Facility Layout Simulation and Optimization: an Integration of Advanced Quality and Decision Making Tools and Techniques

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Abstract

The purpose of this paper is to propose an integrated approach of simulation, fuzzy analytic hierarchy process and Quality Function Deployment (QFD) and Multiple Criteria Decision Making (MCDM) for facility layout design improvement and optimization. Computer simulation has been used to determine quantitative measures. Analytical Hierarchy Process (AHP) has also been used to determine the weight of qualitative measures for layout alternatives. Non equal weights have been derived with respect to the quantitative and qualitative criteria. QFD has been used to determine weights of criteria and the importance of the alternatives in relation to quantitative and qualitative measures. Finally, Topsis approach has been used for ranking the alternatives and identifying the best alternative. The results imply that the proposed methodology is more reliable compared to existing approaches. In addition, the methodology requires managers' concentration on Facility Layout Problem (FLP). This paper provides organizations a way to devise and refine adequate criteria and alleviate the risk of selecting optimal solutions.

Keywords: Simulation, FAHP, QFD, Topsis, Facility Layout Problem (FLP)

1. Introduction

In recent years, major changes such as variable customer demand, short product life cycle and increasing worldwide competition have taken place in the manufacturing industry. To meet these changes, a company must be able to offer superior quality products at lower costs than competitors and remain flexible if it wants to survive in the business world (Wang et al., 2001).

Optimal design of physical layout is an important issue in the early stage of system design. To achieve this goal, new manufacturing systems must be designed (Ertay et al., 2006). Facility Layout Problem (FLP) is known as to have a significant impact upon manufacturing costs, work in process, lead time and productivity. A good facility layout contributes to overall efficiency of operations and can reduce up to 50% of the total operating costs (Xie and Sahinidis, 2008). FLP deals with finding the optimal facility arrangement in the existing layout such that a set of criteria is met and/or some objectives are optimized. Also, it is a fundamental optimization problem encountered in many manufacturing and service organizations (Wong and Komarudin, 2010). A number of objectives are addressed in the facility layout literature, some of which are summarized as minimizing material handling cost, minimizing overall production time, minimizing investment in equipment, effective utilization of space, providing for employee safety, convince and comfort, flexibility in rearrangement and operations and facilitating the manufacturing process (Gonzalez-Cruz et al., 2011).

FLP solutions need integrated decisions from many different areas. For this reason, the facility layout design problem is very much related to the selection of production system types (Abdou and Dutta, 1991) and material handling systems (Heragu and Kusiak, 1990). According to literature, an FLP features two aspects; it can be solved either qualitatively or quantitatively (Sahin, 2010). To this end, the layout problem can have different formulations, but it is usually considered as an optimization problem. An assignment of the coordinates and orientations of components that minimizes the cost and satisfies certain placement requirements is sought. The problem can be viewed as a generalization of the quadratic assignment problem and therefore belongs to the class of numerous practical hard (NP-hard) problems. Numerous practical problems are integer optimization problems that are intractable. Such problems are commonly addressed with heuristics that provide a solution, but not information on the solution's quality (Drira et al., 2007).

FLP has been investigated in depth by a number of researchers (Tompkins and Reed, 1976; Levary and Kalchik, 1985; Kusiak and Heragu, 1987; Das, 1993; Meller and Gau, 1996; Russell et al., 1999; Lin and Sharp, 1999;

Drira et al., 2007). Most of the literature of layout design problems fall into two major categories; algorithmic and procedural approaches. Algorithmic approaches usually simplify both design constraints and objectives in order to reach a surrogate objective function, the solution of which can then be obtained. The majority of the existing literature is concentrated on algorithmic approaches (Heragu, 1997). Procedural approaches can incorporate both qualitative and quantitative objectives in the design process (Yang and Kuo, 2003). For these approaches, the design process is divided into several steps which are solved sequentially. The success of a procedural approach implementation is dependent upon the generation of quality design alternatives, often provided by an experienced designer. Thus, such an approach may be subjective and may generate an inferior solution due to a lack of appropriate objective data. Respectively, both possible subjectivity and inefficiency hinder the adoption of a procedural approach to solve a layout design problem.

Layout generation and evaluation is often challenging and time consuming due to its inherent multiple objective natures and its data collection process (Lin and Sharp, 1999). Past and emerging research has been aimed at developing a solution methodology to meet these needs (Zouein et al., 2002; Chen and Sha, 2005; Aiello et al., 2006). However, algorithmic approaches have focused mainly on minimizing flow distance in order to minimize material handling costs. On the other hand, procedural approaches have relied heavily on experts' experience. Neither an algorithmic nor a procedural layout design methodology is necessarily effective in solving practical design problems (Yang et al., 2000). The proposed methodology features both the merits of the algorithmic and procedural layout design approaches.

Over the past two decades, most of facility layout approaches emphasized on the design stage and very few results were accomplished in the evaluation stage (Cheng et al., 1996; Chung, 1999; McKendall and Shang, 2006). Mathematical programming and simulation models have been developed to measure the performance of an operating system, which may or may not include the considerations of the layout design. The objective of a layout evaluation is to investigate the characteristics of a layout alternative, under the real constructions of time and information available, before the system starts its operations; otherwise the re-layout would incur higher costs and lead to loss of production time. The performance factors, which still provide useful insight for the impacts resulting from a layout alternative, would be valuable for evaluation of the layout alternatives (Lin and Sharp, 1999).

The generation of a model for the layout design is a critical step because of its unstructured and vast nature. Yang and Kuo (2003) proposed an integrated approach of Analytical Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) to solve a facility layout design problem. 'Spiral' as a computer aided layout planning tool, is used to generate a considerable numbers of layout alternatives as well as to generate quantitative Decision Making Unit (DMU) outputs. The qualitative output performance measures are weighted by AHP. DEA is then used to solve the multiple-objective layout problems. Ertay et al. (2006) used DEA and AHP to solve layout design problem. Shang and Sueyoshi (1995) proposed a unified framework to facilitate decision-making in the design and planning stage for the problem of selecting the most appropriate solution of Flexible Manufacturing System (FMS). This framework contains three models; an AHP, a simulation module and an accounting procedure. These modules are unified through DEA. Both AHP and simulation models are used to generate the necessary outputs for DEA, whereas the accounting procedure determines the required inputs, such as expenditures and resources for realizing the potential benefits. There is a limited literature on the simultaneous use of both AHP and DEA methodologies for the facility layout design. Foulds and Partovi (1998) applied AHP to evaluate a closeness relationship among planning departments for a layout problem. Their goal was to generate a block plan based on the resulting closeness relationship. Cambron and Evans (1991) used the different computer-aided layout design methods to generate a set of design alternatives and then these alternatives were evaluated by AHP according to a set of design criteria. Yang et al. (2000) used AHP to evaluate multiple-objective layout design alternatives generated from Muthers' Systematic Layout Planning (SLP) procedure.

