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A New Hybrid Approach for Machine Layout Design Under Family Product Evolution for Reconfigurable Manufacturing Systems

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Abstract: Reconfigurable manufacturing system (RMS) is a new paradigm that answers many of the challenges that the market nowadays imposes. In this paper, we address one of the most important aspects related to the reactivity of RMSs. We consider the relations, which link the conceived system with two important environments: its logical environment, i.e., the product family in which the RMS can evolve, and its physical environment, i.e., the physical workshop that implements this RMS. More specifically, we study the machine layout problem by considering the family product evolution where two sub-problems are considered. The first sub-problem concerns the evolution of the product, in the same family, towards new products to meet the evolutions and the requirements of the customers. The second sub-problem deals with the machine layout problem based on the results of the first sub-problem. We develop an approach which combines the well-known metaheuristic, archived multi-objective simulated annealing (AMOSA), with an exhaustive search-based heuristic to determine the best machine layout for all the selected machines of our product family. The approach is based on the initially generated process plans of products (in the product family) for the RMS design under performance metrics. The proposed layout must at its best, respects both the constraints imposed by the generated process plans and those depicting the available location in the shop floor where machines can be placed. To show the applicability of our approach, we present a simple numerical example and discuss the obtained numerical results.

Keywords: Reconfigurable manufacturing system (RMS); changeable manufacturing system; layout; machine layout design; machine importance index; performance metrics; AMOSA.

1. CONTEXT AND MOTIVATIONS

Manufacturing is and has always been a cornerstone of the global economy. Nevertheless, to be relevant in nowadays' highly competitive market, the manufacturing system of a company has to be, simultaneously, cost and time efficient and more flexible. According to a visionary report of Manufacturing Challenges 2020 conducted in USA, this trend will continue, and one of the six grand challenges of this visionary report is the ability to reconfigure manufacturing systems rapidly in response to changing needs and opportunities. Reconfigurable manufacturing system (RMS) is one of the latest manufacturing paradigms where, machines components, machines software's or material handling units can be added, removed, modified or interchanged as needed and when imposed by the necessity to react and respond rapidly and cost-effectively to changing requirements.

RMS is a logical development of the two manufacturing systems already used in the industries, respectively, the dedicated manufacturing system (DMS) and the flexible manufacturing system (FMS). It is designed to combine the high flexibility of FMS with the high production ratio of DMS (Koren *et al.* 2010). In fact, the high responsiveness and performance efficiencies of RMS make it a convenient manufacturing paradigm and flexible enabler of mass customization to face the complexity of manufacturing environments. This is possible, thanks to reconfigurable machine tool (RMT) which gives the RMS its customized flexibility and variety of alternatives.

In this research work, we consider the reconfigurable manufacturing systems (RMSs) design problem. Nevertheless, reconfigurability is a non-functional requirement of the system, linked to its long-term behavior (Andersen, 2017). This implies that conventional approaches that consider only the immediate requirements of the system will not necessarily lead to dynamically changeable systems. Thus, it is necessary to design systems with a dynamic capacity for change and include the key factors of reconfigurability through adapting design approaches and/or developing new design methodologies. Hence, our goal is to design responsive systems based on reconfigurability features key. For that, we address the RMS design problem on the machine level and their interactions, while considering the product family (products that share similarities) in which the RMS can evolve. This is done through studying the relation that links the conceived RMS to its two environments respectively logical (i.e., the family of products in which this RMS can evolve) and physical (i.e., the physical workshop implementing this RMS). These later are treated as two sub-problems in this paper.

Linked to the logical environment, the first sub-problem concerns the evolution of the product, in the same family, towards new products to meet the evolutions and the requirements of the customers. Three criteria are optimized respectively: (1) the minimization of the evolution effort of the system during the transition within the product family, (2) the maximization of the average use of the machines in order to reduce at best the imbalance of the loads and (3) the maximization of the presence of replacement machines in the production lines of

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the product family. While, linked to the physical environment, the second sub-problem is related to the machine layout. It is based on the results of the first sub-problem. Indeed, the physical structure of the workshop must be able to guarantee the necessary flexibility to follow the evolutions of the RMS in an efficient and fast way.

