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Multi-criteria decision making for the selection of a performant manual workshop layout: a case study

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Abstract: The purpose of this paper is to evaluate and to select a new workshop layout among a set of alternatives to meet changes in demand. We suggest a multi-criteria decision making approach using Analytic Hierarchy Process (AHP) technique coupled with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to help decision makers in the selection process. AHP is applied to get the weights of selected criteria by comparing them pair-wise by experts. The final ranking of potential configurations is obtained through the application of TOPSIS according to their performance levels. This methodology identifies the most performer configuration responding to the selected criteria. The approach is applied to a real case in Tunisia.

Keywords: Layout reconfiguration, Manual assembly shop, Multi-criteria decision making, AHP, TOPSIS.

1. INTRODUCTION

Manufacturing systems have to be reconfigured to align their production capability with their management goals or customer needs, see (Youssef et al., 2006). Plant configuration has significant impacts on the system performance including its reliability and productivity, product quality, capacity scalability, and cost (Koren et al., 1998). Facility design is the scientific field in which such configuration problems are studied (Meller et al., 1996; Singh et al., 2005; Drira et al., 2007). In this field we look for proposing a layout which guarantees the best the smooth products, persons and information circulation within the system. Various criteria are used to compare alternatives such as costs of handling systems, average work-in-process, satisfaction of weighted adjacency, satisfaction of distance requests or added-value occupied surface (Aiello et al., 2006; Saraswat et al., 2015). A facility layout is an arrangement of everything needed for production of goods or delivery of services. A facility is an entity that facilitates the performance of any job (Drira et al., 2007). For this kind of problem, “materiel flow”, “information flow” and “equipment flow” should be taken into account. The problem is clearly multi-criteria in nature and trade-offs do often exist between various objectives. The main studied sub-problems in facility design are: alternative generations, criteria selection, alternatives evaluation, alternative selection (Al-Hawari et al., 2014). In this paper we deal with the three last questions; the alternatives do exist or are suggested by users (as in our case study) but the choice of the most relevant one remained unsolved.

This paper contributes to: (i) the choice of the quantitative and qualitative criteria influencing the layout configurations in a manual assembly shop, and (ii) the choice of the most performer layout among the suggested configurations or layout using an innovative approach that combines AHP and TOPSIS technique.

This paper is organized as follows. In section 2, we provide an overview of the related works developed in the literature. It will be shown in section 3 that combining the techniques of multi-criteria decision-makings could help users to make a better configuration selection. In fact, it can be understood that the selection criteria do not have the same criticality; weights should be associated with them. The Analytical Hierarchical Process (AHP) technique is therefore a very suitable tool for the determination of the criteria weights involving the field experts and users. From the other side, the alternatives have to be assessed and compared. TOPSIS is used to rank the alternatives to select suitable configuration. Section 4 presents the methodology set up for such alternative selection. In section 5, the case study is presented and the application of the methodology is illustrated. We discuss then the benefits of such methodology highlighting its strengths while pointing out the necessary improvements in the future works. Finally, section 6 contains the conclusions and perspectives.

2. LITERATURE REVIEW

2.1 Related works

Reconfiguration of manufacturing systems is considered as a means for creating sustainable manufacturing firms. It has significant impacts on the efficiency of the manufacturing system. Three main issues arise in the reconfiguration problem are: “When do we reconfigure the manufacturing systems?” “How do we reconfigure manufacturing firms?”

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and “How do we evaluate the reconfiguration process?” see (Garbie, 2014). To be complete we should add the last question related to the multi-criteria selection of the best alternative.

Some of these aspects are studied before. In a first work, (Garbie et al., 2008) tackled the problem of evaluation of configurations based on agility level, production system size, plant layout and material handling systems. Authors published a newer reconfiguration methodology for the manufacturing systems (Garbie et al., 2014). (Hon et al., 2007) present the relationship between the product life cycle for a family of products and the manufacturing systems performance optimization via reconfiguration. (Makssoud, 2014) treated the reconfiguration problem for transfer and assembly lines.