In order to cope with the difficulties as the cause of this complexity, this paper purposes an integrated framework based on Fuzzy AHP, simulation, QFD and Topsis to solve plant layout design problems. For this purpose, SLP is used to generate a considerable number of layout alternatives. Computer simulation is used to determine quantitative measures and AHP is applied to determine the weight of qualitative measures for layout alternatives. In the next step, with respect to all criteria (quantitative and qualitative) which do not have the same importance, House of Quality (HoQ) as the first phase of QFD is applied and simultaneously both quantitative and qualitative performance data are considered. In fact, HoQ is used to initially prioritize the alternatives in relation to quantitative and qualitative measures. Then, the Topsis methodology is used to solve the layout design problem to generate more robust layout design alternatives. One of the problems, which has not been pointed in previous investigations, is that the criteria (quantitative and qualitative) do not have equal weights. Therefore, this paper attempts to provide a new approach to overcome this problem. For this purpose, the HoQ model has been used as an advanced evaluation technique for determining the weight of each criterion and to evaluate the alternatives against the criteria in order to identify overall priorities of the alternatives and it has been integrated with Topsis to present better results for selecting plans.

2. Fuzzy Analytical Hierarchy Process (FAHP)

The reason for adopting AHP especially for the qualitative performance data is the fact that qualitative factors are often complicated and in conflict. Also, the user acceptability and confidence in the analysis provided by the AHP methodology is high when it is compared with other multi-attribute decision approaches (Zakarian and Kusiak,1999). AHP has been widely used as a useful Multiple Criteria Decision Making (MCDM) tool or a weight estimation technique in many areas such as selection, evaluation, planning and development, decision making, forecasting, etc. (Vaidya and Kumar, 2006). Traditional AHP requires crisp judgments. However, due to the complexity and uncertainty involved in real world decision problems, a decision maker may feel more confident to provide fuzzy judgments than clear comparisons. Also, with respect to the purpose of AHP, which is to capture the experts'knowledge, the conventional AHP still cannot reflect the human thinking style (Kahramana et al., 2004). There are numerous fuzzy AHP methods proposed by various authors (van Laarhoven and Pedrycz, 1983; Buckley, 1985; Chang, 1996; Cheng, 1997). These methods are systematic approaches to alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision makers usually find that it is easier to make judgments using interval scales rather than exact values. This is because usually they are unable to be explicit about their preferences due to the fuzzy nature of the comparison process (Bozbura et al., 2007). Among the FAHP approaches, the extent analysis method has been employed in a number of applications due to its computational simplicity. Decision maker can specify preferences in forms of natural language expressions about the importance of each performance attribute. The system combines these preferences using fuzzy AHP, with existing data (from industrial surveys and statistical analysis) to reemphasize attribute priorities. In the FAHP procedure, the pair wise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer's emphasis.

In the following, the outlines of the extent analysis method based on fuzzy AHP are introduced (Wang et al., 2008):

Let $X=\{x_1,x_2,\ldots,x_n\}$ be an object set, and $U=\{u_1,u_2,\ldots,u_m\}$ be a goal set. According to the method of extent analysis by Chang (1992), each object is taken and extent analysis for each goal is performed, respectively. Therefore, extent analysis values for each object can be obtained, considering the following signs:

$$M_{gi}^{1}, M_{gi}^{2}, \ldots, M_{gi}^{m} \qquad i = 1, \ldots, n \tag{1}$$

Where all the M_{gi}^{j} (j=1,…,m) are triangular fuzzy numbers.
The steps of Chang's extent analysis include:

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{2}$$

Step 2: The degree of possibility of $M_1(l_1,m_1,u_1)$ and $M_2(l_2,m_2,u_2)$ is defined as:

$$V(M_1 \geq M_2) = 1 \qquad \text{If } m_1 \geq m_2 \tag{3}$$

$$V(M_1 \geq M_2) = \frac{u_1 - l_2}{(u_1 - l_2) + (m_2 - m_1)} \qquad \text{Otherwise}$$

To compare M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are needed.

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i(i=1,…,k) can be defined as:

$$V(M_1 \geq M_2, \ldots, M_k) = V\{(M_1 \geq M_2), \ldots, (M_1 \geq M_k)\} = \min V(M_1 \geq M_i) \quad i = 1, \ldots, k \tag{4}$$

Assume that: $d^*(A_i) = Min(S_i \geq S_k)$

For k =1,…,n; k≠1, then the weight vector is:

$$W^* = ((d^*(A_1), d^*(A_2), \ldots, d^*(A_n))^T \tag{5}$$

Where A_i (i=1,…,n) are the n elements.
Step 4: Via normalization, the normalized weight vectors are:

$$W = ((d(A_1), d(A_2), \ldots, d(A_n))^T \tag{6}$$

Where W is a non-fuzzy number.

3. Simulation

Simulation has been commonly used to study the behavior of real world manufacturing systems to gain better understanding of underlying problems. Simulation modeling is arguably more widely applied to manufacturing systems (Azadeh et al., 2008). A reason for this is the competitive environment in many industries that has resulted in a greater emphasis on automation to improve productivity and quality. Since automated systems are

more complex, they typically can only be analyzed by simulation. Another factor is that the cost of equipment and facilities can be very large, thus the relatively small expenditure on simulation can reduce the risk of failed implementation. Thus the process industries with their generally high level of automation and capital investment would seem an ideal opportunity for the utilization of the simulation technique (Saeheaw et al., 2009).