In this paper, we propose a new hybrid approach that combines an exhaustive search based heuristic, with the known metaheuristic, archived multi-objective simulated annealing (AMOSA). The objective of our approach is to find the best transition between different process plans of products within the product family (first sub-problem). This is done by finding the best layout of the nominated machines (second sub-problem). Additionally, we use an adapted machine importance index (firstly developed by Haddou Benderbal *et al.* (2017c)) to guide the selection of the RMTs that comprise our designed RMS. The adapted importance index considers the evolution of the product family. It helps considering the product family's imposed changes while ensuring a better responsiveness and high performances for the designed RMS.

The rest of the paper is organized as follows: Section 2 briefly reviews the literature regarding machine layout design problems as well as RMS design. Section 3 presents the considered problem with its mathematical formulation. Section 4 illustrates our hybrid approach. Section 5 presents an illustrative numerical example. Section 6 presents the conclusion with some future work directions.

2. RELATED WORKS

Designing a RMS undergoes two main and distinct tasks. The first task deals with the selection of the set of machines that will realize the production process. Once the set of machines is selected, the second task addresses the problem of finding an optimal layout of the selected machines on the shop floor.

The state of the art related to process plan generation in the context of RMS, is very rich. Process plan is defined by Nallakumarasamy (2011) as "*the activity that decides the sequence, which the manufacturing process must follow*". This latter determines the required order to complete operations of a single unit of product. This is done by assigning the proper machine with the suitable configuration to each operation. ElMaraghy (2007) discussed the importance of reconfigurable process plans to encompass changes and evolutions of both products and manufacturing systems. In other studies, authors emphasized the importance of integrating performance metrics at the early stage of RMS design. The objective of this early consideration is enhancing the performance of the designed RMS (Haddou Benderbal *et al.*, 2018). Haddou Benderbal *et al.* (2017a) proposed a new flexibility metric to generate efficient process plan by integrating unavailability constraints of the selected machines. The resulting multi-objective problem is solved using an adapted version of the non-dominated sorting genetic algorithm (NSGA-II).

It is well known that machine layout influences the entire manufacturing system in terms of productivity and responsiveness. Thus, the machine layout problem is regarded as a facility layout problem (FLP) by several authors (Altuntas and Selim, 2012). Drira *et al.* (2007) and Singh and Sharma (2006) analyzed the literature by presenting existing works that treated the FLP through larger and non-restricted approaches. For conventional manufacturing systems like flexible manufacturing systems (FMS), the literature identified five different configurations of machine layout— open field layout, loop layout, single row layout (known also as spin layout), multi-row layout (known also as ladder layout) and robot centered layout (Yang *et al.*, 2005, Drira *et al.*, 2007). Moreover, based on the chosen material handling system and possible flows allowed for products, many configurations could be determined for machine layout (Devise and Pierreval, 2000). Heragu *et al.* (2001) presented a framework that determines the layout of manufacturing systems that are defined by recurrent product volumes and mix change. In the same context and to handle the next generation factory layouts design, Benjafaar *et al.* (2002) argued that there are two major approaches. First, by considering various manufacturing periods through the development of more robust layouts. Second, by developing flexible layouts. The authors stated that the reconfiguration of these layouts must be ensured by minimal effort in order to fulfill the frequent production requirement changes. Sharma and Singhal (2016) handled the layout design problem using a procedural approach based on an altered version of the traditional systematic layout planning (SLP).

Even though the layout is considered as one of the main steps in RMS design as stated earlier, we find a dearth of research works when it comes to the integration of layout problems with the design of RMS. Goyal *et al.* (2016) studied the design of an economic RMS flow line configuration and proposed a multi-objective optimization approach. However, they didn't consider the layout design problem properly. Haddou Benderbal *et al.* (2017b) quantified the layout evolution effort by developing a metric that considers product family to guarantee the high performances of RMS. To solve the optimization problem, the authors proposed an adaptation of AMOSA. In a later work, Haddou Benderbal *et al.* (2017c) resolved the machine layout problem while considering the RMS design through an exhaustive search based approach. Nevertheless, the authors didn't consider the influence of the product family on the machine layout.

To the best of our knowledge, we observe that little works have considered the machine layout problem for RMS design while considering the product evolution within the product. *In this paper, we try to tackle the problem using a combination and an adaptation between the works of Haddou Benderbal et al. (2017b and 2017c).*

3. PROBLEM DESCRIPTION AND FORMULATION

Machine layout problem in an RMS context, must account for other dimensions. Hence, the problem considers classical layout constraints, and must consider RMS core characteristics, specifically those related to its reconfigurability. This early consideration of characteristics in the workshop design phase will ensure a high performance level of the RMS (e.g. ability to reconfigure, flexibility, ...) as well as a better responsiveness. Our objective is to maximize the benefits from the RMS intrinsic capacities which increases the system responsiveness. Moreover, knowing that RMS is built around a product family which tend to evolve throughout the system life cycle, we aim to ensure a better transition between different products (respectively their process plans) within the same product family while preserving the high performances.