One of the most important aspects of the workshop design concerns the level of implemented automation. In the case of highly automated lines, the reconfiguration or redesign objective is to minimize the investment costs. Nevertheless, in highly manual workshops, the goal is to minimize costs associated with learning operators caused by the task reallocation. In fact, for a new configuration, new process, movements or standards should be invented to accompany the configuration. This is long and expensive and reduces the awaited performance targets.

There are extra costs that should be associated with any reconfiguration possibility. This is the case for instance of cabling, energy supply modifications, masonry activities, certifications, etc. A reconfiguration problem is then much larger than just displacing machines and all extra-costs should be taken into account for any further decisions. In this paper, we voluntarily focus only on the evaluation of configuration alternatives; the other aspects of configuration problems are not addressed here.

Several techniques and theories can be used to assess the impact of each suggested alternatives. Among the methods applicable for criteria weighting, we quote the analytic hierarchy process (AHP) (Ben Cheikh et al., 2015, 2016) and the Fuzzy AHP (Abdi et al., 2009).

Abdi et al. (2009) suggest a multi-criteria decision making approach based on Analytic Hierarchy Process (AHP) for the selection of layout configurations. The AHP model is proposed to take into account both quantitative and qualitative criteria of reconfigurability, cost, quality and reliability. Ben cheikh et al. (2015) develop an AHP model to assist decision makers in the selection process. They consider both strategic and operational criteria when evaluating the reconfiguration decisions. The same authors proposed some human factors and ergonomics related indicators that allow taking into account working conditions when reconfiguring a manufacturing system. Experiments show the importance of considering such human factors and ergonomics issues in reconfiguring manufacturing systems (Ben cheikh et al., 2016). Abdul-Hamid et al. (1999) present an alternative approach to select a suitable type of layout using Analytic Hierarchy Process (AHP). The methodology considers three main objectives for the selection of layouts: increasing flexibility, increasing production volume and reducing manufacturing costs. The three possible types of layout are considered: functional (process) layout, group technology (cellular) layout and transfer (flow) lines.

There are numerous techniques of multi-criteria decision-making. Interested readers should refer to (Velasquez et al., 2013) for a very complete and up-to-date survey of main techniques. Regarding our case study, the most relevant technique seemed to be at the same time one of the most common one, i.e. TOPSIS.

(Yang et al., 2007) use TOPSIS and Fuzzy TOPSIS to solve a layout design problem. A practical application from an Integrated Circuit packaging company was adopted. This study aimed at searching an improved solution to an existing design. (Maniya et al., 2011) propose a multiple attribute decision making based on preference selection index (PSI) for selection of facility layout design. (Al-Hawari et al., 2014) apply the Analytic Network Process for the selection of the best facility layout. The criteria taken into account are related to closeness value, expansion flexibility, routing flexibility, productive area utilization, volume flexibility and human issues.

There are some previous works tending to make use of AHP-type methods and a MCDM technique. For instance, (Yang et al., 2003) propose AHP and Data envelopment Analysis (DEA) to solve the plant layout design problem. A computer aided layout planning tool entitled Spiral is adopted to generate alternative layout design approach. (Vencheh et al., 2012) addressed the configuration problem, and presented a decision-making methodology based on a simple nonlinear programming model (NLP) with AHP. The available configurations are evaluated according to quantitative criteria (distance, adjacency score and shape ratio) and qualitative criteria (accessibility, maintenance and flexibility).
Up to our knowledge, there is no research that utilizes the coupling AHP-type technique and a multi-decision decision-making for the configuration choice. Due to the complementarity of these two techniques, we will couple them together. Here we are going through these techniques more deeply.

