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7th International Conference on Industrial Engineering and Industrial Management
XVII Congreso de Ingeniería de Organización

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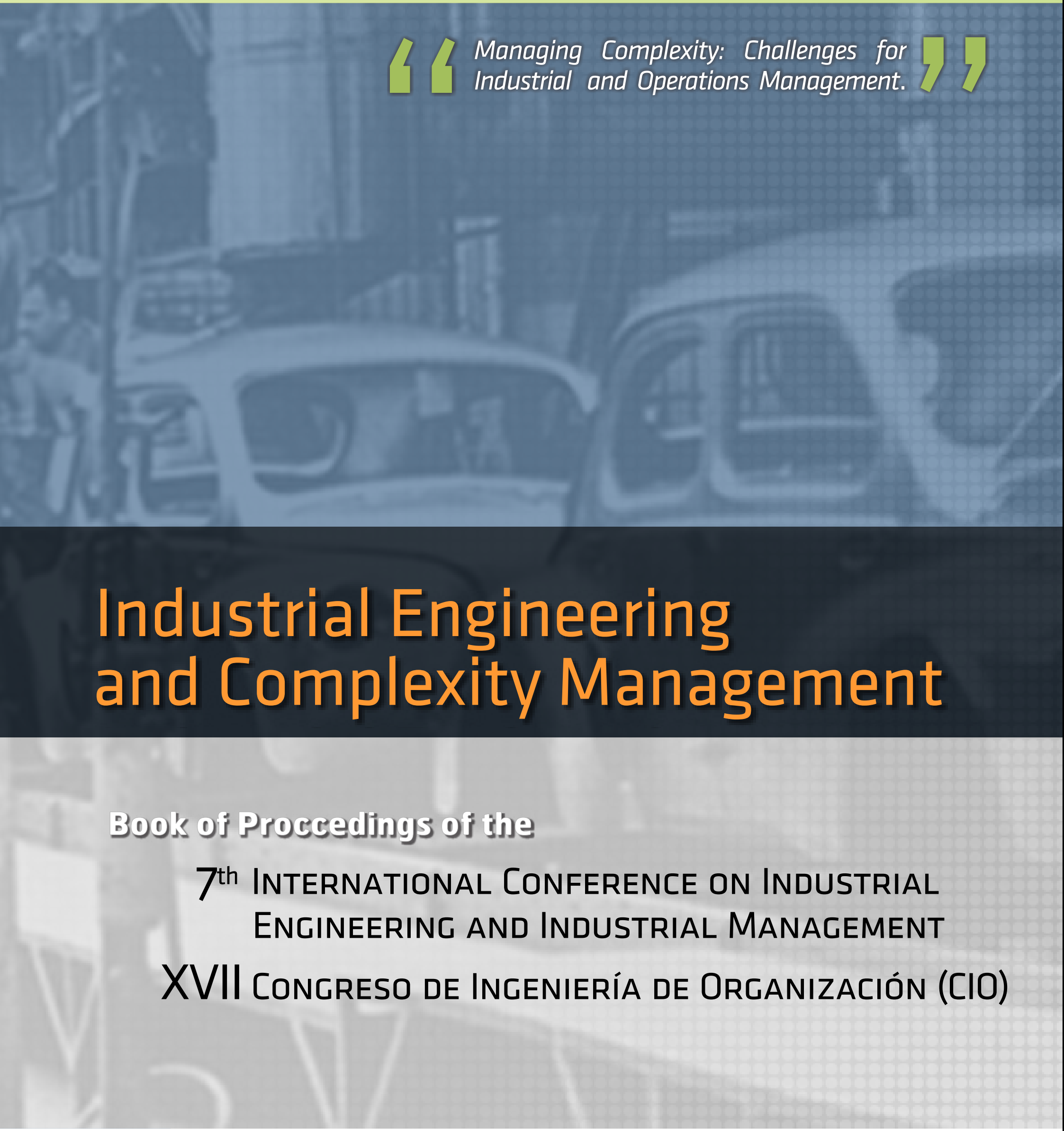

“Managing Complexity: Challenges for Industrial and Operations Management.”

Industrial Engineering and Complexity Management

Book of Proccedings of the

7th International Conference on Industrial Engineering and Industrial Management

XVII Congreso de Ingeniería de Organización (CIO)

ABEPRO
Associação Brasileira de Engenharia de Produção

ADINGOR
Asociación para el Desarrollo de la Ingeniería de Organización

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Industrial Engineering and Complexity Management

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Foreword and Welcome

It is our honour to present the Proceedings of the 7th International Conference on Industrial Engineering, XVII Congreso de Ingeniería de Organización (CIO2013) and the XIX International Conference on Industrial engineering and Operations Management (ICIEOM). The CIO&ICIEOM 2013 is being organized by the INSISOC Group and the Industrial engineering School of the University of Valladolid.