Despite their widespread occurrence, available examples of the application of simulation modeling are few, and those that do occur tend to focus on the analysis of production planning and control issues. Katayama (1996) uses simulation to assess a production planning procedure for a multi-item continuous production system in a petrochemical plant. White and Tsai (1999) use simulation to analyze the logistics of solvent recovery in a chemical processing plant. Vaidyanathan et al. (1998) use simulation as a daily production scheduling tool in a coffee manufacturing process. Therefore, a simulation model is an easier way to build up models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resource utilization, cycle times and lead times.

Some of the advantages of computer simulation methodologies are that they provide feasible solutions within a short period, cuts inventory and throughput time, optimizes system dimensions including buffer sizes, maximizes the use of manufacturing resources, improves line design and schedule, enhances productivity of existing production facilities, reduces investment in planning new production facilities and reduces investment risks by early proof of concept (Law and Kelton, 2000).

4. Quality Function Deployment (QFD)

QFD is a systematic procedure for defining customer needs and interpreting them in terms of product features and process characteristics. The systematic analysis helps developers avoid rushed decisions that fail to take the entire product and all the customer needs into account (Cohen, 1995). It is a process that involves constructing one or a set of interlinked matrices, known as "quality tables". The first phase of this technique is called the "House of Quality" (HoQ). The HoQ matrix has two principal parts; the horizontal part, which contains information relevant to the customer, and the vertical part, which contains corresponding technical translation of their needs (Almannai and Greenough, 2008). The basic process underlying QFD resides in the centre of the matrix where the customer's and technical intersect, providing an opportunity to examine the customer’s voice versus each technical requirement.

QFD helps companies to maintain their competitiveness using three strategies of decreasing costs, increasing revenues, and reducing the time to produce new product or service (cycle time reduction) (Hunt and Xavier, 2003). QFD allows the company to allocate resources and to coordinate skills and functions based on customer needs, and thus, may result in lower production costs by ignoring aspects meaning little or nothing to the customer. Its systematic nature also evaluates the necessary decisions for change and development at the beginning of the design process, reducing and even avoiding the mid-project changes and corrections. Customers would have no knowledge of whether or not a firm uses QFD. It is the price and the specifications that emerge as a result of using QFD that attracts the customer. In this way, QFD facilitates the entire development process, minimizing the corrections and waste during this phase, and optimizing the time required for introducing a new or improved product or service to the market (Karsak et al., 2002).

In this paper, only the first phase, i.e. the HoQ is utilized. In today’s competitive environment, the HoQ is a key strategic tool to aid companies in developing products that satisfy customer needs. HoQ provides a conceptual map that facilitates the means for inter-functional planning and communications. HoQ includes five major elements as (Shahin, 2008):

i) customer needs (Whats);
ii) design requirements (Hows);
iii) relative importance of the customer needs;
iv) relationships between Whats and Hows; and
v) overall priorities of the design requirements.

5. TOPSIS method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the useful Multiple Attribute Decision Making (MADM) techniques to manage real-world problems (Yoon and Hwang, 1985). TOPSIS was initially proposed by Hwang and Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution (Benitez et al., 2007). In fact, the ideal solution is composed of all the criteria with the best values attainable (aspired/desired levels), whereas the negative ideal solution is made up of all the criteria with the worst values attainable (tolerable level) (Wang, 2007).

The following characteristics of the TOPSIS method make it an appropriate approach which has good potential for solving selection problems (Amiri et al, 2010):

i) an unlimited range of alternatives and performance attributes can be included;

ii) in the context of alternatives selection, the effect of each attribute cannot be considered alone and must always be seen as a trade-off with respect to other attributes. TOPSIS seems a suitable method for multi-criteria selection problems as it allows explicit trade-offs and interactions among attributes. More precisely, changes in one attribute can be compensated in a direct or opposite manner by other attributes;

iii) the output can be a preferential ranking of the alternatives with a numerical value that provides a better understanding of differences and similarities between alternatives, whereas other Multiple Attribute Decision Making (MADM) techniques (such as the ELECTRE method) only determine the rank of each alternative;

iv) it can include a set of weighting coefficients for different attributes; and

v) it is relatively simple and fast, with a systematic procedure.

In this paper, the TOPSIS method is used for determining the final ranking of the alternatives. The general step-by-step procedure of TOPSIS is briefly introduced as follows (Ertugrul and Karakasoglu, 2009):

Step 1. Decision matrix is normalized:

$$n_{ij} = \frac{r_{ij}}{\sqrt[2]{\sum_{i=1}^{m} r_{ij}^2}} \tag{7}$$

where r_{ij} indicates the performance rating of alternative A_i (i=1,....,m) with respect to criterion C_j (j=1,...,n) and the normalized value of n_{ij} is the value of the corresponding element r_{ij} divided by the operation of its column elements.

Step 2. Weighted normalized decision matrix is formed as:

$$V = ND \times W_{n \times n} \tag{8}$$

Step 3. Positive and negative ideal solutions are determined as:

$$A^+ = \{(\text{Max V\_ij} \,|\, j \in J), (\text{Min } V_{ij} \,|\, j \in J^*) \,|\, i = 1, \dots, m\} = \{V_1^+, V_2^+, \dots, V_n^+\} \tag{9}$$

$$A^- = \{(\text{Min } V_{ij} | j \in J), (\text{Max } V_{ij} | j \in J^*) | i = 1, \dots, m\} = \{V_1^-, V_2^-, \dots, V_n^-\}$$

Where J is associated with the benefit criteria and J* is associated with the cost criteria.

Step 4. The distance of each alternative from ideal solution is calculated as:

$$D_j^+ : \sqrt[2]{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \tag{10}$$

$$D_j^- : \sqrt[2]{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2}$$

D^+: Distance of design from the positive ideal solution for the i^{th} candidate.

D^-: Distance of design from the negative ideal solution for the i^{th} candidate.

Step 5. The closeness coefficient of each alternative is calculated as:

$$CL_i^+ = \frac{D_i^+}{D_i^+ + D_i^-} \tag{11}$$

Step 6. By comparing CL_i values, the ranking of alternatives are determined.

6. Proposed methodology and findings

In this section, an algorithm is proposed, which can be divided into two major phases. In the first phase, the HoQ is constructed using the FAHP and simulation approaches, and in the second phase, the results of the first phase are integrated with Topsis approach for ranking plans. In order to examine the proposed algorithm, the Part Safeh Industry Co., which is a manufacturer of extrusion products in Iran is studied. Its products vary in three sub-groups depending on color, size and shape. Fig. 1 shows the current facility layout plan (flow diagram) of the company.