2.2 The AHP technique

AHP is developed by Thomas Saaty, to structure a complex multi-attribute evaluation problem hierarchically. It includes four basic steps:

1- Classify the overall goal of the decision, criteria and alternatives into a hierarchical structure as shown in Fig.4.
2- Construction of comparative judgment matrices by pair-wise comparisons based on decision makers preferences using the scale of Saaty, (1990), see Table1. Decision makers compare each criterion to all other criteria at the same level of the hierarchy structure.

Table 1. AHP comparison scale

Verbal judgments	Degree of preferences
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong or demonstrated importance	7
Extreme importance	9
For compromise between the above values	2,4,6,8

3- Determine the criteria weights.

4- Compute the consistency ratio (CR). The CR is obtained by applying the Equation 1. This is the ratio of the consistency index (CI) and the Random Index (RI). CR is computed thanks to (2) where λ_{max} is the maximum eigenvalue of the considered matrix and n is its size. The random index stands for the level of reliability of the same assessment made repeatedly.

$$CR= \frac{CI}{RI} \quad (1)$$

where $CI=\frac{\lambda_{max}-n}{n-1}$ (2)

If CR<0.1, it means that the experts judgements consistency is acceptable. Otherwise, the decision maker needs to revise the judgments and improve the evaluation process.

2.3 The TOPSIS method

TOPSIS is a multi-criteria decision making technology proposed by Hwang and Yoon (1981), (Behzadian et al., 2012). The standard TOPSIS method attempts to choose alternatives that simultaneously have the shortest "distance" from the positive ideal solution and the farthest "distance" from the negative-ideal solution. This distance qualifies the quality of the solution regarding the best and the worst solutions. The TOPSIS method can be summarized as follows. Suppose there are m alternatives $A_1, A_2, ..., A_m$ and n decision criteria $C_1, C_2, \ldots, C_n$.

1- Generate an evaluation matrix by considering of 'm' alternatives and 'n' criteria, with the intersection of each alternative and criteria given as x_{ij}.

2- Construct the normalized decision matrix. Each of this matrix component is defined by:

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \text{ , i=1… m, j=1… n} \quad (3)$$

where r_{ij} is normalized score of the decision matrix.

3- Calculate the weighted normalized ratings.

$$v_{ij}=w_j * r_{ij} \text{ , i=1… m, j=1… n} \quad (4)$$

where w_j is the weight for j criterion (obtained in our case from the AHP application).

4- Determine the positive ideal and negative ideal solutions.

5- Calculate the separation measures for each alternative.

The separation from positive ideal alternative A^* is:

$$S_i^*=\sqrt{\sum_{j=1}^{n}(v_{ij}-v_j^*)^2} \text{ , i=1… m.} \quad (5)$$

Similarly, the separation from negative ideal alternative A^- is:

$$S_i^-=\sqrt{\sum_{j=1}^{n}(v_{ij}-v_j^-)^2} \text{ , i=1… m.} \quad (6)$$

6- Calculate the relative closeness to the ideal solution C_i^*.

$$C_i^*=\frac{S_i^-}{S_i^-+S_i^+}\text{, i=1… m. Note that } 0\leq C_i^* \leq 1 \quad (7)$$

Choose an alternative with maximum C_i^* or rank alternatives according to C_i^* in descending order.

3. MOTIVATION TO COUPLE AHP-TOPSIS

(Hsieh et al., 2006) justified the combination of AHP and TOPSIS as a way to avoid the problem of obtaining the same order of preference for two different alternatives and therefore, it cannot be appropriately ranked. For example: A1 and A2 are two alternatives, A^+ is the positive ideal solution and A^- is the negative ideal solution as shown in Fig. 1. we notice that line $\overline{A_2A^+}$=$\overline{A_1A^+}$. Computing the distance of these two solutions to the positive ideal solution, it might be concluded that A1 ≈ A2. Now, if we add the distance to the negative ideal solution, line A_1A^- is larger than A_2A^-line. That is line $\overline{A_1A^-}$>$\overline{A_2A^-}$ i.e. A1 is farther, therefore, according to TOPSIS, we can judge A1 > A2, as shown in Fig. 1 since it takes into account the positive ideal and negative ideal solutions. Moreover the TOPSIS method uses the weights already calculated by the AHP and the AHP gives decision makers the confidence of the consistency. This is the rationale for choosing AHP-TOPSIS integrated method.

