are:

- Inventory level which can be low, medium or high.
- Transport which can be low, medium or high.
- Lead Time which can be low, medium or high.
- Quality which can be low, medium or high.

Based on these 4 criterions, the production flow layouts waste can be observed. It must be noted that the waste amount due to production flow layout will not be definitely identified with the mentioned criterions because the basic nature of waste in production flow layouts lacks definiteness but here it has been tried to achieve the study's goal using a fuzzy system according to the mentioned criterions. The provided fuzzy system has an output which indicates the waste amount which can be very low, low, medium, high or very high. In figure 3, the total shape of the designed fuzzy interference system has been shown with its inputs and outputs.

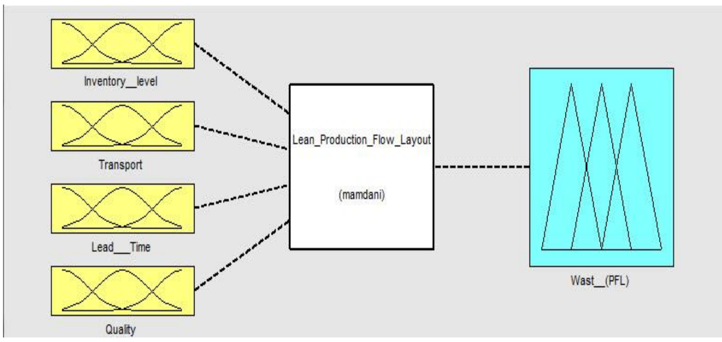
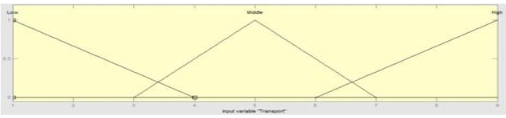
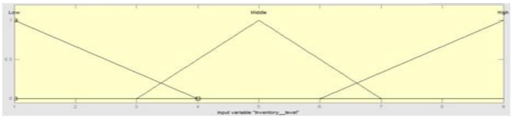


Fig. 3. Total shape of the designed fuzzy interference system

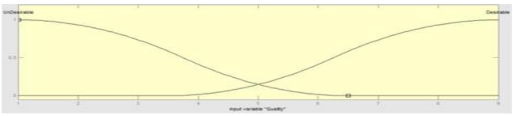
As it is clear, the designed system has four inputs and one output or in other words it is a (MISO) type. In order to set the rules, the factors effective on input parameters must be investigated and analyzed by the experts. The membership functions of each criterion's have been obtained according to the experts' opinions. In contrast to AHP, where all experts gave their ideas separately, the membership functions were obtained using the brainstorm method during a session with four preferable experts. Figure 4 indicates the membership functions in relation to the inputs and outputs of fuzzy interference system.



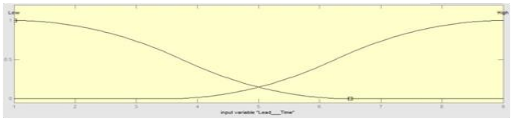
a) Membership function related to inventory level (input)



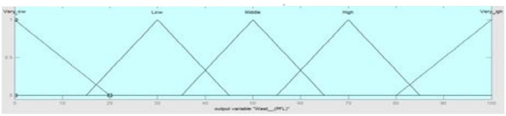
b) Membership function related to transport (input)



c) Membership function related to lead time (input)



d) Membership function related to quality (input)



e) Membership function related to amount of waste (output)

Fig.4. Membership functions of inputs and outputs

- Step 5 (creating a fuzzy rule base using the expert opinion)

After determining the membership functions, the fuzzy rules were as well written separately by four of the experts. After writing the rules, the group of rules that were similarly written by four experts got the weight "1", and so rules that were written by three, two and one expert got the weights "0.75", "0.5" and "0.25" respectively. According to the descriptions provided 4 inputs which result in 36 possibilities, have been investigated in this fuzzy interference system. These 36 possibilities are shown in Table 5 as separate rules with their regarded outputs and the weight values.