The aim of the new algorithm is to address a facility plan that produces quality products in a flexible and low cost manner. When product demands vary, frequent changes in the production line are unavoidable. In those time spans where the demand is very high, customers' needs might not be fully met. Mostly this is related to the high setup times; hence the low production velocity causes the low production flexibility, which in turn is a result of the low production volume and high production variety in the production lines. Therefore, changing the design of facility layout is necessary to cope with these problems. It is important to note that the application of the integrated approach is expected not to be limited to special cases and it could be applied in any organization with any type of services/products. The proposed methodology solves the layout design problem in a hierarchical framework, as illustrated in Fig.2. In the following, the steps of the proposed model are described.

6.1 Step 1: Data collection

Data collection should include characteristics of products, quantities, routing, support, and time considerations in order to assure the validity of the input data at the design stage. The design objectives usually include both quantitative and qualitative criteria**.** The process of Part Safeh Co. is divided into nine departments in the company's existing layout. The material flow is from department one to nine sequentially and regardless of product type. Table 1 represents the relationship codes and space requirements of the departments. The performance measures are determined through discussion with the company's managers and based on general layout guidelines. They include total cost, waiting time, flexibility, accessibility, and maintenance**.** Flexibility involves two aspects; the capability to perform a variety of tasks under a variety of operating conditions and the flexibility of future expansion. Accessibility involves material handling and operator paths. Finally, maintenance involves the required space for maintenance engineers and tools movement.

6.2 Step 2: Layout alternative generation

In production management one of the best-known methods for determining this arrangement is systematic layout planning (SLP), as developed by Muther (1973). SLP is a procedural layout design approach and is used for layout generation. The process of performing SLP is relatively straightforward. However, in recent decades it has been addressed as a common approach in providing layout design guidelines. The SLP begins with a data collection analysis called PQRST (step 1) for the overall production activities. It includes product (P), quantity (Q), routing(R), supporting (S), and time (T), which should be scrutinized in order to assure the validity of the input data at the design stage. In the flow of materials analysis (step 2), all material flows from the whole production line are aggregated into a from-to chart that represents the flow intensity among different tool sets or departments. The step of "activity relationships" (step 3) performs qualitative analysis towards the closeness relationship decision among different departments. The step of relationship diagram (step 4) locates departments spatially. Those departments that have strong interactions and/or close relationships are placed in proximity. The steps of "space requirements" and "space available" (steps 5 and 6) determine the amount of floor space to be allocated to each department. The step of “space relationship diagram” (step 7) adds departmental size information into the relationship diagram of step 4. Additional design constraints and limitations are considered before the start of block layout generation in steps 8 to 9. In step 10, layout alternatives are developed as design candidates. In step 11 the final design is chosen from the design candidates (Yang et al., 2000) and the alternative layout generation is constituted. These stages are presented in Fig.3. Also, in the case study, 12 alternatives are preliminary considered for further evaluation as illustrated in Fig.4.

6.3 Step 3: Quantitative data obtained from simulation

The focus of modeling and simulation process is on formulating and solving a real system such as facility layout problem. Furthermore, the system being studied is simulated, verified and validated. The next step involves scenarios definition. Data related to problem objectives would be extracted from simulation with respect to selected scenarios. Then, the result is normalized to be used in HoQ. The following assumptions are used to define the problem:

• the process line is never starved;

• set up times are not taken into consideration, since in a real system the setup process is usually accomplished at the end of the working time;

• eight hours working time does not include breaks;

• no maintenance process is performed during the working period;

• all process times for operations include ‘insignificant breakdowns’; and

• transportation of raw materials is performed by workers who are assigned for operations.

A simulation model is an easy way to develop models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resource utilization, cycle times, lead times, etc. Simulation has been recognized as a good tool to evaluate performance of different optimization methods. Good results have been obtained in the case of basic scheduling policies, allowing comparison between different options. The models can be applied in a real system to analyze the system performance, more efficiently and effectively. Thus, managers can prevent any unexpected situation by analyzing results using the simulation model.

In this study, the process is examined and the simulation model is run to be verified and validated. The comparison between simulation results and pre-historical records show the consistent throughput. After validation of the simulation model, the solution of improvements was generated by concurrently considering the practical changes in production operations and work constraints. Qualitative measures obtained from simulation model include total cost, waiting time and cycle time. Quantitative measures obtained from simulation for scenarios are addressed in Table 2.

The simulation models are implemented in the Arena simulation software. This software has a high capability to model manufacturing systems and embed key technology for desktop application integration, enabling the use of

existing enterprise models. As an example, the Arena model of the production process for alternative 1 is presented in Fig.5.

6.4 Step 4: FAHP for qualitative data evaluation

The purpose of the FAHP approach is to tolerate vagueness and ambiguity of information and to provide a vector of weights expressing the relative importance of the layout alternatives with respect to each criterion. Qualitative measures are weighted by FAHP. Qualitative data includes aspects of flexibility, accessibility and maintenance. The resulting weights are addressed in Table 3.

In order to construct fuzzy positive matrices, the scores of pair wise comparison are transformed into linguistic variables, which are represented by positive triangular fuzzy numbers listed in Table 4. For all stages of the hierarchy, the consistency index (CI) of the fuzzy judgment matrix is calculated. The resulting CI values of accessibility, maintenance and flexibility are 0.873, 0.902 and 0.848, respectively, indicating good consistency**.**

6.5 Step 5: Developing HoQ using data from previous steps

QFD could be used in different ways considering its flexible nature. This stage involves the integration of QFD, simulation (normalized results from simulation) and FAHP model. All these techniques are used to support the process of system optimization decision-making. With respect to the fact that the criteria (quantitative and qualitative) do not have equal weights, the purpose of this stage is to determine the weights and to provide the importance of the evaluation criteria in relation to alternative layouts. In other words, the relationship matrix indicates that how much each of the Hows affects each of Whats. The relations can either be presented in numbers or symbols. In this investigation, the results obtained from the previous steps (AHP and simulation) are used to denote the relationship between Whats and Hows. The HoQ matrix is then developed as depicted in Table 5. The required data such as pairwise comparison judgments of "Whats" are collected from experts' opinions and historical data in the company records. Also, the CI of the fuzzy judgment matrix is 0.896, indicating good consistency.

