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Technical Paper

An integrated mathematical model for the optimization of hybrid product-process layouts

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ABSTRACT

The layout of a manufacturing process plays a significant role to maintain a profitable production and make competitive a company. Product-oriented layouts aim to minimize the distance travelled by the manufactured units; the process-oriented approach attempts to maximize the saturation of the facilities. However, in many cases a hybrid approach may be necessary to achieve a compromise between the two objectives. This paper aims to present a mathematical model capable to define a hybrid product-process layout by autonomously: (i) defining the process cells and, for each of them, evaluating the number of machines necessary for stability; (ii) identifying the position of the machines within each cell; (iii) determining the best position for the cells in a given shop-floor area; (iv) evaluating a set of KPIs for the obtained layout proposal. The numerical implementation of the model led to obtain a layout proposal within 10 seconds for a process made of 30 distinct operations. The approach is validated through case-studies taken from the automotive industry; the obtained results show that the model is an effective tool to support the activities of designers of manufacturing processes.

1. Introduction

The position of the facilities within a plant is known to have a significant impact on manufacturing costs and overall productivity [1]. A poor layout and flow path design can result in excessive work-in-process inventories, high lead times, low or unbalanced equipment utilization and high costs for material handling and logistics equipment [2]. A study made by Tompkins et al. [3] stated that 20–50% of the manufacturing costs are due to the handling of parts and that a good arrangement of handling devices might reduce them for 10–30%.

The optimization of the facilities positions is named "facility layout problem" (FLP); Shayan and Chittilappilly [4] defined it as an optimization problem that tries to make layouts more efficient by considering various interactions between facilities and material-handling systems while designing layouts. Nonetheless, the solution of a layout problem is non-trivial and generally exhibits a NP-hard complexity [5].

FLPs have been studied in literature since the 1960s [5]. Various efforts have been made to systematize the knowledge about this class of problems: literature surveys have been proposed by Kusiak and Heragu [6], Meller and Gau [7], Singh and Sharma [8], Drira et al. [1], Anjos and Vieira [5]. In particular, Drira et al. proposed a tree representation of the different factors to be taken into account when dealing with an FLP. They categorized the organisation of manufacturing systems in:

- Fixed product layouts, in which the product is not moved and the facilities circulate around it to perform the necessary operations;
- Process layouts, where facilities with similar functions are grouped together in cells to deal with a wide variety of products;
- Product layouts, where facilities are organized to match with the sequence of manufacturing operations to be performed for obtaining a specific product;
- Cellular layout, in which heterogeneous machines are grouped into cells, and each cell is in charge of manufacturing a product.

Montreuil et al. proposed the following paradigms. In fractal layouts, cells having a similar composition of machines are dispersed in the shop floor. The main objective of this approach is to reduce material movements; hence each fractal cell must be able to process most of the demanded products, and behave like a factory within the factory [9]. Distributed layouts have been defined in [10]. In this type of layout, duplicate machines are dispersed throughout the shop-floor as much as possible by keeping the proximity of distinct machines. This method ensures that when a new product is

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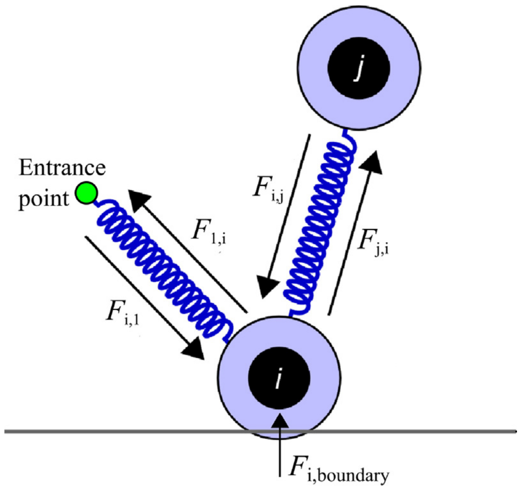

Fig. 1. Example of the interaction forces involving the agent *i*. The black circles have radius R^{in}; the lilac circles have radius R^{out}.

introduced into the system, an efficient routing can easily be found without rearranging the facility [11].