Table 5: Rule Base

Rule	IL	T	LT	Q	W	Weight	Rule	IL	LT	T	Q	W	Weight
1	L	L	L	D	VL	1	19	M	M	H	UD	VH	0.75
2	L	L	L	UD	M	0.25	20	M	M	H	D	M	0.25
3	L	L	H	UD	M	0.25	21	M	H	L	UD	H	0.25
4	L	L	H	D	L	0.5	22	M	H	L	D	M	0.25
5	L	M	L	UD	M	0.25	23	M	H	H	UD	VH	0.75
6	L	M	L	D	VL	0.5	24	M	H	H	D	M	0.25
7	L	M	H	UD	H	0.5	25	H	L	L	UD	M	0.25
8	L	M	H	D	L	0.25	26	H	L	L	D	L	0.5
9	L	H	L	UD	M	0.25	27	H	L	H	UD	H	0.5
10	L	H	L	D	L	0.75	28	H	L	H	D	M	0.25
11	L	H	H	UD	H	0.75	29	H	M	L	UD	H	0.25
12	L	H	H	D	M	0.25	30	H	M	L	D	L	0.25
13	M	L	L	UD	M	0.25	31	H	M	H	UD	VH	0.75
14	M	L	L	D	VL	0.75	32	H	M	H	D	M	0.25
15	M	L	H	UD	H	0.5	33	H	H	L	UD	H	0.75
16	M	L	H	D	M	0.25	34	H	H	L	D	M	0.25
17	M	M	L	UD	H	0.5	35	H	H	H	D	H	0.5
18	M	M	L	D	L	0.5	36	H	H	H	UD	VH	1

Abbreviations: Inventory Level (IL); Lead Time (LT); Transport (T); Quality (Q); Waste (W); Very Low (VL); Low (L); Middle (M); High (H); Very High (VH); Desirable (D); Undesirable (UD).

- Step 6 (designing fuzzy Inference Engine)

In this study, the minimum inference engine, Implications minimum Mamdani, singleton fuzzifier, center of gravity defuzzifier and inference rule-based separate with sum composition have been used in order to create the fuzzy system. Thus, the minimum inference engine will be as the phrase mentioned in equation 2.

$$\mu_{B'}(y) = Sum_{i=1}^{36}\left[\sup\left(\min\left(\mu_{A'}(x), \mu_{A'_1}(x_1), \ldots \mu_{A'_n}(x_n), \mu_{B'}(y)\right)\right)\right] \quad (2)$$

Center of gravity defuzzifier is the most common defuzzifier used in fuzzy systems which In terms of Intuitive is justifiable. Center of gravity defuzzifier is calculated as the phrase mentioned in equation 3:

$$y^* = \frac{\int_a^b \mu_A(x).xdx}{\int_a^b \mu_A(x)dx} \qquad (3)$$

- Step 7 (Inference System simulation using MATLAB software)

In order to simulate this system the MATLAB software version 8.1 was used which has a proper environment for simulating such systems. To do so, the input and output parameters have been defined along with membership functions and the 36 mentioned rules in the previous section. Next, the 5,6,7 and 8 images show the results of the product layout using the simulating model along with the reciprocal effect of input variables on each other and as a result on the output ones.

