Machine Layout Problem Solving in Reconfigurable Manufacturing System Using Hybrid Optimization Method

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Abstract: - In reconfigurable manufacturing system (RMS) design, production process requirements or product specifications required in manufacturing are often governed by the reconfigurable machinery and capabilities it offers. In such a system, the capabilities and functions of the process can be changed exactly when necessary. Improving productivity, reducing inaccuracies, and avoiding wasting time switching are key factors in manufacturing system design. The high receptiveness and efficiency of RMS performance make it a convenient and feasible industrial model that is flexible for mass customization. This paper describes a multi-objective strategy for improving RMS design. A novel method to RMS design was utilized in this study to assure the optimal process plans by picking the best collection of machines from a pool of available machines. To show the usefulness of this suggested technique, an illustrative numerical example is provided.

Keywords: *- RMS, machine layout problem, performance metrics, facility layout problem, machine selection, robustness index, modularity index.*

I. Introduction

The rapid growth for a larger range of products has mandatory many firms to reassess their approach in order to give additional product options while maintaining production efficiency. Product variety may help industrial firms upsurge sales and profitability in today's modern competitive business environment. A significant increase in the sum of process variants, such as various machineries, tools, accessories, configurations, cycle durations, and labor, is a direct result of product variety in manufacturing. Like a consequence, production processes must be very dynamic and adaptive to meet the demand for modified items in a shorter time frame and at a lower cost. In the late 1990s, the concept of RMS arose to transcend the limits of conventional production in response to acceptable prices [1].

Scalability is an important aspect of an industrial manufacturing process since it allows for the addition, removal, or alteration of various workstations or machines, as well as the reconfiguration of the manufacturing system. Using optimization approaches for capacity planning, aids in the discovery of a cost-effective strategy to deal with changes associated with various client requirements. Furthermore, scalability is a methodical strategy for increasing or decreasing a system's ability to satisfy market demand. In today's business, there is a demand for a more dependable and efficient scheme that can offer the finest equipment in terms of cost and time. Allocating processing capabilities initially in the product enterprise phase and then utilizing these capabilities later in the reconfiguration phase can result in product cost savings and responsiveness [2].

Machinery, Material handling, and organizational staff are all components of RMS that contribute to its long-term success. All of these pieces are change facilitators, and they tend to rearrange the scheme logically or physically contingent on its constraints. The first level is the "Factory Level" where it is necessary to adjust the plant design to accommodate changing requirements due to production differences. The "assembly level" is the second location where process lines can be transferred when design and product demand change. Following that is the "process planning level," which is the primary focus of businesses when producing items in a single family. One of the most difficult difficulties for creators is adapting to differences in product enterprise and production levels in order to respond quickly to market fluctuations. RMS offers the potential to reconfigure fast with minimal reconfiguration effort and at a cheap cost. By retaining it on the assembly line and in product programming, the updated reconfigurable design can assist in achieving the required configuration [3].

Mathematical programming was implemented to generate process plans that take into account design and manufacturing changes in the various attributes of the part. The precedence chart is rebuilt by regularly adding / deleting features to maximize the cost acquired to find the optimum position for the novel added feature of the component family. Because of the dynamic nature and flexibility of RMS, Reconfigurable Process Planning (RPP) assists in reconfiguring the system throughout production change procedures with little effort to meet changing production needs. The chart is reconfigured by regularly adding / deleting features to enhance the cost acquired to identify the optimum position for the novel added feature of a family of components. Because of the dynamic nature and flexibility of RMS, RPP assists in reconfiguring the system throughout production changeover procedures with little effort to accommodate changing production requirements [4].

It is advised that settings be changed as demand changes in order to reduce capacity and underutilized features. Furthermore, there should be a high degree of smoothness between each subsequent configuration to decrease the cost, time, and effort of reconfiguring the system. The capacity of RMS to retain efficiency in mass production while concurrently creating diverse goods and in unexpected amounts within the house is a significant benefit. This is achievable by physically or logically reconfiguring the RMS to change the performance and functionality within the component family. The RMS design is based on the resolution of numerous difficult issues, and one of the important challenges that has a considerable influence on the design of the resulting RMS is the authors find a problem with the layout of the machine. On the one hand, since RMS planning must take into account new characteristics of the system [5].

This paper presents the solution to a machine planning problem in a reconfigurable manufacturing situation. The results indicate that the constructs can be used reliably. The organization of this document is as follows. In the second section, the literary survey. The machine layout problem is explained in the third section. The results of the simulation and implementation are presented in fourth section. Finally, the work on the fifth section can be concluded.