The sum of the overall priority of hows in Table 5 is not equal to 1. In fact, the sum of the values is 0.9995. The difference is due to rounding normalized values derived from simulation. However, this does not influence the priorities of alternatives in QFD. Alternatives 2, 3, 4, 6 and 7 have relatively higher weights than the first alternative, i.e. they have better performance compared to the existing layout. In selecting the best alternative, the 11 proposed alternatives are further prioritized in the next step based on more criteria and factors. It is important to note that since the existing layout (first alternative) is being utilized, its evaluation by Topsis criteria, i.e. cost and ease of implementation might become useless.

6.6 Step 6: Using Topsis

In general, MCDM is a powerful decision-making tool that structures the problem clearly and systematically. In this paper, in order to rank the alternatives according to attributes, the Topsis approach is used. In this approach, priority ranking of the 12^{th} alternative is computed by four attributes and in every problem a geometrical system can be considered consisting of 11 points in four dimensional spaces. The attributes which will be used for the evaluation of alternatives in the Topsis model include overall priorities of the Hows from HoQ (importance), implementation cost for each layout, ease of implementing each plan and number of essential personnel for each alternative. In this step, linguistic terms are used to describe the ease of implementing each plan as illustrated in Table 6. Also, by the use of Topsis approach and the experts' opinions, the decision matrix is constructed as Table 7. Then, the decision matrix is developed based on equation 7 (Table 8) and the attributes' weights are determined by the FAHP approach (Table 9). The weighted normalized decision matrix of the alternatives is developed by multiplying the normalized decision matrix and the weights (Table 10). After developing the weighted normalized decision matrix, the final ranking procedure determines the ideal solution and negative-ideal solutions as it is addressed in Table 11. Finally, the relative closeness of the ideal solution is calculated (Table 12).

7. Discussion

Considering the results of the case study, it is found that the integrated approach of simulation, FAHP model and QFD enhances the evaluation processes. In the first phase, the twelve alternatives were prioritized according to the six criteria derived from applying each of the two approaches of FAHP and simulation. According to the experts' opinions, quantitative measures had higher importance compared to qualitative measures and it is concluded that plans 6 and 11 had the highest and lowest priorities, respectively. However, with respect to the fact that there are additional factors for consideration (i.e. FLP), Topsis assures that plan 6 can become the best alternative for implementation. An important fact that should be noted here is that beside the potential advantages that the proposed approach might provide, there might be limitations. For example, the proposed approach can only be used in production systems with process layout (i.e. job shop). Also, depending on the strategies of organization, there might be limitations associated with the resource for implementation of each layout such as budget constraints and personnel level, i.e. required personnel for each layout. It is suggested to the organization to overcome the first limitation by solving FLP via the integrated approach proposed in this

research (i.e. FAHP, simulation and Topsis) and using methodologies such as genetic algorithm. Also, if resource limitations exist, it should be solved via models of programming such as goal programming.

The findings compared to the work of Yang and Kuo (2003) and Ertay et al. (2006) imply that the proposed methodology provides a more accurate, effective, and systematic decision support approach for problem solving (Fig.6). In addition, consideration of the relationships among criteria and plans of this paper provides organizations a way to refine and determine adequate criteria and decrease the risk of selecting optimal solutions.

In addition to the above discussion, it is argued that the systematic framework presented in this paper seems flexible and it can be easily extended to solve different management decision-making problems.

8. Conclusions

The objective of this paper was to propose an integrated approach of simulation, fuzzy AHP, QFD and MCDM for facility layout design improvement and optimization. The results indicate that the proposed approach enhances problem solving in facility layout, compared to the reviewed literature. The methodology was successfully applied in a plastic profile production system. In the proposed methodology, both quantitative and qualitative objectives were simultaneously considered by simulation and AHP and the most efficient scenario was determined by the Topsis model. This is quite important for systems where some of their performance measures are qualitative such as production systems. The objective of simulation model was to increase the reliability of the production system. FAHP was proposed to take the decision makers subjective judgments into consideration and to reduce the uncertainty and vagueness in the decision process. According to the flexible nature of QFD, the interaction of different approaches (FAHP and simulation) should be embraced and incorporated within the QFD process in order to utilize its full potential. Considering resource factors and multi-objective nature of the problem, a Topsis model was constructed to determine the best plan among all feasible alternatives according to the assessment of multiple quantitative and qualitative attributes. Overall, in this paper the development of system improvement and optimization decision support approaches were described with the aim of supporting management in reducing cost and increasing production rate.

While the developed model includes considerable advantages, its application is limited to process layout (job shop). Also, factors such as organizational strategy and constraints of resource, budget and personnel competence have not been considered. It is important to mention that the constraints of the eighth and ninth steps in SLP are associated with the location of departments, which are close to each other. For instance, the first department (raw materials) should not be located next to the sixth department (painting). Also the third and fourth departments should be located in a particular space, since the work pieces must be moved through underground system to be washed. In addition, it should be noted that the findings may be relevant to the studied company (i.e. Part Safeh Co.) and applicability of the processes and tools used should be further examined in wider samples of organizations.

Although the proposed methodology was related to a production system, it can also be developed for different systems. Modification and adjustment may be required on the proposed approach due to two reasons: the components constituting the QFD of the proposed model such as criteria (quantitative and qualitative) and number of alternatives (layouts) may vary depending on the organization vision; and relationships or dependencies among criteria or performance measures may also vary. However, it seems that the modification and adjustment will make the new methodology more effective.