Following with the promotion of internationalization the Conference is the first joint event of ADINGOR (Asociación para el Desarrollo de la Ingeniería de Organización) and ABEPRO (Associaçâo Brasileira de Engenharia de Produçâo) the two main Spanish and Brazilian Scientific Societies in the field of Industrial and Management Engineering.

The mission of the Conference is to promote links between researchers and practitioners from different branches to enhance an interdisciplinary perspective of industrial engineering and management. It is a forum to exchange ideas, academic and professional experiences to all branches of industries, information on the most recent and relevant research, theories and practices in Industrial Engineering, Management and Operations.

The motto of the Conference “Managing Complexity: Challenges for Industrial and Operations Management” underlies the fact that in an open and global world, to handle complexity, cooperation is needed.

We want to thanks the support given by the Cátedra Michelin of Industrial Organization and the Industrial Engineering School of the University of Valladolid.

We also send our recognition to the keynote speakers for sharing with us their wisdom and experience and to the authors that sent their work for revision. Last but no least we gratefully acknowledge the hard and generous effort of those that took part in the peer-review process to maintain the high scientific level of the Conference series. And of course we do not forget the backstage work of the Scientific and Organizing Committees.

We hope that the Conference will meet your expectations and will strength your professional and personal relations. We invite you to enjoy Valladolid, a name full of historical significance for the Spanish, Portuguese and Brazilian citizens, since the signing of the “Tordesillas Treatry” back in 1494.

Best wishes,

Valladolid, July 2013

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Incorporating the Work Pace Concept into the *MMSP-W*

Bautista J[1], Alfaro R[2], Batalla C[3], Cano A[4]

Abstract This work proposes an extension for the *MMSP-W* (Mixed-Model Sequencing Problem with Work overload Minimization) with variable processing times by the incorporation of the work pace or work speed concept. A computational experience, linked to a case study of Nissan Powertrain plant in Barcelona, is carried out to compare the performance of the reference model with the new model proposed.

Keywords: Mixed-model Assembly Line, Sequencing, Work Factor, Work Overload, Linear Programming

1 Introduction

The product variety, that is demanded today, forces manufacturers to have mixed-product assembly lines. These lines are composed by a set of workstations (K) ar-

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ranged serially. Each workstation is characterized by its workload, or set of task assigned to it, and the available standard (normal activity or normal pace) time or cycle time (c) to process these tasks.

Because of that type of assembly lines treat several product types and each one may require different processing times and resources, it is necessary to sequence the manufacturing order of the product unit to avoid (1) high stock levels in the production system, and (2) the inefficiency of the line.

Thus, the sequencing problems (Boysen et al., 2009) can be focused on (A) minimizing the work overload or lost work, and (B) minimizing the stock levels.

In this work, we study a problem focused in objective (A), the *MMSP-W* (Mixed-Model Sequencing Problem with Work overload Minimization). That problem consist of sequencing T products, grouped into a set of I product types, of which d_i are of type i $(i = 1, \ldots, |I|)$. Each product unit requires a processing time at normal work pace, $p_{i,k}$, for each homogeneous processor at each workstation $(k = 1, \ldots, |K|)$. If the cycle time is not sufficient to complete the required work by a product unit at the workstation k, the product unit can be held at the station for a time, called the time window, equal to l_k, which is longer than the cycle time $(l_k > c)$, reducing the available time of the workstation for processing the next product unit.

When it is not possible to complete all of the work required, it is said that an overload is generated. The objective of the *MMSP-W* is to maximize the total work completed (Yano and Rachamadugu, 1991), or minimizing the total overload generated (Scholl et al., 1998), being equivalent both objectives (see Theorem 1 in Bautista and Cano, 2011).

Usually, deterministic and fixed operation processing times, $p_{i,k}^{\circ}$, are considered in sequencing problems. These times are initially determined, through the *MTM* system (Methods and Time Measurement) in *JIT* (Just In Time) and *DS* (Douki Seisan) manufacturing environments and correspond to the time required by an average skilled operator, working at normal pace or normal speed, to perform a specified task using a prescribed method, allowing time for personal needs, fatigue, and delay. Therefore, these operation processing times correspond to the predetermined standard times (Zandin, 2001).

The present study aims the extension of reference models for the *MMSP-W* considering variable processing times of the operations regarding the operator activation or work pace. In particular, we focus on minimizing the work overload, increasing the work pace at certain intervals of the workday, taking into account the usual conditions of the automotive companies and the relationship between the performance of the operator and his level of activation or stress level.