In this context, our design RMS is facing a major challenge, which is the frequent evolution of the manufactured product. So, to increase its responsiveness, we must design the system with a number of alternative solutions within the generated process plans. Therefore, to react to products changes, our proposed approach privileges the reuse and integration of already selected RMTs in the next process plan when introducing new products. Thus, we facilitate resources sharing to generate the different needed process plans of the product family. In our case, we note that resource sharing is anticipated from the outset of the RMS design.

In this paper, we assume that the machines that comprise the RMS are previously selected. Thus, the preliminary process plans of products of the same family, are previously generated following the proposed approach of Haddou Benderbal *et al.* (2017a, 2018). Table 1 illustrates the structure of the used process plan. Moreover, for a better understanding of the problem, Table 2 presents the used notations.

Table 1. Process plan structure of product P1

Operation	OP2	OP5	OP1	OP6	OP7	OP9	OP3	OP13
Selected Machines	M2	M10	M1	M10	M1	M4	M6	M3

Table 2. Notations

NP	Number of products in the product family
NL	Number of total candidate locations on the shop floor
NPM	Number of candidate machine used to generate input process plans for each product of the product family
NSM_p	Number of selected machines for the product Pp
NM	Number of distinct selected machines for the product family
$L_1, \dots, L_{NL}$	Available locations
$M_1, \dots, M_{Nm}$	Available machines
NC_j	Number of available configurations for the machine M_j
$C_1^j, C_2^j, \dots, C_{NC_j}^j$	Configurations of the machine M_j
$\mathrm{OPTN_p}$	Total number of operations for the product Pp
TFOP	Number of all operations of the product family
$OP_1^p, \dots, OP_{\mathrm{OPTNp}}^p$	Operations of the product Pp
$NO_p[M_j]$	Number of occurrences of the machine M_j for product Pp
$\mathrm{C_l^j(u)}$	The configuration l of the machine M_j on which the operation u is realized
$\mathrm{M_j(OP_u^p)}$	The operation u of the product Pp is being executed on the machine M_j
$Conf_j[\,]$	Matrix of available configurations for the machine M_j
$PM_p[M_j]$	Matrix of selected machines for product Pp
$MT_j[\,]$	Matrix of available tools for the machine M_j
$\mathrm{MTOP}[OP_u^p]$	Matrix of required tools for the operation u of the product Pp
$\mathrm{PRM}[OP_u^p]\,[OP_{u'}^p]$	Operations precedence matrix
$MinAD[M_{j1o1}][M_{j2o2}]$	Minimum accepted distance between the occurrence o1 of the machine M_{j1} and the occurrence o2 of the machine M_{j2} (if j1 = j2 then o1 ≠ o2)
$MaxAD[M_{j1o1}][M_{j2o2}]$	Maximum accepted distance between the occurrence o1 of the machine M_{j1} and the occurrence o2 of the machine M_{j2} (if j1 = j2 then o1 ≠ o2)
$P[M_{jo}]$	Position of occurrence o *of* the machine M_j

For our first sub-problem— i.e. logical environment that treats the transition effort evolution between products of the same family product — we adapted its formulation from Haddou Benderbal *et al.* (2017a). Consequently, we use the following concepts as basis for the first sub-problem:

- *Inclusion concept* (i.e., inclusion of functionalities between machines). It consists in choosing machines with richer functionalities compared to the needs of the initial product, thus offering the necessary functionalities to manufacture the initial product, but also other additional functionalities that can facilitate the evolution (the transition) towards other products from the same family. Therefore, the question that arises is to assess the relevance of replacing one machine (M_i) with another (M_j) that includes it functionalities in all relevant process plans. It is a matter of finding the compromise between, on the one hand the need to minimize the effort of evolution between the products and on the other hand, the risks incurred related to the balance of the loads and the presence of alternative machines.
- *Preserving the system's capacities in terms* of: (i) the balance of loads and (ii) the presence of alternative machines. This is to take into consideration the risks involved with the inclusion concept of additional features.
- *Diversity of machines*. It consists of selecting machines with partially similar capabilities in order to reduce exclusivity in the operations-machine relationships. This will reduce the risk of load imbalance and the risk of missing replacement machines.

