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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.