Layout evolution effort for product family in Reconfigurable Manufacturing System design

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Abstract: This paper describes a multi-objective approach that assesses the evolution and layout transition efforts between products of a product family in reconfigurable manufacturing systems (RMS) design. The layout evolution effort is minimized and system performance metrics (i.e., average machine utilization and alternative replacement machines within the system) are maximized. The problem considers various manufacturing constraints as well as various metrics to ensure the high performance of the designed reconfigurable manufacturing system following the generated layouts. The effectiveness of the developed approach is evaluated using an illustrative numerical example. The results show the effectiveness of the multi-objective approach to help decision maker’s designing RMS. The approach can be used later to guarantee a better system performance when solving the problems of machine layout in the context of RMS.

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1. INTRODUCTION

Nowadays, the manufacturing world witnesses a frequently varying product demand and fast introduction of new products that leads to unpredictable market changes as well as a ferocious global competition. To cope with these increasingly influencing manufacturing factors and to offer a cost-effective and rapid response to production requirements, reconfigurable manufacturing systems (RMS) were proposed by Koren (1999). RMS is formed by using reconfigurable, automated, and multifunctional machines. These machines are seen as one of the major components of RMS. They are known as reconfigurable machine tool (RMT). RMT can be easily transformed when requirements change. This ability is due to the specification of their design for a customized range of requirements (Mehrali et al. 2002). One of the most critical issues in designing the RMS is machine layout problem. Unlike conventional manufacturing systems, the RMS layout needs to take into consideration not only the current product to be produced and classical constraint (precedence relations, machine capabilities …etc.) but also the new specificities of RMS, the whole product family and the transition that may occur when switching from one product to another in this product family. This transition can be seen in Figure 1 as described by (Koren 2010). The figure describes that during the lifetime of RMS, the system undergoes some changes in response to new products. Under these conditions, RMS requires being more flexible, robust and reconfigurable, and must adapt to different production requirements by going through frequent configuration changes.

The goal of such frequent change is to reduce manufacturing cost as well as increasing the system efficiency. Thus, the layout must be more changeable. It must go through frequent reconfiguration as well as frequent redesigning. The aim of this process is to ensure the needed reconfigurability that characterize the RMS. The frequent reconfiguration and redesign of layout must also maintain the system high performance (productivity, reactivity, maintainability…etc.). Maintaining high performance can be achieved by integrating performance metrics at the outset of the layout design process. Compared to conventional and existing systems, RMS provides new principles and alternatives. Thus, it is a very active research field.

![Fig.1. RMS changes during product family transition (Koren 2010)](image)

Research efforts are mainly addressed to RMS design, modelling, and the generation of process plans. Nevertheless, there is very little works on the operational aspects of RMS design along with layout. Therefore, there is a necessity of reconsidering the existing methods and approaches used for existing systems. This reconsideration will help us better meet
the needs and challenges of RMS by adapting existing methods and/or developing new ones.

One of the aspects to be explored more deeply is how to deal with machines layout problems in a RMS context. Why? Because RMS comprises combinations of software modules, as well as hardware ones, that can be rearranged, or removed when needed in a rapid and reliable way. This kind of rearrangement could be the consequence of quickly adjusting functionality and production capacity, reconfiguration, product change within a part family or market requirement change amongst other, etc. When designing a RMS, a manufacturer finds several feasible configurations for each product family (Lacksonen and Hung 1998, Kochhar and Heragu 1999). Thus, an important issue arises, which is the choice of optimal configurations or rearrangement for each family, since different configurations have a significant impact on profits as well as the whole system (Xiaobo et al., 2000)

Our research work concerns the question of managing the machines positioning within an RMS layout. More precisely, our problem consists in finding the best rearrangement of selected machines in a layout to ensure the system responsiveness and high performance when transitioning from one product to another in the product family. A metaheuristic is adapted based on the well-known Archived Multi-objective Simulated Annealing (AMOSA). The approach is based on three objectives namely the minimization of the transition effort between layouts of the product family, the maximization of machine average utilization for all products of the product family and finally the maximization of alternatives replacement among the selected machines in case of unavailability. The three objectives guide the adapted AMOSA to the best solution based on the given process plan of each product in the product family.