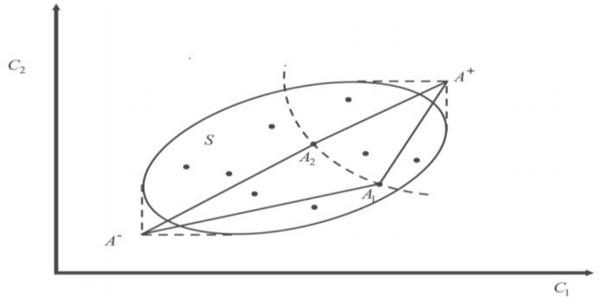

Fig. 1. TOPSIS positive ideal and negative ideal chart (Hsieh et al., 2006; Joshi et al., 2011).

4. THE PROPOSED METHODOLOGY

In order to reconfigure a manufacturing system, decision makers have to choose one configuration among a set of alternatives. These alternatives were generated by commercial software such as Spiral (Yang T et al. 2007), by industrial engineers or by any other method or technique. Each alternative is evaluated against the criteria related to general aspects that are generic and suitable for a wide range of manufacturing companies. In fact, even in such a narrow perspective, the layout design problem concerns more than one criterion. We would focus on material handling costs, space, labor, bottlenecks, communication and interaction between workers, between workers and their supervisors, or between workers and customers, manufacturing cycle time and customer service time. A preliminary study was conducted to determine all factors that affect the effectiveness of a facility layout. These aspects or criteria were collected from the state of the art and experts.

- Expansion flexibility, a good layout will be the one that can rapidly be modified to meet changing in circumstances.
- All workstations must be accessible to get an efficient process flow.
- Productive area utilization should be maximized.
- Resources utilization has to be maximized.
- Human issues such as inherent safety and security must be considered in the evaluation of any manufacturing layout because of its direct impact on productivity.

In order to facilitate an accurate decision analysis, we assign to every aspect one or more criteria. The importance of each criterion is determined by AHP. The choice of the appropriate configuration is achieved by TOPSIS after evaluation by experts. Two experts are invited to grade the alternatives when applying both methods which are the production manager and the manufacturing designer.

The proposed methodology is illustrated in Fig. 2.

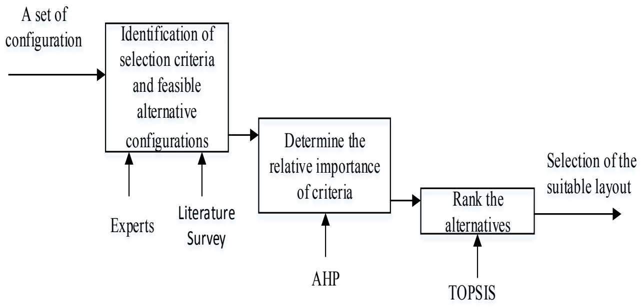

Fig. 2. The proposed methodology

5. CASE STUDY

In this section, the proposed methodology will be applied to a case studied.

5.1 Description of the manufacturing system

The studied company is AMECAP. It produces a complete range of accessories for sanitation, and subcontract high precision mechanical parts. Due to the increased demand, the number of operators working in the manual assembly workshop has also increased. The current configuration of the workshop is no longer adapted to its activity. We applied the suggested methodology to solve the reconfiguration problem. The task was focused on the manual assembly shop.

The main problems of the workshop were listed during a meeting with the general manager: (i) unnecessary movements, (ii) high work-in-process and (iii) poor arrangement of fixtures stations. The new configuration has to solve these problems or at least reduce their effects.

Three configuration alternatives are evaluated in this study: the current one and two other configurations proposed by the production manager of the company.

