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# Solving a multi-floor layout design model of a dynamic cellular manufacturing system by an efficient genetic algorithm

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ABSTRACT

This paper presents a mixed-integer programming model for a multi-floor layout design of cellular manufacturing systems (CMSs) in a dynamic environment. A novel aspect of this model is to concurrently determine the cell formation (CF) and group layout (GL) as the interrelated decisions involved in the design of a CMS in order to achieve an optimal (or near-optimal) design solution for a multi-floor factory in a multi-period planning horizon. Other design aspects are to design a multi-floor layout to form cells in different floors, a multi-rows layout of equal area facilities in each cell, flexible reconfigurations of cells during successive periods, distance-based material handling cost, and machine depot keeping idle machines. This model incorporates with an extensive coverage of important manufacturing features used in the design of CMSs. The objective is to minimize the total costs of intra-cell, inter-cell, and inter-floor material handling, purchasing machines, machine processing, machine overhead, and machine relocation. Two numerical examples are solved by the CPLEX software to verify the performance of the presented model and illustrate the model features. Since this model belongs to NP-hard class, an efficient genetic algorithm (GA) with a matrix-based chromosome structure is proposed to derive near-optimal solutions. To verify its computational efficiency in comparison to the CPLEX software, several test problems with different sizes and settings are implemented. The efficiency of the proposed GA in terms of the objective function value and computational time is proved by the obtained results.


## 1. Introduction

To improve both flexibility and efficiency in today's modern competitive manufacturing environments, such as flexible manufacturing systems (FMS) and just-in-time (JIT) production, cellular manufacturing (CM) can be employed that is an innovative manufacturing strategy derived from a group technology (GT) concept. Setup time reduction, work-in-process inventory reduction, material handling cost reduction, machine utilization improvement and quality improvement are some reported benefits of CM implementation. The design steps of a cellular manufacturing system (CMS) includes: (1) cell formation (CF) (i.e., clustering parts with similar processing requirements into part families and related machines into machine cells), (2) group layout (GL) (i.e., intra-cell layout arranging machines within each cell, and inter-cell layout arranging cells with regard to each other), (3) group scheduling (GS) (i.e., scheduling part families), and (4) resource allocation (i.e., assigning tools, human, material resources and material handling devices) [1].

An increasingly significant issue in designing a modern manufacturing system producing multiple products and working in highly unstable environments is that the existing layout configurations (i.e., product, functional and cellular type layout) are not suitable to reach an optimal strategy [2]. This disadvantage exists because these layouts are generally designed for a given product mix and demand volume in a fixed planning horizon. Unplanned changes in a product mix and demand volume necessitate reconfiguration of these layouts. Hence, ignoring these changes (e.g., new products incoming at future) imposes subsequent unplanned changes to the CMS and causes production disruptions and unexpected costs. As a result, product life cycle changes should be incorporated in the design of cells. This type of a system is called the dynamic cellular manufacturing system (DCMS) [3]. Drolet et al. (2008) [4] developed a stochastic simulation model and indicated that DCMSs are generally more efficient than classical CMSs or job shop systems, especially with respect to performance measures (e.g., throughput time, work-in-process, tardiness and the total marginal cost for a given horizon).

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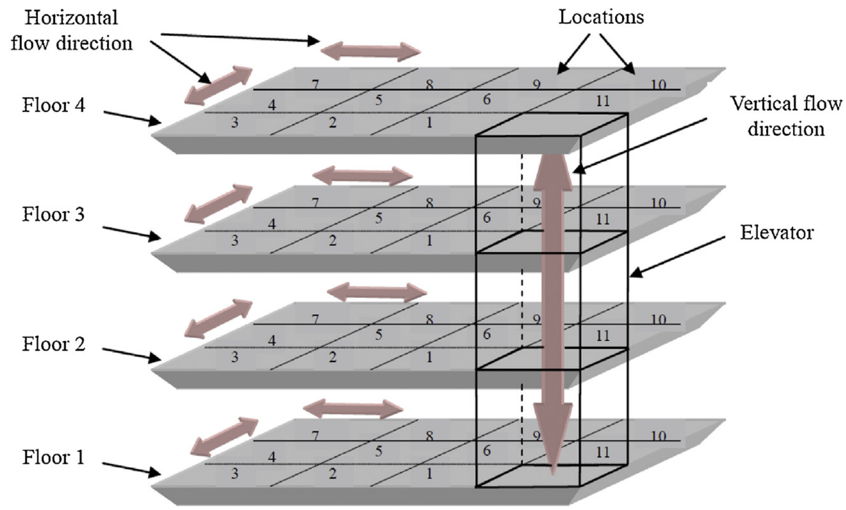