Based on the above concepts, our first sub-problem is guided by three criteria to optimize respectively:

1. The maximization of the average use of machines to reach equilibrium if possible, depicted by the average machine usage per product (AMUP) criterion as follows:

$$MUF_p(M_j) = \left(\frac{NO_p(M_j)}{OPTN_p}\right) \times \sum_{u=0}^{OPTN_p} \left(\alpha_j(OP_u^p) \times M_j(OP_u^p)\right) \tag{1}$$

$$Max \left\{ AMUP = \left(\frac{1}{NP \times NMf}\right) \sum_{j=1}^{NMf} \sum_{p=0}^{NP} MUF_p(M_j) \right\} \tag{2}$$

where: $M_j(OP_u^p) = 1$ *if the machine Mj can accomplish operation u of product Pp, 0 otherwise.*

$\alpha = 1$ *if the machine Mj is selected to perform operation u of product Pp, 0 otherwise.*

2. The maximization of the presence of replacement machines in the production lines of the product family formulated as follows:

$$Max \left\{ MRP = \frac{1}{NP} \sum_{p=0}^{NP} \left(\frac{1}{OPTN_p \times NSM_p} \sum_{u=0}^{OPTN_p} \sum_{j=0}^{NSM_p} \left(\begin{array}{c} M_j(OP_u^p) \\ \times NO_p(M_j) \end{array} \right) \right) \right\} \tag{3}$$

3. The minimization of the layout evolution effort (LEE). It quantifies the change that may occur to the selected machines and or to their rearrangement from one product to another among products of the family product. The LEE is based on two aspects namely:

- Machine similarities (PSimM$_p$). It allows selecting the best machine layout in term of similarities between the selected machines. This later assesses the average similarity between selected machines of products from the product family. The similarity calculation is based on the number and type of configuration changes between two given machines and it is formulated like so:

$$PSimM_p = \frac{1}{NSM_p} \sum_{j=1}^{NSM_p - 1} \sum_{k=j+1}^{NSM_p} SimM[M_j][M_k] \qquad \textbf{(4)}$$

where: $SimM[M_j][M_k] = \beta(\mathrm{j,k}) - \frac{\beta(\mathrm{j,k}) \times |Nconf_j - Nconf_k|}{Nconf_j + Nconf_k}$ and

$$\beta(\mathrm{j,k}) = \begin{cases} 1, & \text{if machines } Mj \ and \ \mathrm{M}k \ have \ the \ same \ basic \ modules \\ 0, & Otherwise \\ k,j \in & 1..NPM \end{cases}$$

- Selected machine type difference (SMDif$_p$). It is related to the type of selected machines. Through this aspect, we can see within the product family, which type of machines (SMT) are used for each product, how many machines are removed (RM) when passing from one product to the other and how many ones are added (AM).

$$SMDif_p = \frac{AM + RM}{SMT} \qquad \textbf{(5)}$$

where:

$$SMT = \sum_{j=0}^{NM} Max(PM_p[M_j], PM_{p'}[M_j])$$

$$RM = \sum_{j=0}^{NM} Max(PM_p[M_j] - PM_{p'}[M_j], 0)$$

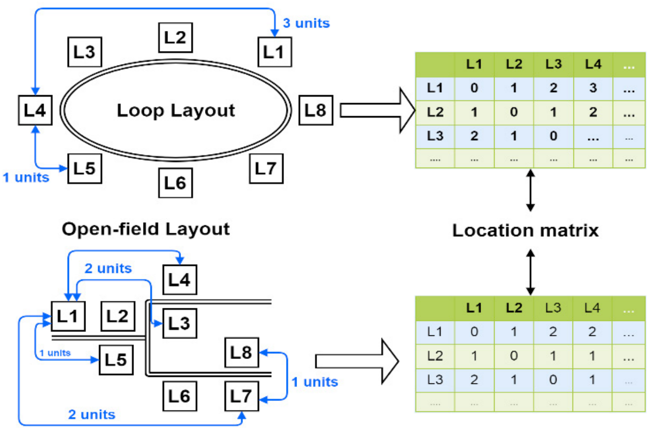
$$AM = \sum_{j=0}^{NM} |Min(PM_p[M_j] - PM_{p'}[M_j], 0)|$$

$$PM_p(M_j) = \begin{cases} 1, & if \ product \ Pp \ is \ realized \ by \ machine \ M_j \\ 0, & \text{otherwise} \end{cases}$$