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Table 1. The relationship codes and space requirements of the departments

No.	Departments	Required space (m^2)	1	2	3	4	5	6	7	8	9
1	Raw material warehouse	300		A	I	I	O	O	O	O	U
2	Mix material	100			A	A	O	O	O	O	O
3	Production line 1	300				I	E	E	O	I	O
4	Production line 2	300					O	O	E	I	O
5	Recapping	100						I	O	E	O
6	Painting	100							O	I	O
7	Cutting	80								I	O
8	Packaging	70									A
9	Final products warehouse	300									

Table 2. Quantitative measures obtained from simulation

	1	2	3	4	5	6	7	8	9	10	11	12
Total cost($)	12926	12676	12010	12983	13011	11950	11841	12413	13022	13046	13099	13070
Wait time(M)	140.016	135.684	109.114	148.238	151.553	103.123	92.047	124.589	157.113	163.252	176.899	174.498
Cycle time(M)	6.91	6.85	5.98	7.09	7.39	5.81	5.35	6.43	7.42	7.53	8.97	7.71

Table 3. Qualitative measures obtained from FAHP

Criteria \ Alternatives	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Flexibility	0.0796	0.0805	0.1089	0.0782	0.0713	0.1208	0.1219	0.0811	0.0707	0.0686	0.0552	0.0632
Maintenance	0.0840	0.0911	0.1106	0.0786	0.0708	0.1109	0.1019	0.0894	0.0701	0.0672	0.0623	0.0631
Accessibility	0.0813	0.0829	0.1168	0.0803	0.0752	0.1200	0.1204	0.0983	0.0649	0.0621	0.0410	0.0568

Table 4. Triangular fuzzy numbers (Lee et al., 2008)

Linguistic variables	Positive triangular Fuzzy number	Positive reciprocal triangular fuzzy number
Extremely strong	(9, 9,9)	(1/9, 1/9, 1/9)
Intermediate	(7, 8,9)	(1/9, 1/8, 1/7)
Very strong	(6, 7,8)	(1/8, 1/7, 1/6)
Intermediate	(5, 6,7)	(1/7, 1/6, 1/5)
Strong	(4, 5,6)	(1/6, 1/5, 1/4)
Intermediate	(3, 4,5)	(1/5, 1/4, 1/3)
Moderately strong	(2, 3,4)	(1/4, 1/3, 1/2)
Intermediate	(1, 2,3)	(1/3, 1/2, 1)
Equally strong	(1, 1,1)	(1, 1,1)

Table 5. HoQ matrix for the evaluation alternatives

Methods	HOWs (Alternative) / Whats (criteria)	Current layout	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10	Alternative 11	Alternative 12	Weight of Whats
Via simulation	Total cost	0.0850	0.0833	0.0789	0.0853	0.0855	0.0785	0.0778	0.0816	0.0856	0.0858	0.0861	0.0859	0.2622
	Wait time	0.0835	0.0809	0.0650	0.0884	0.0904	0.0615	0.0549	0.0743	0.0937	0.0973	0.1055	0.1041	0.1709
	Cycle time	0.0828	0.0820	0.0716	0.0849	0.0885	0.0696	0.0641	0.077	0.0889	0.0902	0.1075	0.0924	0.1679
Via FAHP	Accessibility	0.0796	0.0805	0.1089	0.0782	0.0713	0.1208	0.1219	0.0811	0.0707	0.0686	0.0552	0.0632	0.1320
	Maintenance	0.0840	0.0911	0.1106	0.0786	0.0708	0.1109	0.1019	0.0894	0.0701	0.0672	0.0623	0.0631	0.1313
	Flexibility	0.0813	0.0829	0.1168	0.0803	0.0752	0.1200	0.1204	0.0983	0.0649	0.0621	0.0410	0.0568	0.1357
	Overall priorities of the Hows	0.0830	0.0833	0.0886	0.0833	0.0816	0.0896	0.0863	0.0828	0.0807	0.0806	0.0797	0.0802	

Table 6. The linguistic scales used for the easy implementation of each plan

The linguistic variable	Linguistic scale	Weightings for each alternative
VE	Very easy	5
E	Easy	4
M	Medium	3
T	Tough	2
VT	Very Tough	1

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Table 7. Decision matrix based on Topsis approach

	Importance (QFD)	Cost ($)	Personnel	Ease of implementation
Plan 2	0.0833	11526	58	3
Plan 3	0.0885	11018	55	3
Plan 4	0.0832	14116	64	1
Plan 5	0.0816	9000	60	5
Plan 6	0.0896	11101	56	3
Plan 7	0.0863	12130	55	2
Plan 8	0.0828	12213	57	2
Plan 9	0.0807	12000	61	3
Plan 10	0.0806	12007	61	3
Plan 11	0.0797	15000	64	1
Plan 12	0.0802	10985	62	4

Table 8. Normalized decision matrix

	Importance(QFD)	Cost($)	Personnel	Ease of implementation
Plan 2	0.30122	0.28925	0.29416	0.30619
Plan 3	0.32002	0.2765	0.27894	0.30619
Plan 4	0.30086	0.35425	0.32459	0.10206
Plan 5	0.29507	0.22586	0.3043	0.51031
Plan 6	0.324	0.27858	0.28402	0.30619
Plan 7	0.31207	0.30649	0.28909	0.20412
Plan 8	0.29941	0.30649	0.28909	0.20412
Plan 9	0.29182	0.30114	0.30937	0.30619
Plan 10	0.29145	0.30132	0.30937	0.30619
Plan 11	0.2882	0.37643	0.32459	0.10206
Plan 12	0.29001	0.27567	0.31445	0.40825

Table 9. Attributes weights

Attribute	Importance	Cost	Personnel	Ease of implementation
Wj	0.6859	0.1118	0.1069	0.0954

Table 10. The weighted normalized decision matrix

	Importance (QFD)	Cost($)	Personnel	Ease of implementation
Plan 2	0.206605	0.032338	0.031446	0.02921
Plan 3	0.219503	0.030913	0.029819	0.02921
Plan 4	0.206357	0.039605	0.034699	0.009737
Plan 5	0.202389	0.025251	0.03253	0.048684
Plan 6	0.222231	0.031146	0.030361	0.02921
Plan 7	0.214046	0.034265	0.030903	0.019473
Plan 8	0.205365	0.034265	0.030903	0.019473
Plan 9	0.200157	0.033668	0.033072	0.02921
Plan 10	0.199909	0.033687	0.033072	0.02921
Plan 11	0.197676	0.042085	0.034699	0.009737
Plan 12	0.198917	0.03082	0.033614	0.038947

Table 11. The ideal solution and negative-ideal solution obtain for each criteria

	Importance(QFD)	Cost($)	Personnel	Ease of implementation
ideal solution	0.222231	0.025251	0.029819	0.048684
negative-ideal	0.197676	0.042085	0.034699	0.009737