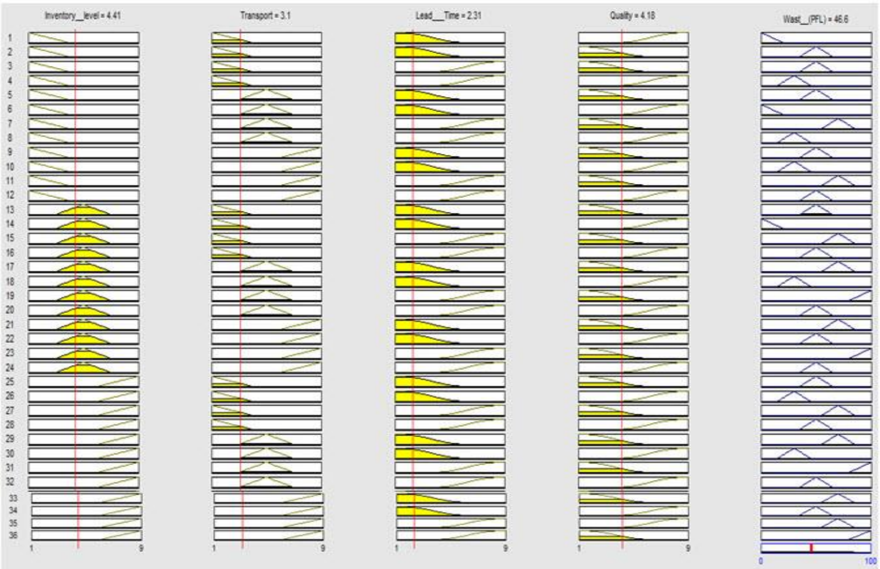


Fig. 5. results product Layout by using the model simulation

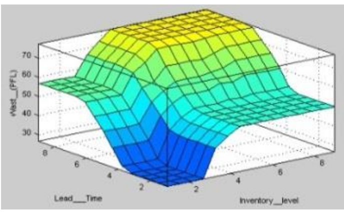


Fig. 6.result of the reciprocal effect of inventory level and lead time

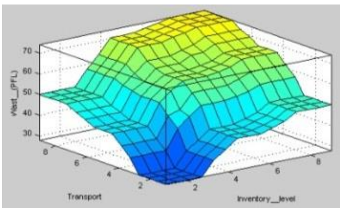


Fig. 7.result of the reciprocal effect of inventory level and transport

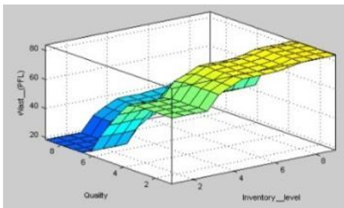


Fig. 8.result of the reciprocal effect of inventory level and quality

- Step 8 (selecting Lean production flow layout)

Now we enter the scores of three production flow layout layouts (product, process and group layouts) in the criterions of the simulated model and obtain the waste amount of each layout. Table 6 shows the waste amount of each layout. Finally, as it is clear, product layout which has the lowest waste amount is selected as the most appropriate Lean production flow layout.

Table 6: waste amount of each layout

Production Flow layout	Waste
Product Layout	46.6
Process Layout	67.6
Group Technology (Cellular) Layout	48.6

5 Conclusion

In this study, we are faced with two general and specific conclusions; specific conclusion point out the output result of the designed model while general conclusion is about achievements of the designed model.

5-1 Specific Conclusions

Given the waste amount of the three product, process and group (cell) layouts which are 46.6, 67.6 and 48.6 respectively, it can be said that the product layout with 46.6 waste amount and slight different compared to group layout has the lowest waste amount and selected as the most appropriate Lean production flow layout for Alborz Cable Company. This is true while product layout has been medium in most criterions. Perhaps it can be said that this layout has gained lower waste amount due to fair distribution of scores of sub-criterions (not that a sub-criterion obtains a higher score and another lower one). It must be noted that in addition to comparing the layouts with each other, the interval of each layout with the desired state (less waste) can be estimated and identified by analyzing the criterions that result in more waste amount reduction; while most of the decision making methods with multiple criterions are about rating and comparing options. Using the built model their importance can be easily determined by the changing the inputs and observing the outputs, thus the problems for obtaining lower waste in production flow layout could be solved.

5-2 General Conclusion

- considering all the effective factors in decision making
- doing team-work in decision making
- Obtaining management policy regarding utilization improvement
- units' satisfaction increment due to being involved in decision making
- providing a clear image of the amount of the existing waste in the production unit in better planning and decision making

This proposed method can be a good model for other production and service fields as well. The agile of the production flow layout can also be analyzed.

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