The rest of the paper is structured as follows: section 2 discusses some existing works on the process plan generation in RMS as well as studies on layout problem in general. Section 3 presents the considered problem. Section 4 describes the proposed approach. Section 5 illustrates a numerical example and discusses the obtained results. Section 6 concludes the paper with some future work directions.

2. RELATED WORKS

RMS design undergoes two main tasks. One is related to selecting the machines to be included in the design, which is generally based on process planning. Whilst the second, concerns the disposition of these machines in the layout process. When it comes to process plan generation in RMS, the state of the art is very rich. Process plan (or process planning) is described as the activity that decides the sequence, which the manufacturing process has to follow (Nallakumarasamy, 2011). It depicts the required operations order to complete, to produce a single unit of product, as well as assigning each operation to the suitable machine under its right configuration. Bensmaine et al. (2012) studied the process plan generation problems by considering a multi-objective approach based on AMOSA. The considered objectives were the cost and the completion time. According to Elmarghny (2007) there is a necessity for a reconfigurable process-plan reconfiguration and evolution to be associated to the evolution and the changes of both manufacturing systems and products. The author also attempt to discuss and classify various process-planning concept.

Other authors tried to generate more performant process plans by integrating performance metrics at the outset of process design. Haddou-Benderbal et al. (2015a) considered the possible unavailability of selected machine in their final generated process plans. They argued that once process plans are deployed, if eventual unavailability’s are not taken in consideration, they might interrupt the production process. The authors solve the problem by proposing a flexibility index that guides the process plan generation and proposed an adapted non-dominated sorting genetic algorithm (NSGA-II) based approach. The flexibility index depicts the number of alternatives that the process plan may have to dodge the production process interruption caused by the unavailability. In another study, Haddou-Benderbal et al. (2015b) guided the generation of process plans by introduced a new performance metric called robustness index. This metric represent the perturbation time caused by eventual machine unavailability. It helps to generate process plans with minimum perturbations in the case of machines unavailability’s. A more operational level approach was proposed in Haddou-Benderbal et al. (2016) to take a full advantage from these metrics. Authors attempted to ensure the production process continuity through managing machine unavailability during the process plan execution. They adapted the robustness index and solved the problem by proposing a new hybrid heuristic to minimize the impact of perturbations on the system, caused by eventual unavailability of selected machines. In the same context, reconfigurability effort index was developed Dahane and Benyoucef (2016). The index determines the reconfigurability effort in RMS. An adapted NSGA-II algorithm was proposed to resolve the problem following two objectives namely the maximization of the reconfiguration index and the minimization of the total cost of the system.

Guan et al. (2012) adapted an electromagnetism-like mechanism for the layout design of reconfigurable manufacturing systems. More specifically the use of automatic guided vehicles AGV and the reconfiguration of their path that they consider as a change of layout. The objective of their work was to reduce system costs (more specifically material handling cost and reconfiguration cost at the system level).

Goyal et al. (2016) studied the design of an economic RMS configuration. Authors proposed a multi-objective optimization for the RMS flow line configuration. They did not consider layout design problem.

Benjaafer et al. (2002) stated that for the next generation factory layouts design, two approaches could be used. The first approach consists in developing layouts that are more robust for various manufacturing periods. While the second one involves the development of flexible layouts. To meet the frequent production requirement changes, the reconfiguration of these layouts is achieved with minimal effort.

Heragu et al. (2001) presented a framework in order to determine the layout for manufacturing environment known for their constant change in product volumes and mix.

To the best of our knowledge, and by considering the literature, we can clearly notice even with the very large amount of research in the field of RMS that there is a dearth of research incorporating with machine layout problems in the
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