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Equipment selection and evaluation approach for an adaptable assembly line

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Abstract: In an evolving manufacturing sector, decisions about production systems design, reconfiguration and management are critical tasks. In addition, the rapid evolution and underlying uncertainty of market conditions, make these decisions more important and capital intensive. In this paper, we focus our attention on the equipment selection in an adaptable assembly cell where different easy-changeable hardware modules can be arranged around a skeleton architecture to provide different assembly technologies with different execution modes and performances. In this paper we present the architectural framework of a procedure defining the different sequencing of the tasks in relation to alternative execution modes, a possible skeleton architecture and a procedure that, given the selection of the equipment, provides the evaluation of the associated performance to be compared against the capability requests, expressed in terms of volumes and mix of the products. The modularity provided by the considered architecture is also exploited through the possibility of a fast setup of the assembly line, thus allowing the rearrangement and substitution of the different hardware modules to cope with the production of different parts. Both equipment cost and performance are taken into consideration to identify the most promising configurations. A testing of the approach through the application to a realistic case is also provided.

Keywords: assembly cell, manufacturing, design, analytical method, optimization process

1. INTRODUCTION

The worldwide manufacturing sector has faced a rapid and consistent change in the last few years. Most of consumers products and goods have incurred into a shorter life-cycle and thus a shorter time to market. In addition, customers often require an increasing level of *customization* entailing the increase of the variety of products and reduction of volumes (Wiendahl et al. (2007)). In order to deal with these market needs and to maintain their competitiveness, production and manufacturing companies are asked to answer these challenges with cost-effective and yet efficient solutions. In the last few years, several concepts have been developed in manufacturing systems design to address these issues: *modularity*, *reconfigurability* and *flexibility*. These kind of system paradigms (ElMaraghy (2006)) have the prerogative to be easy and quickly adaptable to cope with new requirements in terms of both hardware and software capabilities. The impact of these solutions is maximized when product, process and production system can evolve jointly, in a *co-evolution* context (Tolio et al. (2010)). The same rapid and consistent change is also affecting assembly industry. In fact, the shortening of product life-cycles and the increasing set of product variants to be assembled in the same automated system (ElMaraghy et al. (2013)), require the assembly resources to be endowed with technologies designed to be flexible and able to operate on more than one product. These technologies can be tailored at process level (i.e. by using flexible technologies like Remote Laser Welding) or/and system level by using the aforementioned concepts. A good example of this kind of application is represented by assembly cells used in the automotive sector, in which a cell is designed and used for the production of different parts (S.J. Hu et al. (2011)). To exploit these technological features, an optimized system design needs to be generated. For these reasons, design and performance evaluation of an easy changeable assembly cell represent two key tasks for these reconfigurable production systems. This paper presents an integrated methodology to select equipment and assess performance of an adaptable assembly cell where different easy changeable hardware modules can be arranged around a skeleton architecture to provide different assembly technologies with different execution modes and performances. Its main aim is to be able to deal with high product variety with low volumes request. The proposed approach is composed of three integrated tools. The first one addresses the definition of process alternatives for parts to be produced. Process alternatives take into consideration both technology and execution modes for a given set of operations. Moreover, also requirements in terms of volumes and product mix are considered. The second one considers the selection of hardware modules able to

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provide requested technologies and execution modes, and arrange them within a given system architecture. Finally, the third one is a performance evaluation based analysis: it consists in an analytical method to estimate main *KPI*s (i.e. throughput and WIP) for given configuration and execution modes selected. Given the results of performance evaluation, the configuration tool is able to select best set of pieces of equipment and the associated arrangement able to manage the production of requested parts and volumes at minimal cost. A testing of the developed approach to a realistic case study in automotive industry is also reported.

The structure of the paper is the following: Section 2 provides a review of the available approach, considering both the configuration and performance evaluation area. Section 3 describes the approach in terms of the function and characteristics of the different tools. Section 4 reports results of the test on an industrial use case, while Section 5 reports the conclusions and foreseen evolution of the presented approach.