II. Literature Survey

Various design aspects of the machine layout problem have been studied in various research papers. In this section, some important literature related to the proposed work is discussed.

According to Hichem Haddou Benderbal et al. RMS are necessary to overawe the shortcomings of earlier production schemes in terms of efficiency and usability to the progressively influencing variables placed on the corporate setting by uncertain market circumstances and worldwide competitiveness. RMS must be more robust, flexible, and adjustable, so addressing the machine layout delinquent is a key step in attaining such a design. As a result, every proposed design should be easily modified and altered. Consider the device design challenge in a reconfigurable environment using this technique. To begin, develop a thorough research-based heuristic to resolve the issue. To suggest the best machine design, the guide takes into account the many constraints of the manufacturing environment, as well as the initial process plan developed for the RMS based on performance data. This design works best when both the limitations imposed by the developed process [6].

Hichem Haddou Benderbal et al. has suggested that for improving productivity, reducing inaccuracies, and avoiding wasting time switching are key factors in manufacturing system design. Reconfigurable manufacturing schemes are a new paradigm connected to these features. RMS performance's great responsiveness and efficiency make it a practical and feasible production approach that is versatile for mass customisation. Because of the Reconfigurable Machine Tool (RMT), RMS provides unique flexibility and a number of alternative features. These machines, which are a critical component of RMS, are built on an adaptable, modular, and changeable chassis. As a result, the modularity of the system is critical. This technique provides a multi-objective method to RMS design improvement. This method uses a modular-based multipurpose method that uses a modified version of Archived Multipurpose Simulated Annealing (AMOSA) to solve an optimization problematic by choosing a set of the most suitable candidate devices [7].

Hichem Haddou Benderbal et al. proposed for today's environment, driven by economic globalization, responsiveness and high performance are critical drivers. One of the current manufacturing paradigms influenced by these elements is the RMS. The system's capabilities and functionality may be adjusted precisely as needed under such a paradigm. As a result, the needs of the manufacturing process, the specifications of the intended product, and the capabilities that reconfigurable machines provide drive the design of these systems. This method takes into account a project problem in a reconfigurable manufacturing system (RMS) and provides a new indicator of the robustness of the system. A new approach to RMS has been designed to ensure the best process plans by choosing the best set of devices from a pool of available (nominated) devices. The method is based on an uncontrolled classification genetic algorithm (NSGA-II) that is directed by the reduction of two goals: total accomplishment time and the disruption caused by the unexpected unavailability of the chosen machines. A numerical instance and a discussion of the findings obtained are used to demonstrate the applicability of the proposed technique [8].

Tariq Aljuneidi and Akif Asil Bulagak proposed that durability is becoming an increasingly important problem in several facets of life. There does not appear to be much attention in research on sustainable manufacturing system design concerns today. Regarding which, this process identifies a simultaneous independent inquiry of tunable cellular manufacturing systems (CMS), hybrid manufacturing, analysis, and making plans to resolve a sequence of sustainable production system design issues. Mixed Linear Programming Model (MILP) that takes into account the classic cell configuration problem in CMS [9].

Hichem Haddou Benderbal and Lyes Benyoucef suggested on one of the most critical components of RMS efficacy. This approach takes into account the development of the product family when assessing the machine planning issue, which is split into two sub-problems. The very first subproblem involves the evolution of a product within the same family toward new products in order to fulfill customer advancements and requirements. The second subproblem solves the machine layout problem utilizing the first problem results. For this purpose, the two-stage approach syndicates the well-known simulated annealing, Archived Multipurpose Simulation (AMOSA), includes a thorough research-based guidance for selecting the optimal machine design for all selected devices in the product family [10].

From the above discussion, various works have been previously proposed to implement the machine layout problem. Most companies focus on reducing costs. Also, more are implemented on the basis of reconfiguration. The main objectives of this work was defined as follows:

- To analyse the need of reconfigurability.
- To simplify how reconfigurability may be accomplished by producing minimal machining capabilities at a cheap cost.

III. Proposed Method

In an RMS setting, the machine layout problem must consider the other aspects, particularly those linked to its re-configurability. This primary evaluation of attributes throughout the manufacturing business design process provide a high degree of RMS performance as well as improved responsiveness. As a result, in order to improve its responsiveness, the suggested system must include a variety of alternate options inside the created process plans. Find a new unit of production that has been allocated to its optimal processing strategy in order to complete this goods in this task. As a consequence, the ideal collection of machines employed to create the RMS, as well as their frequencies, are recognized.