Following these two aspects, the LEE is given by:

$$Min \left\{ LEE = \frac{1}{NP} \sum_{p=1}^{NP} \left(\frac{SMDif_p}{PSimM_p} \right) \right\} \qquad \textbf{(6)}$$

On the other hand, for our second sub-problem— i.e. physical environment that treats the machine layout problem — based on the numerous layout configurations of machines present in the literature, we used a generic model proposed in (Haddou Benderbal *et al.*, 2017c) and depicted in Figure 1. This later allows the representation of machine layouts configurations in the form of a matrix called localization matrix (LoC). LoC makes it possible to represent a layout configuration by specifying the distances between machines in the workshop according to the capacities and constraints of the system (ex. the constraints of size) as well as the available positions. This assumption makes our model more generic to include all the possible layout configurations. Note that, the distances between the positions (machines) rely on the transfer capacities between the machines and ensured by the chosen material handling system. They are provided by the decision maker and considered as input for our model. In Figure 1, L1, ..., L8 are the previously known candidate locations. They are intended to accommodate the selected machines to be part of the designed RMS, where the number of slots in the array corresponds to the total number of occurrences of the selected machines for the product family.



	L1	L2	L3	L4	...
L1	0	1	2	3	...
L2	1	0	1	2	...
L3	2	1	0	...	...
....	...	...	...	...	...

	L1	L2	L3	L4	...
L1	0	1	2	2	...
L2	1	0	1	1	...
L3	2	1	0	1	...
....	...	...	...	...	...

Fig. 1 Representation of layout configurations

We expect to determine the best machines layout based on the following information: (i) the characteristics and needs of the products to be considered from the product family, (ii) the process plans to adopt to manufacture these products, and (iii) the selected RMTs and the number of their respective occurrences, to be included in the new designed RMS.

We consider a RMS composed of several RMTs, having the capacity to manufacture several products of the same family. Each RMT has one or more instances to integrate into the workshop according to the needs and requirements of the process plan of each product. Note that, we consider a single unit of each product of the product family with its initial process plan to accomplish this product. Accordingly, the machines that comprise the RMS design and their respective occurrences are known. Moreover, a machine can be used several times in any process plan and this number of uses may exceed the number of available occurrences for this machine (i.e. each machine can have multiple occurrences and appear several times in the process plan). Based on these inputs, we are able to generate an initial layout using the given process plans of products from the product family.

The initial layout is generated according to the order of appearance of the machines in the adopted process plans as well as to the importance of these machines to the whole product family. For example, if a machine M_j is used directly after a machine $M_{j'}$, then the chosen layout must offer the possibility of a connection between the two machines. Hence, based on this initial layout as well as the constraints imposed by the adopted process plans, we define two new matrices respectively, maximum and minimum accepted distances (**MaxAD, MinAD)** between different machines and their occurrences as well. This set of information helps us to define the importance of each machine regarding the adopted process plans of all products from the product family.

Finally, our problem is to find the best RMTs layout. This layout must minimize the penalties engendered by the non-satisfaction of constraints related to machine-candidate position relationship in the system. This non-satisfaction can be the result of conflicting requirements between different machines. To compute the penalties, we use each machine importance regarding both the product family and the process plan.

The machine importance indicator $MI(M_j)$ provides an insight over the dependency of different process plans of the product family regarding the selected machines. This later is adapted from the work of (Haddou Benderbal *et al.*, 2017c) and formulated for all the given process plans of the product family as follows:

$$MI(M_j) = \sum_{p=1}^{NP} MI_p(M_j)/NSM_p \quad \textbf{(7)}$$

where:

$$MI_P(M_j) = \sum_{k=1}^{NO_p[M_j]} MOI_p(M_{jk}) \quad \textbf{(8)}$$

$$MOI_P(M_{jo}) = CP_P(M_{jo}) \times \sum_{k=1}^{NSM_P^o} \frac{MR_P[M_{jo}][M_{j'k}]+MR_P[M_{j'k}][M_{jo}]}{NO_p(M_j)} \quad \textbf{(9)}$$