To choose the most appropriate manufacturing layout, the products variety to be manufactured must be considered, as well as the material handling system (MHS) to be deployed: on the one hand, the facilities should be arranged along the MHS path; on the other hand, the type of handling device may determine the pattern to be used for facilities positioning [12]. Due to the difficulties in solving the FLP and the MHS choice jointly, the two problems are usually solved sequentially [13].

Luggen [14] defined some basic configurations for facilities layout, e.g. single row, closed loop, ladder, open-field. All of them take into account the rigidities due to the MHS. Conversely, technical efforts have been made in the last two decades to develop Automated Guided Vehicles (AGVs) capable of freely navigating into a given space and safely interacting with other vehicles and with humans. This capability opens new possibilities for the definition of manufacturing systems layouts. Further, manufacturers require facilities capable to quickly shift from one product to another without huge investments for major retooling, resource reconfiguration, or replacement of equipment [15].

In order to support manufacturers dealing with these challenges, this paper aims to present a novel mathematical model for the evaluation of layout proposals based on a hybrid product-process layout. The term "hybrid product-process" is used because the model is able to formulate product layouts, process layouts, and intermediate solutions in which process cells may be conveniently duplicated. In particular, the model here presented is able to: (i) autonomously define the process cells to achieve a compromise between the distance travelled by the manufacturing units (which is minimized in product-oriented layouts) and the number of deployed machines (which is minimized in process-oriented layouts), and evaluate the machines to be used in each cell; (ii) select the best position of the machines within each cell; (iii) identify the best position for such cells in a continuous, rectangular domain with the aim of minimizing the impact of inter-cellular transport; (iv) calculate a set of KPIs for an objective evaluation of the layout proposal.

As the number of machines assigned to each cell can be different, the problem can be classified as an unequal-areas facility layout problem (UA-FLP).

The content of the paper is organized as follows. In Section 2 the existing methodologies to deal with the FLP are reviewed. In Section 3 the original model presented here is explained. The experiments performed to validate the methodology are presented in Section 4, and the results are discussed in Section 5. Conclusive remarks and improvement perspectives are presented in Section 6.

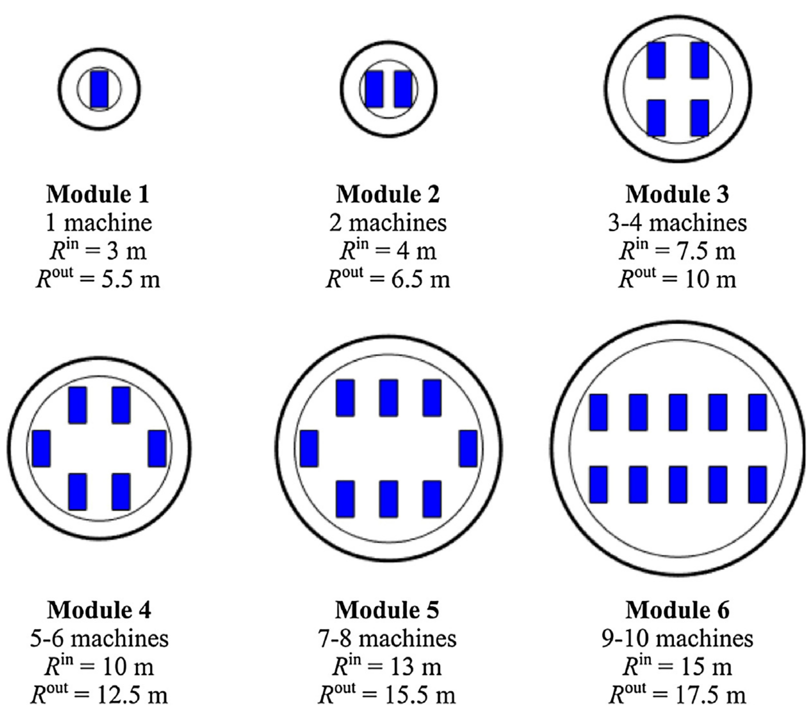

Fig. 2. Representation of the defined modules and the corresponding parameters. Blue rectangles represent machines. The inner circle – with radius R^{in} – models the area necessary to place the machines; the outer circle – with radius R^{out} – includes the area necessary for the MHS to move around the cell. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)