A. Problem Statement

The study investigates the impose requirements problem within the framework of RMS. In addition to the usual constraint of machine layout difficult in conventional production systems, it investigates the RMS's configurability and its impact on adequate control solutions.. To improve the system's responsiveness and utilize the benefits of its inherent capabilities. An optimization problem is regarded to be the extreme selection of a certain style of layout. Assume that a location matrix can represent any layout arrangement consisting of distances between accessible locations in the manufacturing firm. These distances are resolute by the decision maker and are based on the material handling capacities under consideration.

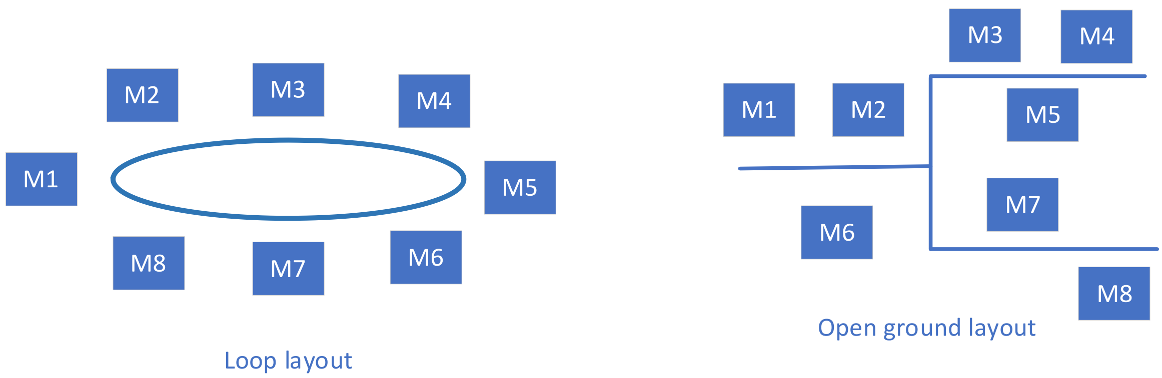

Figure 1 representation of layout configurations

The recommended model is meant to be generic, taking into consideration the different types and capabilities for machine rearranging on the manufacturing company's grounds. It should be emphasized that layout approaches vary in terms of the expected outcomes of arranging the machines. The distinction lies in the portrayal of the area to be utilized for the arrangement, which is dependent on the features of the item (machines) to be put. Regardless, the kind of production scheme has a major influence on the structure of working machines.

Number of candidate locations in company	NL
Available locations	$L1, \dots Ln$
Total amount of instances of all machines	NM
Total amount of all product P operations	$OPTN$
Available machines	$M1, \dots Mn$

Minimum accepted distance between the occurrence of the same machine or of alternative machine	$MinAD\ [Mj][M'j]$
Maximum acceptable detachment between one occurrence of a machine and another existence of the same or other machine	$MaxAD\ [Mj][M'j]$
Occurrence Position o of the Machine j	$P[Mj]$

B. Importance of machine in process

The machine significance allows us to evaluate how dependent the process plan is on a certain machine and how that machine connects with the other machines. It is defined by the sum of times a machine is utilized inside a process plan. As a consequence, each machine event has a significance index. Once the initial layout is produced, this index is calculated. The relevance index aids us in calculating the penalty that may be imposed if the machine condition for position is not met.

$$MoI_j(M_{jo}) = \mathrm{CP}(M_{jo}).\sum_{k=1}^{NSMo} \frac{MR[M_{jo}][M_{jok}]+MR[M_{jok}][M_{jo}]}{\mathrm{NO_p}(\mathrm{M_j})} \quad (1)$$

Cp (Mjo): the number of covered positions by the occurrence o of the machine j in the initial process plan.

MR[Mjo] [Mjo'] is the connections between all machine occurrences in the process plan, equals 1 if within the procedure plan the incidence o of the machine j is openly prospered by Mjo′, 0 otherwise.

C. Penalty

The penalty function reflects how well the generated layout adheres to the limitations placed by the planning process. Its chosen machine in accordance with the min and max allowable distance among each incidence of all machines once they have been placed in their respective candidate positions.

This research has contributed to leveling the playing field by solving the machine layout challenge while taking configurable surroundings needs into account. This is accomplished by employing a hybrid algorithm to find the optimal machine configuration for a certain armed conflict while keeping system performance restrictions in mind.