**Fig. 1.** Multi-floor layout [11].

Layout strategies, which can be employed for a dynamic environment, have been divided by Benjafaar et al. [2] into four groups: (1) modular layouts, (2) reconfigurable layouts, (3) agile layouts and (4) distributed (scattered) layouts. In the reconfigurable layout approach, it is assumed that facilities can be easily relocated. Once this assumption is considered; then, the layout problem becomes a dynamic layout problem (DLP). In this problem, the optimal location of each facility in each manufacturing period is investigated to be obtained by minimizing the total costs of material handling and relocation [5].

Keshavarzmanesh et al. [6] considered adaptability and responsiveness to the layout changes as well as the costs of material handling and machine relocation in reconfiguration of a shop floor layout. They divided the shop floor layout problem into two subproblems and handled by two modules: (1) re-layout dealing with major shop floor changes and deriving an alternative layout using a genetic algorithm (GA) when the reconfiguration cost can be appropriately justified against the material handling cost and (2) find-route utilizing a function block to handle soft changes, such as an urgent job or a robot breakdown, with determination of alternative assembly routes within the existing layout.

If there is no cost in transforming from one optimal configuration to another, the best strategy will be utilizing the optimal configuration in each period. However, reconfiguring cells incurs corresponding costs, such as moving machines, installing or uninstalling machines, lost production time and relearning. By considering reconfiguration costs, it is possible that a sub-optimal configuration is the best one to utilize in a period because utilizing this sub-optimal configuration might impose a lower reconfiguration and overall costs [7]. Thus, when creating manufacturing cells it is important to consider the reconfiguration cost of cells.

Since in our integrated model, GL and multi-floor layout decisions are made in a dynamic environment, we actually incorporate a DLP and multi-floor layout in a DCMS model. In this case, an appropriate decision should be made among the available strategies (e.g., purchasing a new machine to meet increased demand requirements, relocating the machine that is underutilized in a cell to another cell where demand requirements are higher, keeping machines that are underutilized in a depot to reduce the overhead costs and re-planning the part production in order to make a trade-off between resultant costs of purchasing machine, reconfiguration and material handling including intra-cell, inter-cell and inter-floor).

While constructing a factory in urban area, land supply can be generally insufficient and expensive. Therefore, using a vertical dimension of the factory and locating the facilities on several floors can be reasonable because of the limitation of available horizontal space, as shown in Fig. 1 [8].

As it is shows in Fig. 1, parts can be transferred horizontally on a given floor (i.e., horizontal flow direction) by horizontal material handling devices (e.g., manpower, robot or AGV), it is also possible from one floor to another floors located at a different level (i.e., vertical flow direction) by a vertical material handling device (e.g., elevator). In general, it is expected that vertical material handling devices impose a more material handling cost in comparison to horizontal material handling devices. In a multi-floor layout problem, both position on the floor and the levels should be determined for each facility [9].

Based on material handling devices, the material handling cost of a given part type can be divided into two terms: horizontal material handling cost and vertical material handling cost. In a specified period, the horizontal material handling cost is the horizontal unit material handling cost multiplied by the demand of a part type in that period and the horizontal distance travelled. Similarly, the vertical material handling cost is the vertical unit material handling cost multiplied by the demand of part type in that period and the vertical distance travelled [10].

The aim of this study are twofold: (1) to present a new mathematical model with an extensive coverage of important manufacturing features including alternative process routings, operation sequence, processing time, production volume of parts, purchasing machine, duplicate machines, machine capacity, machine depot, material flow between machines, intra-cell layout, inter-cell layout, multi-floor layout, multi-rows layout of equal area facilities and flexible reconfiguration, and (2) to extend an efficient genetic algorithm for solving the presented model. The objective is to minimize the total costs of intra-cell, inter-cell and inter-floor material handling, purchasing new machines, machine relocation, machine overhead and machine processing. The main constraints are machine capability, demand satisfaction, machine availability, machine location, cell size, machine time-capacity and material flow conservation.

The model presented in this study is an extended version of the integrated model proposed by Khaksar-Haghani et al. [11], whose advantages include: (1) considering multi-rows/multi-floor layout of equal-sized facilities, (2) considering flexible configuration of cells, (3) calculating relocation cost based on the locations assigned to machines, (4) computing intra-cell, inter-cell and inter-floor material handling costs based on distances travelled, (5) considering intra-cell movements between two machines of a same type, (6) applying the equations of material flow conservation, and (7)