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Multi criteria assembly line design and configuration – An automotive case study

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ABSTRACT

The aim of this paper is to deal with a method that enables the user to design and configure a production line against multiple-user defined criteria. Machine utilization, investment cost, resource energy consumption, availability and annual production volume are some of the criteria used in the design. The production line design/configuration is a very hard and complex problem to be solved. The proposed method tackles this decision making problem, by formulating it as a search problem and applying intelligent search algorithms for the identification of high quality solutions. The method's real life applicability has been ensured by the examination of the problems and the requirements that arise during the actual design process, as it is carried out by modern assembly line builders. The method is tested and evaluated on a case study, inspired by a real automotive assembly line.

1. Introduction

The great size and complexity of assembly lines, like the ones that are currently used by the automotive industry, call for efficient methods of efficient assembly line design and configuration. The assembly line design is a process that is currently carried out by expert designers and therefore, the quality of the final design depends on their personal knowledge, experience and intuition. To this direction, the tools required are those that can systematically represent the design problem and provide quick generation and evaluation of different design alternatives that would to enable the designer to briefly review and consider them in his/her project. The main concept behind such a structured approach is that the solution to the problem of the design space is more consistently explored by the developed tools, whose exploration is driven by quantified criteria rather than the user's experience.

Having considered the above, this paper aims to investigate the design process of assembly lines and to formulate a decision making method that can be in support of designers when designing and configuring/detailing assembly lines. To better define the contribution of this paper, the definition of the assembly line design and configuration problems are given hereafter.

The term assembly line design refers to the determination of an assembly line concept capable of producing the desired product. The assembly line design (ALD) comprises several problems such as those of the equipment selection [1,2] the balancing of the assembly line (ALB) and the spatial layout determination [3,4]. The ALB problem in turn, consists of the task of assigning operations to workstations so that the idle time is minimized [5,6]. If the multiple equipment types are considered, then the problem is known as resource planning (RP). Both the RP and ALB problems have been proven to be NP-hard and thus difficult to be solved [3,7]. Considering further the classification of Boysen et al. [8], our approach focuses on the first-time installation phase of a single model, automated, paced assembly lines.

Following the above definition, this study addresses the design of serial assembly lines, by considering a two stage approach (see also Fig. 2):

1. In the first stage described in Section 3.1, the number of required stations and resources are calculated analytically on the basis of the product constraints and specifications (type of required processes, number of welds etc.). The aim is to determine the minimum number of resources that are required in each station in order for the required operations to be carried out, thus minimizing the idle time. This functionality is in-line with the ALB problem definition provided by Boysen et al. [8]:

   Any type of assembly line balancing problem (ALBP) consists in finding a feasible line balance, i.e., an assignment of each task to a station, such that the precedence constraints and further restrictions are fulfilled. More specifically, the problem can be further categorized as a SALBP-1 [3] problem since for a given

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cycle time (CT) (Eq. (1)), the method tries to minimize the sum of station idle times by efficiently allocating the tasks to each resource. The method also tackles the RP problem as the minimum number of different resource types required for each operation (e.g. loading robots, welding robots etc.) are also determined (Eqs. (3) and (7)). Thus, the ALD (ALB and RP) problem definition by Boysen et al. [3] is also satisfied. The result is an initial configuration of the line design. However, at this stage, the system's final configuration (exact model/characteristics of resources) is not yet known and therefore, it cannot be further enhanced.

2. In the second stage, the configuration of the assembly line is carried out as described in Section 3.2. In this study, the term configuration is used to denoting the alteration of the characteristics of the initial system design (result of the aforementioned design process); for the improvement of its performance under a set of criteria, involving investment cost, energy consumption and resource utilization as well as the response to a demand profile. This also includes aspects of the optimization definition provided by Kühn [9] where it is described as the process involving the optimization of material flow, resource utilization and logistics, at all levels of the plant planning, from global production networks, through local plants down to specific lines. In this paper, an intelligent search algorithm is used in parallel with discrete event simulation for the identification of specific resources' combination that provides the best criteria values for the given set of resources. The convergence of the algorithm guarantees that for the given set of available resources, the selected combination is the one that best justifies the criteria values.