Table 12. Relative Closeness

	D^+	D^-	Relative Closeness	Ranking
Plan 2	0.026149	0.03135	0.545227	4
Plan 3	0.020463	0.03169	0.607637	3
Plan 4	0.026005	0.02376	0.477443	5
Plan 5	0.030972	0.021386	0.408457	7
Plan 6	0.020026	0.042745	0.680964	1
Plan 7	0.020353	0.033476	0.62189	2
Plan 8	0.030788	0.021421	0.410291	6
Plan 9	0.03493	0.015148	0.302489	9
Plan 10	0.031665	0.020936	0.398016	8
Plan 11	0.049264	0.0	0.0	11
Plan 12	0.044707	0.009028	0.168015	10

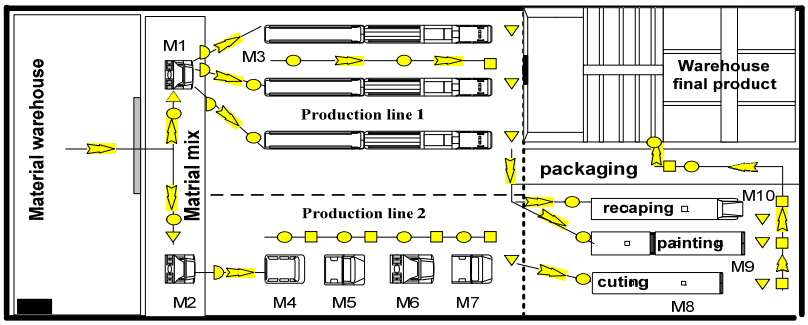

Figure 1. Flow diagram at Part Safeh Industry Co.

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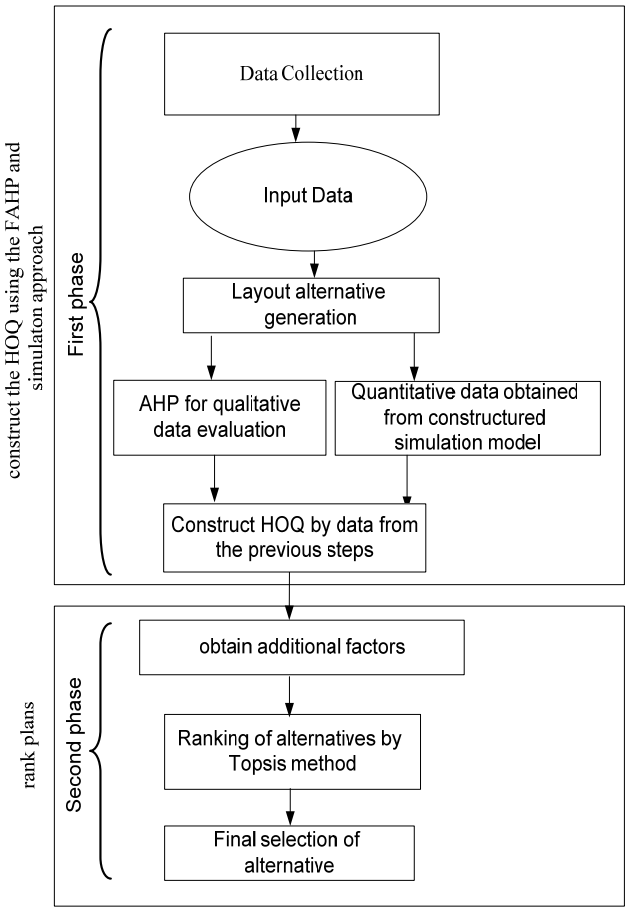

