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Consideration of human resources in the Mixed-model Sequencing Problem with Work Overload Minimization: Legal provisions and productivity improvement

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ABSTRACT

Beginning with a variation of the sequencing problem in a mixed-products line (*MMSP-W*: Mixed-Model Sequencing Problem with Workload Minimization), we propose two new models that incorporate a set of working conditions in regard with human resources of workstations on the line. These conditions come from collective agreements and therefore must be respected by both company and labor unions. The first model takes into account the saturation limit of the workstations, and the second model also includes the activation of the operators throughout the working day. Two computational experiments were carried out using a case study of the Nissan motor plant in Barcelona with two main objectives: (1) to study the repercussions of the saturation limit on the decrease in productivity on the line and (2) to evaluate the recovery of productivity on the line via both activation of operators, while maintaining the same quality in working conditions achieved by limiting the saturation, and auxiliary processors. By results we state that saturation limitation leads an important increase of work overload, which means average economic losses of 28,731.8 Euros/day. However, the productivity reduction may be counteracted by the work pace factor increase, at certain moments of workday, and/or by the incorporation of auxiliary processors into the line.

1. Preliminaries

Currently, many production systems exist in which the manufacture or assembly of an entire product (or a subcomponent of the product) is carried out on the production line. At the same time, the increasing market requirements demand that companies offer a wide range of products with different options. This situation is commonly found in the automotive industry in which different products are manufactured and although these products belong to the same family, they have variable characteristics that require different component consumption and resource use, such as different processing times of operations. Obviously, not all vehicles share the same type of motor, and not all are equipped with the same components.

Assembly lines in the automotive industry are a clear example of this type of mixed-product lines, which are known as Mixed-Model Assembly Line (*MMAL*). In this type of lines, different components (seats, steering wheels, pedals, etc.) are incorporated into the vehicle body depending on the type of vehicle that is assembled at each moment. Therefore, these lines must be flexible and able to adapt to each type of product assembled in them without incurring excessive costs.

In this way, to increase flexibility and reduce costs in terms of both workforce and storage, the *MMAL*s face two basic problems: (1) the balancing of the line, known in the literature as the Assembly Line Balancing Problem (*ALBP*) (Salveson, 1955), and about which many variants exist (Battaïa & Dolgui, 2013; Becker & Scholl, 2006); and (2) the sequencing of mixed products in production lines and workshops.

The latter issue can be classified according to the variability of processing times of the operations required to assemble the products. If the units have heterogeneous processing times, in the stages of the production process in a workshop, we are facing permutation problems such as Flow-Shop Problems (Bautista, Cano, Companys, & Ribas, 2012; Pan & Ruíz, 2013). When the processing time of any operation depends on the number of units it is convenient to sequence the units in batches of pieces. In this case the problems are known as Economic Lot Scheduling Problems (*ELSP*) (Elmaghraby, 1978; Raza & Akgunduz, 2008). Finally, when the processing times are homogeneous during the stages of the production process the aim is to establish a manufacturing order for the products (and this order must be maintained as much as possible). These problems appear in the supply chain of production systems governed by the Just In Time (*JIT*, Toyota) and Douki-Seisan (*DS*, Nissan) ideologies and they are known as

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Mixed-Model Sequencing Problems (*MMSP*) (Bautista & Cano, 2011; Boysen, Fliedner, & Scholl, 2009a,b; Solnon, Cung, Nguyen, & Artigues, 2008).

In turn, the *MMSP* can be classified according to the optimization criterion that affects one or more elements of the production system.

(a) Minimization of the stock level of products and components. This category contains the Product Rate Variation Problem (*PRVP*) proposed by Miltenburg (1989) and whose purpose is to minimize the variation of production rates; and the Output Rate Variation Problem (*ORVP*) proposed by Monden (1983) and whose aim is to minimize the variation in the component consumption rates.
(b) Minimization of the work overload. The variation of the processing times of operations based on the type of product can cause sometimes the time assigned to a workstation is less than the processing time of the operation of a product. When this happens, the processor does not have sufficient time to complete the work on the assigned product and then work overload appears. Without extra effort, this situation ends up generating backlog. In this case, the objective is to minimize the uncompleted work, which is also known as work overload. One example of this type of problems is the Mixed-Model Sequencing Problem with Workload Minimization (*MMSP-W*) both the original version, Yano and Rachamadugu (1991), and its variants Bautista, Cano, and Alfaro (2012a,b).
(c) Minimization of the number of subsequences with special options. These problems are focused on avoiding blockages caused by products that require additional work by offering special options. This problem is known as the Car Sequencing Problem (*CSP*) and was first described by Parrello, Kabat, and Wos (1986).