It has to be clarified that the approach to the SALBP problem is different in the sense that it does not focus on finding the proper (analytical) solution. Instead, it uses simulation and search methods for the identification of good quality solutions aiming at decision making support. The research in this study has also been supplemented with the development of a decision making support tool that can automatically generate simulation models for the assembly line designs, through the incorporation of flexibility, productivity, and cost criteria.

To validate the performance of the approach, the specific method has been applied through the developed software tool to the design of a passenger car underbody assembly line (Fig. 1). The resulting production line design has been compared with that of an existing line, provided by a European assembly line builder that uses the existing – traditional design procedures.

The paper is structured as follows: Section 2 is dedicated to providing the state of the art on relevant approaches in order for the design and configuration of assembly lines to be tackled. Section 3 provides the theoretical background underlying this method and presents the design/configuration criteria as well as the method for the consideration of multiple criteria during the design process. The applied search algorithm which allows the automation of the resource selection process is also presented. Section 4 gives an overview of the software developed in order for the method to be applied to an automotive assembly case study, which is presented in Section 5. Finally, Section 6 presents and discusses the results of the case study, while Section 7 is used to drawing the conclusions from this study and to outlining areas for future research.

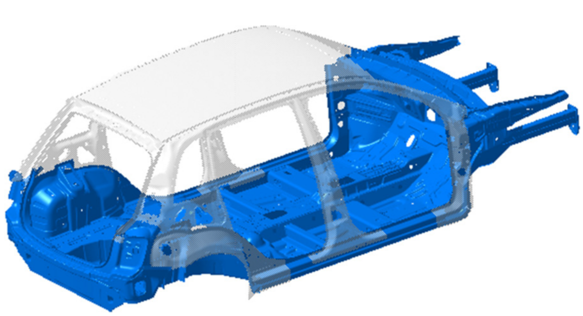

Fig. 1. Complete BiW and under-body structure.

2. State of the art

The era of mass customization leads to continuously increased product variability. This fact apart from considering the cost and lifecycle of the assembly line, raises the need for the line to be designed as efficiently as possible [10]. It has been observed that literature has focused on the high level strategic assembly line design and in many cases, has neglected the real life constraints and product specifications [11]. As it was mentioned in the previous section, the ALD problem involves the tackling of several problems such as the ALB, the RP and the buffer allocation that have been mainly dealt with independently so far. Especially for the ALB and RP problems, which are NP–hard, a lot of approaches have been reported since the seventies in order for these problems to be solved [12–17]. These attempts are mostly based on linear and integer programming, neural networks and genetic algorithms. Constraint satisfaction procedures, meta-heuristics, real-coded genetic algorithms (GAs) and Tabu Search (TS) have also been applied [18]. Specifically, for the automotive industry meta-heuristic based optimization approaches such as genetic algorithms and simulated annealing have been considered for the optimization of the planning problem [19].

Over 125 different approaches [20,21,3,6,7,18,22] have been revealed so far from extensive classifications of the proposed solutions that have been applied to the ALB and RP problems. Out of these, 12 consider the case of multiple processing alternatives and only 7 take into account resource alternatives, where multiple resources need to be assigned to each station at once.

However, none of these have tackled both problems under a single approach, and this is one of the originalities introduced by this study, which also extends to addressing even more challenges, such as the material flow and buffer size determination. The proposed method transforms a decision making problem (design/configuration) into a search one. This allows the application of parametric search algorithms for the efficient identification of high quality design solutions.

Last but not least, the benefits of simulation have not been efficiently exploited in this kind of design approaches. Over the last years, simulation has been proven to yield safer conclusions for the systems examined [23–31]. The multiple objective nature of the design problem includes aspects such as cost [32–35], productivity [36], flexibility [26], quality [37], energy efficiency [38,39] etc. that cannot be tackled by the over simplified models, which rely on single objective minimization functions [6,40] and neglect the stochastic nature of many design parameters [41].

In this paper the software tool introduced in Section 4, is capable of automatically creating discrete event simulation models for every assembly line design that is derived by this method. The tool enables the user to define a desired demand profile as well as to choose among different criteria for the evaluation (cost, resource utilization, annual production volume etc.). By considering a set of the resources available and their operational characteristics (e.g. MTBF and MTTR) an evaluation of each assembly line design performance is provided for supporting the decision making.

3. Method description

This section is dedicated to the description of the model used in order to represent the decision making process during the