The *current configuration A1* in Fig. 3 is composed by ten independent workstations randomly arranged. The blue area represents the space either not occupied at all or used by the non-value adding activities. The yellow rectangles represent the stocks (raw material, work in process and final product). The white rectangles represent workstations and the gray rectangles represent the chairs.

Proposed Configuration A2 consists of six cells, and one of them is composed by two marking units emitting a quite disturbing noise for operators. This ensures a comfortable working environment. As an indication it should be noted that the marking operations in the manufacturing process of several products.

Proposed Configuration A3 is formed by five cells, and the two noisy units are placed in two different cells (cell 2 and 3).

The cell 1, 4 and 5 remains such that it is in the configuration A2.

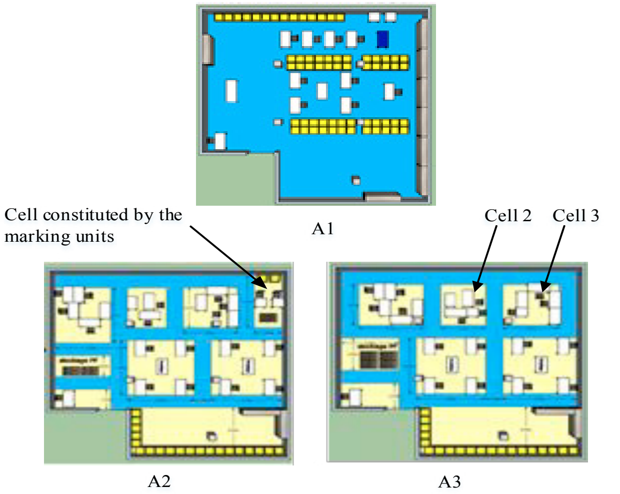

Fig. 3. Presentation of alternative configurations

In next section, the evaluation criteria of these alternatives are presented

5.1.1 Criteria configuration

Based on the scientific literature concerning workshop design and on experts' interviews, five criteria were considered to be the most appropriate ones for the manual assembly shop reconfiguration.

Two first criteria are qualitative and the other three are quantitative.

Flexibility (C1) is the capability to perform a variety of tasks under a variety of operating conditions. It is the ratio of the number of tasks that can be performed by a workstation over the total number of tasks within the workshop.

Accessibility (C2) involves two aspects: material handling and operators paths (Yang et al., 2007), (Venchecha et al., 2013). The accessibility evaluates, from a given scale, how easy is to move within the facility items, goods and operators within the workshop.

Area utilization rate (C3) represents the value-added surface relative to the total surface.

Labor utilization (C4) measures the ratio of average hours worked by an operator over the total working hours allocated to the resource within a given period of time (Xiaohong, 2012).

$$R_L=\frac{T_W}{T_T} *100\%$$

R_L is the average labor utilization, T_W is the work time of labor, including processing, loading, unloading, loaded and empty travel time, T_T is the total time of labor in a factory.

The permanent *Noise (C5)* generated by the marking units make the operators feel uncomfortable although this noise level does not exceed the allowed threshold. This criterion has an impact on the required distance between two workstations (Yang et al., 2007), (Venchecha et al., 2013).

The global problem can be therefore shown in Fig.4. These aforementioned criteria were be used to evaluate the performance of the three configurations designed by the general manager.

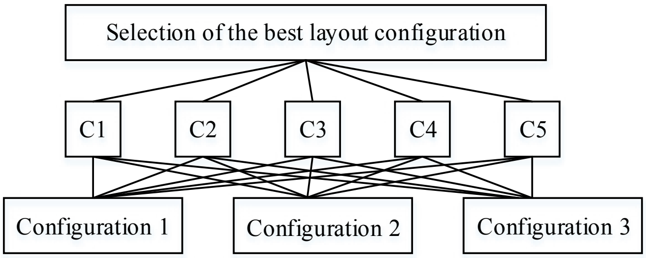

Fig. 4. The AHP structure for the studied problem

5.2 Relative importance of the selection criteria

According to AHP, as the selection criteria are not equivalent, the experts are involved in the first step of criteria weight determination. The criteria are compared pair-wise using the Saaty's scale. The relative importance weighting criteria obtained by AHP is presented in Table 2.