D. KGMO Optimization

Searching policies used by population-based optimization algorithms converge to the optimal solution based on the objective function, which begins at random in the feasible region of the population. Search space is searched in order to arrive at an optimal spot in terms of temperature reduction. Afterwards, think about a framework with N operators (gas atoms). The mth operator's position is defined by its position.

$$P_m = P_m^1, \ldots P_m^c \ldots, P_m^z \ for\ (i = 1,2, \ldots .n) \quad (1)$$

The kinetic energy, in the molecule, is defined as

$$K_{E}{}^{c}_{m(u)} = {}^{3}/_{2} \left(K_y U_{m(u)}^c, j_m = (j_m^1, \ldots j_m^c, \ldots, j_m^z), for\ (i = 1,2,3 \ldots .z)\right) \quad (2)$$

where, y is represented as the Boltzmann constant, m is represented as the number of gas molecules and $U_{m(u)}^c$is the temperature of the ith agent in the c^{th} dimension at time u. The molecule velocity is updated by

$$v_{m(u+1)}^c = U_m^c(u)\omega v_m^c(u) + l1_r(u) \times e_{best}^c - A_m^c(u)$$
$$+l2_r(u) \times \left(\frac{F_{best}^c(u) + F_{best}^c(u-1) + F_{best}^c(u-2)}{K_E}\right) - A_m^c(u) \quad (3)$$

Finally, because the molecule mass is a random value in each algorithm iteration but the same for all molecules in each execution, the location is updated for the unit time interval by

$$v_{m(u+1)}^c = \sqrt{\frac{2 \times \Delta k_c^d}{m}}(u+1)u^2 + g_c^d(u+1)u + h_c^d(u) \quad (4)$$

The best fitness function is found by applying

$$F_{best} = d(a_m), if\ d(a_m) < d(Fbest_m)$$
$$e_{best} = d(a_m), if\ d(a_m) < d(ebest_m) \quad (5)$$

E. GSO optimization

In GSO, a group of Glow-worms is originally transferred to an undetermined location. With a particular amount of luciferin, each glow-worm responds to the target work reaction at the request area. The amount of luciferin present is determined by the agent's location. A more vibrant agent denotes a better stance or solution.

1) Luciferin-Update Stage

The luciferin updates are determined by the fitness value and the preceding luciferin value, and the equation is as follows:

$$b_l(t+1) = (1-\beta)b_i(t) + \gamma \; Fitness\;(x_i(1)\,) \tag{6}$$

Here $bi(t)$ denotes the luciferin value of the glowworm i at the time t and β is signified as the luciferin decay constant and γ is signified as the luciferin enhancement constant.

2) Neighborhood-Select Stage

Neighbors $Mi(t)$ of glowworm i at time t contain of brighter this can be articulated as

$$M\_i\ (t) = \{j: d\_ij(t) < r\_d\hat{}i\ (t); b\_i\ (t) < b\_j\ (t)\} \tag{7}$$

Here $r_d^i(t)$ signifies the decision radius of glowworms $i$at time t and $d_{ij}(t)$ signifies the Euclidean distance among glowworms i and j at the time t.

3) Moving Probability-Computer Phase

A glowworm follows the probability rule while moving from one location to another with a greater luciferin level.

4) Movement Phase

The glowworm movement i is given by

$$x_i(t+1) = x_i(t+s)\left(\frac{x_j(t) - x_j(t)}{||x_j(t) - x_j(t)||}\right) \tag{8}$$

Here $||x_j(t) - x_j(t)||$ represents the Euclidean norm operator and s is the step size.

5) Decision Radius Update Phase

In each update, the radius of glowworm i is given as follows

$$r_d^i(t+1) = \min\{r_s, \max\{0, r_d^i(t) + \alpha(n_t - |M_i(t)|)\}\} \tag{9}$$

Here r_s signifies the sensory radius of glowworm , α is signifies a constant and n_t is a parameter to control the neighbor number.

Table 2. Input(Layout configuration) Location matrix

	L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
L1	0	4	6	7	8	2	1	5	8
L2	3	7	2	8	5	1	3	8	6
L3	5	1	5	2	4	3	5	4	1
L4	1	7	3	6	1	6	1	8	1
L5	3	2	3	5	7	2	8	6	9
L6	4	5	6	8	6	8	7	4	2
L7	1	4	2	3	7	2	6	1	8
L8	9	1	8	2	1	3	8	6	8
L9	6	4	3	9	2	7	4	1	6

Table 2 illustrates the application of the suggested technique by detailing a randomised configuration arrangement. For each machine occurrence, Table 3 provides both the original arrangement and the significance index. The algorithm use it in conjunction with the process plan to create the MinMax acceptable distance matrices, which are then used to determine the best feasible choice.