- CP_P (M$_{jo}$): the number of occurrences of machine *Mj* in the adopted process plan of the product *Pp*.
- $MR_P[M_{jo}][M_{jk}]$: the relation between all the occurrences of the machines used in the process plan of product *Pp* given by:

$$MR_P[M_{jo}][M_{j'k}] = \begin{cases} 1 & \text{if the occurrence o of the machine Mj is followed} \\ & \text{by the occurrence k of the machine Mj'} \\ 0 & \text{otherwise} \end{cases}$$

Based on this importance indicator, we can formulate the penalty function that measure the level of satisfaction of the constraints of the different process plans by the generated layout of the RMTs. It quantifies to 'what extent the locations chosen for the occurrences of the different machines respect the maximum and minimum distances?', while considering the importance of each one. Therefore, our problem is to minimize the penalty generated due to non-satisfaction of the constraints expressed by (eq 10):

$$Min\,\{\,Penalité = \sum_{j=1}^{NSM} \sum_{k=1}^{NSM} X_{jk} \times MI(M_j)\} \quad \textbf{(10)}$$

where: $X_{jk} =$

$$\begin{cases} 1, if\ MinAD\left[M_{jo}\right]\left[M_{j'k}\right] \leq LoC\left[P(M_{jo})\right]\left[P(M_{j'k})\right] \leq MaxAD\left[M_{jo}\right]\left[M_{j'k}\right] \\ 0, otherwise \end{cases}$$

4. PROPOSED APPROACH

Hybrid algorithms are known to be very good search tools and displayed very satisfying results (El-Ghazali, 2009). They are often used to solve conventional and real-world optimization problems. In this context, we proposed a hybrid approach that combines between the well know metaheuristic AMOSA with an exhaustive-search based heuristic. From the multi-objective nature of our first sub-problem, our approach tries to solve it using an adapted version of AMOSA as shown in Figure 2. The obtained results are used, in a second step, as inputs for the exhaustive-search based heuristic to solve the second sub-problem (i.e., machine layout problem of the selected machines in our product family).

Table 3. Process plan of P2

Operation	OP1	OP7	OP6	OP10	OP2	OP13	OP11	OP8
Selected machines	M1	M2	M8	M4	M2	M10	M3	M4