Table 2. Pair-wise comparisons matrices

	C1	**C2**	**C3**	**C4**	**C5**	**Weight of each criteria**
C1	1	4	3	1	4	0.34
C2	0.25	1	0.33	0.2	1	0.073
C3	0.33	3	1	0.33	3	0.16
C4	1	5	3	1	4	0.35
C5	0.25	1	0.33	0.25	1	0.074

Once all criteria weights are calculated, we evaluated the expert' judgement consistency by calculating the consistency ratio CR, as explained in section 3.1.

In our case, CR=0.02 where CI= 0.0231, λ_{max}=5.09 and RI=1.12. As CR<0.1, the results are acceptable and indicate the goodness of judgments (Saaty, 1990).

5.3 Classification of the configurations using TOPSIS

Based on the assessment of the general manager, an evaluation matrix was built where each alternative was evaluated against the selection criteria as shown in Table 3.

Table 3. Decision matrix

	C1	**C2**	**C3**	**C4**	**C5**
A1	8	3	3	4	5
A2	7	1	5	6	4
A3	4	8	4	6	2

After the establishment of the decision matrix, we normalize the x_{ij}. The next step is to create the weighted normalized decision matrix, cf. equation (3). Then we find the positive and negative ideal solution (shown in Table 4) and we calculate the distances (Table 5), see to (5) and (6). The rank of considered alternatives can be decide, according to the descending order of C_i^* refer to the equation (7).

Table 4. The positive and negative ideal solution to corresponding criteria

	C1	**C2**	**C3**	**C4**	**C5**
A_i^+	1.91	0.01	0.57	1.36	0.28
A_i^-	0.48	0.52	0.21	0.6	0.04

Table 5. Calculating distance of each alternative to the ideal and negative solution

	A1	**A2**	**A3**
S_i^*	0.46	1.56	0.84
S_i^-	1.44	0.77	1.4

As shown in Fig. 5, $A_2^* > A_1^* > A_3^*$ the alternative A2 is the most appropriate for the new situation, then the current configuration A1 and finally the second proposition of reconfiguration A3. A reconfiguration process is then required in this case. We verified and validated the results with the experts from the assembly shop AMECAP.

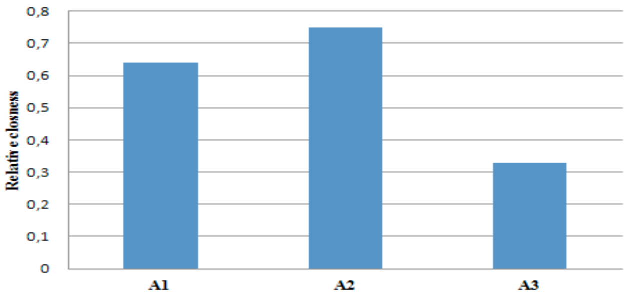

Fig.5.The layout solution for the proposed methodology

6. CONCLUSION AND PERSPECTIVES

This paper contributes to the choice of the quantitative and qualitative factors influencing the layout configuration in a manual assembly workshop.

In addition, no research has been found on the application of the Analytic Hierarchy Process (AHP) coupled with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to evaluate a set of alternatives and determine the efficient configuration of manufacturing systems. Three layout configurations for the AMECAP Company are defined as alternatives for the case study in response to change in demand. Besides, we consider the current configuration as a third alternative. By applying these two methods, we find that A2 is the most appropriate configuration. We recall that A2 is not the current configuration. So, a reconfiguration process is required for our case.

We did not address the alternative generation problem which is one of the most complex problems to solve. In this paper, we dealt with the alternatives proposed by experts which could be biased. In other research works we do focus on this issue to generate alternative that respects the rules of good design that is based mainly on controlling flows.

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