Table 3. Initial Layout								
L1	L2	L3	L4	L5	L6	L7	L8	L9
M1	M2	M3	M4	M5	M6	M7	M8	M9
4	3	1	2	2.5	1		1.5	2

Table 4 displays the results of our algorithm and lists the three best layouts discovered, along with their penalties. It is crucial to note that candidate location encoding does not indicate their proximity.

Table 4 output heuristic layout

L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**Penalty**
M4	M2	M4	M7	M8	M6	M1	M2	M9	**10**
M9	M3	M8	M1	M3	M5	M2	M3	M5	**12.4**
M2	M9	M2	M5	M6	M1	M8	M1	M7	**11.3**

Such designs are seen to be the greatest option in this circumstance since they have the lowest penalty when compared to the rest of the examination area. That because the algorithm initially met the needs of the process plan's most important machine before attempting to reduce the penalty by removing the restriction of the less significant incidences in the planning process. Figure 2 illustrates the performance graph with x axis represent the iteration number and y axis represents the penalty value for the machine arrangement.

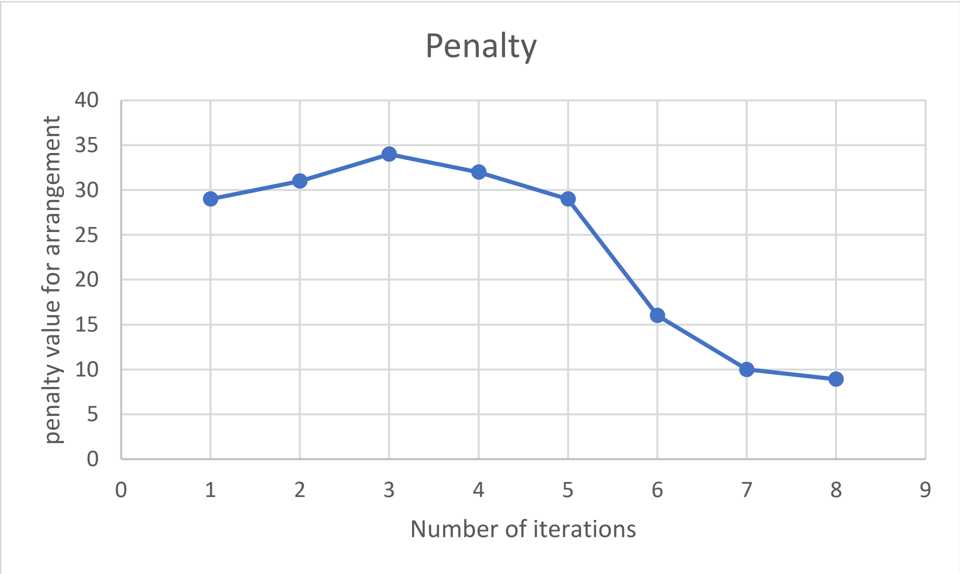

Figure 2 Performance graph for the proposed method

IV. Result and discussion

Digital experiments and analyses are established in this section to demonstrate the applicability of our proposed method. The simulation is carried out with MATLAB 2021a on an i5 machine with 4GB of RAM. The whole number of events of designated machines in the planning process, which indicates the maximum amount of happenings in the product's process plan, is higher than or equal to the total amount of possible candidate sites in the manufacturing business. To evaluate the performance, both existing optimization techniques, and hybrid techniques are compared and the proposed method outperforms both methods.

Table 5 shows the solution to machine layout										
Candidate position	L1	L2	L3	L4	L5	L6	L7	L8	L9	Penalty
Best solution	M4	M8	M4	M7	M1	M6	M1	M2	M4	8.9
Worst solution	M9	M3	M1	M9	M3	M5	M2	M3	M8	13.8

Table 5 displays the machine layout findings for the product P1 process plan without using the results from the first stage of our technique. The model iterates over all possible setups. As a result, only the best and worst penalty-based alternatives are presented in this table. As a result, it is obvious that even the tiniest change can result in a significant difference in the penalty imposed.

V. CONCLUSION

The connections that connect RMS to both logical and physical surroundings are examined in this study. On the one hand, by considering the advancement of an item in same product group as the RMS. This methodology is a one-of-a-kind hybrid that combines an upgraded version of the well-known KGMO optimization with a GSO-based heuristic. This study is based on the idea that an RMS is intended to generate one kind of product but must contain components that allow it to develop to produce other types of products. To demonstrate the applicability of the suggested technique, an exemplary numerical example was provided. This approach outperforms all the existing methods and can be used in the real-world scenario in production for manufacturing companies.

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