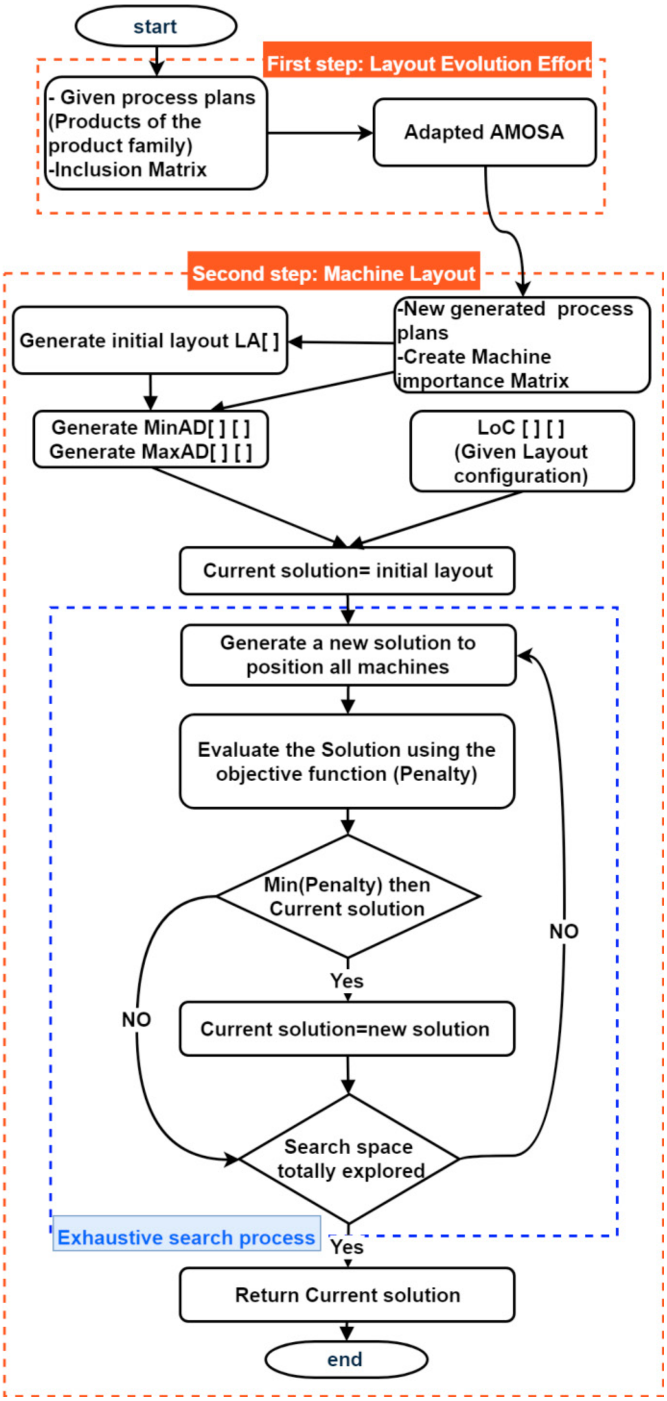


Fig. 2 Flowchart of the developed hybrid approach

5. ILLUSTRATIVE EXAMPLE AND DISCUSSION

In this section, digital experiments and analyzes are developed to show the applicability of our approach. We consider a family of three products namely P1, P2 and P3, with respectively 8, 8 and 7 operations. The total number of different operations required for all products is TFOP = 13. Table 1, Table 3 and Table 4 detail respectively the process plans of P1, P2 and P3.

Table 4. Process plan of P3

Operation	OP3	OP5	OP2	OP12	OP6	OP4	OP7
Selected machines	M9	M6	M1	M9	M1	M8	M2

Table 5 presents a randomly generated configuration layout. We note that the number of available candidate locations in the shop floor is greater than or equal to the total number of all occurrences of selected machines in the process plan, which represent the maximum number of all occurrences in a process plan of the family product. For the sake of simplicity, our example considers 6 candidate positions for machines of the process plan of the product P1.

Table 5. Input Location matrix (Layout configuration)

	L1	L2	L3	L4	L5	L6
L1	0	3	4	5	7	6
L2	3	0	2	4	5	6
L3	4	2	0	6	7	5
L4	5	4	6	0	2	7
L5	7	5	7	2	0	8
L6	8	6	5	7	8	0

Due to the page limitation, we present the results of the first phase of our approach as we can see in Table 6. Moreover, we show only the layout of one process plan of product P1 from the product family.

Table 6. AMOSA output solution

PP (P1)	M1	M7	M7	M7	M1	M10
PP (P2)	M1	M7	M1	M1	M9	-
PP (P3)	M1	M7	M1	M1	M9	-

The first phase has succeeded to reduce the evolution effort by using the inclusion concept and replacing original machines while slightly increasing the presence of alternative machines as well as the average use of machines among all operations of the product family.

Table 7 depicts the results of machine layout for the process plan of product P1, without considering the transition effort between different products of the product family (i.e., with out using the results from the first phase of our approach).

Table 7. Resulted layouts without transition effort

Candidate position	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**Penalty**
Machine	M6	M10	M2	M1	M3	M4	3
Importance index	2	8	1	8	1	2	-

When considering the transition effort (first and second phases), we observe that, for this example, the results of the first phase have reduced the number of machines to be placed (i.e., from Table 6, we see 3 instead of 6 machines for the process plan of P1). Thus, reducing the number of constraints imposed by the process plans and giving more freedom to place the machines on the shop floor. This relaxation has made the placement of the 3 machines easier. Consequently, eliminating the penalty for this specific example. Nevertheless, the relaxation comes with a considerable dependency of process plans on small set of machines, even with the consideration of replacement machines amongst each other. One of the limitations of our approach is computing time when considering more than 11 machines due to the exhaustive search method. The extension of our current work is considering these two problems to enhance the results of our approach.

6. CONCLUSION AND FUTURE WORK DIRECTIONS

In this paper, we have studied the relationships that link RMS to both logical and physical environments. From one hand, by considering the evolution of a product within the same product family for which the RMS is designed. And, by considering the machine layout problem in RMS. We emphasized the lack of research work dealing with machine layout problem for RMS. We have developed a new hybrid approach combining an adapted version of the well-known AMOS and an exhaustive search-based heuristic. This study is based on the premise that a RMS is designed to make one type of product, but must encompass the features that allow it to evolve to make other products from the same family. An illustrative numerical example was presented to illustrate the applicability of the developed approach.

For future work, we aim to integrate the two issues with the process plan generation, to study the impact of product evolution and the layout on the design and composition of the RMS. Also, we expect to use other evolutionary algorithms such as NSGA-II and bee algorithms.

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