Figure 2. Proposed methodology

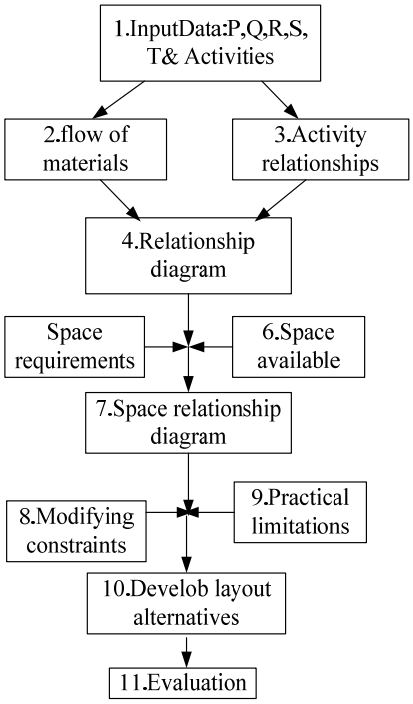

Figure 3. SLP procedure

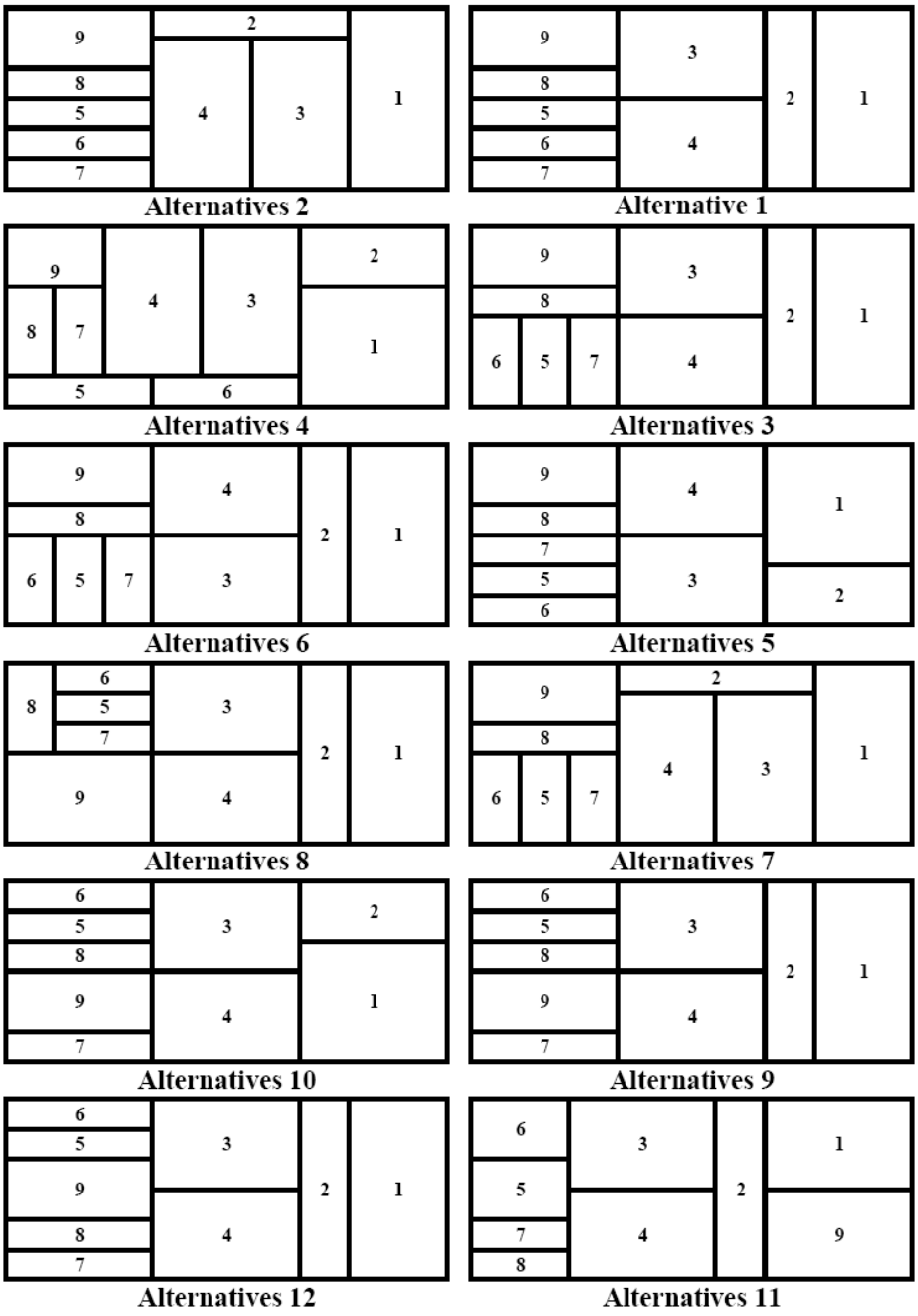

Figure 4. 12 alternatives

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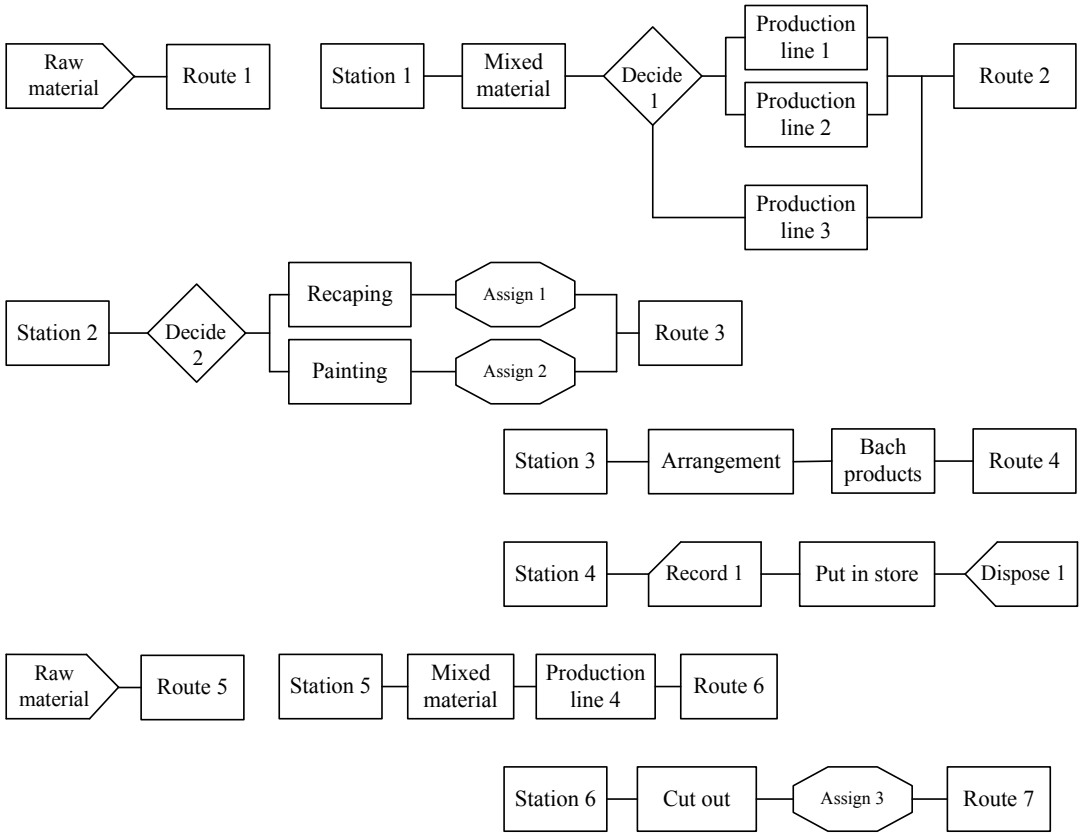

Figure 5. Arena modeling of production process for alternative 1

A hierarchical AHP/DEA methodology for the facilities layout design problem	Integrating DEA and AHP for the facility layout design in manufacturing systems

This research	Approach	Yang and Kuo (2003)	Ertay et al (2006)
Evaluation tools for quantitative criteria	simulation	Handheld computing	Handheld computing
Evaluation tools for qualitative criteria	FAHP	AHP	AHP
Determining importance of each criteria via	QFD	Criteria have equal weights	Criteria have equal weights
Solve problem via	Topsis	DEA	DEA
Advantages of this research compared to previous studies	1.Simulation is used to study behavior of real system 2.QFD is used to determine importance of each criteria (quantitative and qualitative), but in previous studies, the weights were equal. In this research, more criteria are considered for analysis. 3.In this research, the preference ratings of the alternatives are determined by additional goals and overall priorities of HoQ. 4.In order to obtain reliable results, based on alternatives and attributes, an integrated approach of QFD and Topsis models is used.		

Figure 6. Comparison of this research and the reviewed literature