2. STATE OF ART

Regarding the presented methodology, it is possible to classify the related works in two groups of interest: production cell configuration problem, and production cell performance evaluation. The first group contains all the contributions about how it is possible to design a manufacturing system in order to choose the minimum-cost configuration. The second group instead, contains all the contributions and advancements in the field of performance evaluation of production cells.

Regarding first point, contributions taken into account concern the connection between configuration and optimization problem: first works addressing this issue are presented in Wesolowski (1973) and Rosenblatt (1986). In these papers, authors consider the arrangement of physical facilities within a production system by optimizing a cost function. Their most important contribution is on problem formalization: they highlight the need of connection between layout design, production process and market demand. In cell manufacturing design problem, major *differential* cost is the handling system movement and routing, as exposed in Massoud (1999). Other examples of cost minimization are represented by worker's assignment (Aalaei et al. (2010)) or machine reliability and maintenance (Das et al. (2007)). Regarding the design of flexible lines it is possible to include in this investigation Tolio and Urgo (2013). In this paper we propose an innovative framework, because we address the resource needing for a production process by list several ways in which a certain assembly activity can be run using modular devices.

Regarding the second group of interest, there are two main families of performance evaluation techniques, namely simulation and analytical methods. Simulation techniques usually involves precise estimation of systems *KPI*s at the expense of high computation times, model development and validation. Analytical usually involves fast computation times at the expense of high error on *KPI*s estimation. We will focus on the second family of techniques by narrowing the analysis on analytical techniques for modeling production systems with general distributed failure and repair times, multiple-product assembly and non-negligible transportation time. Several researchers have developed approximate analytical models for manufacturing systems with assembly operations, in particular Levantesi et al. (2003) analyzed assembly production systems with multiple failure modes machines. However, this model assumed homogeneous production lines. In Colledani et al. (2005) and Colledani et al. (2008) authors analyzed systems having automated machines with multiple failure modes, without incorporate assembly operations. Currently, the case of multiple products can only be treated by approximating the multiple product flows as an aggregated flow of an averaged and fictitious equivalent single product. However, this approach leads to accurate results only if processing times and reliability parameters for two or more products are the same. Otherwise, the accuracy of this approach is very poor if the results are compared to *DES*. In literature there are also several contributions about the modeling and analysis of production lines with general distributed failure and repair events. In Tan and Gershwin (2009), authors present the modeling of a two-machine line with general distributed failure and repair events; in Tolio and Ratti (2013) a two-machine line with general Markovian machines and generalized thresholds is faced, while in Colledani and Gershwin (2011) authors present a decomposition methodology to analyze long production lines composed by Markovian machines. As advancement from aforementioned contributions, in Colledani et al. (2015) authors present an efficient technique to evaluate multi-product assembly manufacturing systems, with general distributed failure and repair events. In this last contribution, transportation time is not explicitly considered. In the context of the presented paper, analytical method proposed involves the modeling of general distributed failure and repair events, multi-product assembly and transportation time.

3. SOLUTION APPROACH

The presented approach is composed of three different modules that perform a loop iteration, as depicted in Figure 1. These three modules are described below:

(1) *Demand and processes requirements*: it addresses environment representation through volumes and production mix requested by the market and, moreover, it addresses assembly process representation of each product using different *execution modalities*, that are different ways to execute the same set of operations using different equipment pieces.
(2) *Equipment selection tool*: it provides the selection of hardware modules needed to execute a given set of operations in a given execution modality. It also arranges these pieces of equipment onto the assembly line architecture and calculates the investment cost of selected equipment. After the evaluation of the performance, it also selects best combination of pieces of equipment to match the production requests at a minimal cost.
(3) *Performance evaluation tool*: it automatically generates a dynamic model of system behavior to evaluate the performance in an analytic way. Performances are estimated under the assumption that the cell can manage the production of a single product at a time,