Obviously, the above problems have been extended or combined in many papers in the literature. For instance, Lin and Chu (2013, 2014) among others, minimize the manufacturing total cost of a mixed-product assembly line considering labor, warehouse capacity and order fulfillment rates. Giard and Jeunet (2010) consider a cost function that involves two elements: the cost associated with the utility workers and the cost of setup. Thus, they simultaneously try: (1) to minimize the number of auxiliary operators necessary to complete the work required and therefore they minimize the work overload (*MMSP-W* objective); and (2) to minimize the setup times between product models (*CSP* objective).

Following the idea of extending the models in the literature, in this article, we focus on the (b) category of problems. Therefore, we address the sequencing problem of mixed products in production lines with the objective of minimizing the work overload (i.e., *MMSP-W*: Mixed-Model Sequencing Problem with Workload Minimization).

Although this type of problem has been widely treated in the literature, there are few papers that consider specific aspects of human resources involved in the production system. Among these few works, Celano, Costa, Fichera, and Perrone (2004) introduced the human resource into the sequencing problem of a mixed-model U-assembly line in order to evaluate human factor policies impact on the optimal solution of the problem.

However, the processors of line workstations, in addition of automated systems, usually contain operators (i.e. persons) and these are subjected to working conditions defined according to laws, rules, contracts and also negotiations between the company and the workers´ representative. Indeed, these conditions affect certain job characteristics, such as the length of working days, the saturation and occupancy rates of the processors, and the normal activity level of the operators, the acceptable performance level, among others.

As a result of works by Bautista et al. (2012b) and Alfaro (2015) and the scarcity of works on the sequencing problem considering the human factor of the processors of the line and the effect of working conditions on the productivity, in this work we propose an extension of the *MMSP-W*. This extension incorporates working conditions that must be guaranteed to the workers of an assembly line in the automotive Sector.

Specifically, we incorporate through new constraints the fulfillment of the maximum saturation of an operator throughout his working day. These new constraints limit the relation between the time used by the operator to carry out his workload and the available time to work. For this reason, we also incorporate two possible measures to counteract the negative effect of saturation conditions on productivity. First, we incorporate into the model the activity concept according the work by Bautista, Alfaro, and Batalla (2015a). In this way the activation of workers at certain times of their workday will reduce productivity losses due to the limits of saturation. Obviously, the activation level of operators will also fulfill the limits established by collective agreements. Secondly, we reinforce the line with auxiliary processors in order to complete the required work.

This work is structured as follows. In Section 2, the *MMSP-W* problem and some of its variants, such as the reference models used in this paper, are described. In Section 3, working conditions agreed at Collective Agreements are analyzed. Specifically, the focus is on the Work Schedule, the Workday and the processors' saturation. Section 4 is dedicated to incorporate the saturation conditions into the *MMSP-W*. For this purpose, it is necessary previously to distinguish between static and dynamic saturation. This section ends with the formulation of the two equivalent models, the $M3 \cup 4\_\eta$ and $M4 \cup 3\_\eta$. Section 5 is dedicated to an illustrative example. In Section 6, the new models are evaluated through a case study linked to an assembly line of engines of Nissan motor plant in Barcelona. This computational experience measures the impact of the saturation limitations in the stations regarding the increase of global work overload. In Section 7, we propose a series of corrective measures designed to reduce the global uncompleted work. Besides, two of these corrective measures, i.e., the activation of the processors and the incorporation of auxiliary processors, are described in greater detail in Sections 8 and 9. As a result of the natural extension of the $M4 \cup 3\_\eta$ model considering the activation measure, in Section 8 other two new models are formulated the $M3 \cup 4\_\dot{\alpha}I\_\eta$ and $M4 \cup 3\_\dot{\alpha}I\_\eta$ model. In Section 10, we evaluate the results and the profits and losses obtained by the proposed models and the measures proposed to increase productivity, using the same data as in Section 5, in order to achieve a balance between productivity and ideal working conditions. Finally, we dedicate Section 11 to the conclusions and proposals for future work.

2. The *MMSP-W*. Reference models

The *MMSP-W* consists of establishing the manufacturing order of T units, which are grouped into a set $I$of product types, in an assembly line composed of a set K of workstations arranged in series. Each unit of product type i ($i = 1, \ldots, |I|$) requires from each homogeneous processor (operator, robot...) of a workstation k ($k = 1, \ldots, |K|$) a processing time $p_{i,k}$ measured at normal activity(α^N), but each processor has a normal working time known as cycle time(c). This time is the standard time in which each processor is available to work on a product unit. Occasionally, to complete the work on a unit, the processor of workstation k can retain that unit for a time longer than the cycle time. This time is referred to time window or temporal window (l_k) and it fulfills $l_k - c > 0$. However, using this time reduces the time available to work on the next unit of the sequence and finally, when the temporal window is not sufficient to complete the entire work required, the work overload is generated (see Fig. 1).

The objective of the problem is to minimize this work overload or maximize the completed work by taking into consideration the variation in operation processing times according to the product types; and assuming that the cycle time of the processors is determined from the average processing times of each type of product in regard

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