2 *MMSP-W* with Variable Work Pace

Large automotive companies negotiate with representative employees a set of work conditions, once established the processing times of operations according to the MTM system with a work speed 100, MTM_100. Among these conditions we found the selection of work pace considered as normal for the company.

Typically, the processing times accepted are the corresponding to MTM_110, which are obtained as follows:

$$p(MTM\_110) = p(MTM\_100) \cdot \frac{100}{110} = p^{\circ} \cdot \frac{100}{110} \qquad \forall i \in I \quad \forall k \in K \qquad (1.1)$$

Obviously, from the reference times determined with the normal work pace accorded by the company, MTM_110, we can establish a correspondence between the processing times regarding any pair of work paces. To do this, we define the factor work pace, α, of an operation as the division between the processing times measured at normal work pace (p) and those at the work pace that is carried out $(\hat{p})$; that is: $\alpha = p/\hat{p}$.

Therefore, if we consider that the processing times obtained through MTM_100 correspond with the standard work pace and the times MTM_110 with the normal pace, we can determine $\alpha^0 = 0.\widehat{90}$ (standard) and $\alpha^N = 1$ (normal), respectively.

Similarly, the companies set an activity or optimum work speed, which typically corresponds to 20% above the normal work pace ($\alpha^* = 1.2$, MTM_132). This activity is considered the maximum work pace that a worker can develop without loss of working life, working 8 hours a day.

Thus, considering that the work pace can vary throughout the workday and therefore operations can expand or contract over time, we can establish a new model for the $MMSP$-W from the reference model (Bautista et al. 2012). The parameters and variables of the model are:

Parameters

K	Set of workstations ($k = 1, \dots, \lvert K\rvert$).
b_k	Number of homogeneous processors at workstation k.
I	Set of product types ($i = 1, \dots, \lvert I\rvert$)
d_i	Programmed demand of product type i.
$p_{i,k}$	Processing time required by a unit of type i at workstation k for each homogeneous processor (at normal pace or activity).
T	Total demand; obviously, $\sum_{i=1}^{\lvert I\rvert} d_i = T$.
t	Position index in the sequence ($t = 1, \dots, T$).
c	Cycle time, the standard time assigned to workstations to process any product unit.
l_k	Time window, maximum time that each processor at workstation k is allowed to work on any product unit, where $l_k - c > 0$ is the maximum time that the work in progress (WIP) is held at workstation k.

$\alpha_{k,t}$	Work pace factor associated with the t^{th} operation of the product sequence ($t = 1, \dots, T$) at workstation k ($k = 1, \dots, \lvert K \rvert$).
α_t	Work pace factor associated with the period t ($t = 1, \dots, T + \lvert K \rvert - 1$) of the extended workday that includes T manufacturing cycles (total demand) more $\lvert K \rvert - 1$ additional cycles needed to complete the required work by all the units at all workstations. Note that if we associate the same factor to each moment of workday in all workstations, we have: $\alpha_{k,t} = \alpha_{t+k-1}$ $(\forall k, \forall t)$. If $\alpha_{k,t} = 1$ (normal work speed) we will use the *MTM*_110 scale; for $\alpha_{k,t} = 1.1$ and $\alpha_{k,t} = 1.2$ we will use *MTM*_121 and *MTM*_132, respectively.

Variables

$x_{i,t}$	Binary variable equal to 1 if a product unit i ($i = 1, \dots, \lvert I \rvert$) is assigned to the position t ($t = 1, \dots, T$) of the sequence, and to 0 otherwise
$\hat{s}_{k,t}$	Positive difference between the start instant and the minimum start instant of the t^{th} operation at workstation k.
$w_{k,t}$	Overload generated for the t^{th} unit of the product sequence at station k for each homogeneous processor (at normal activity); measured in time.
$v_{k,t}$	Processing time applied to the t^{th} unit of the product sequence at station k for each homogeneous processor at normal work pace or activity.
$\hat{v}_{k,t}$	Processing time reduced by a work pace factor $\alpha_{k,t}$. We impose here: $v_{k,t} = \alpha_{t+k-1} \cdot \hat{v}_{k,t}$

Model $M\_4 \cup 3\_\alpha 1$:

$$Min\ \ W = \sum_{k=1}^{|K|} \left(b_k \sum_{t=1}^{T} w_{k,t} \right) \Leftrightarrow Max\ \ V = \sum_{k=1}^{|K|} \left(b_k \sum_{t=1}^{T} v_{k,t} \right) \qquad (1.2)$$

Subject to:

$$\sum_{t=1}^{|T|} x_{i,t} = d_i \qquad (\forall i = 1, \dots, |I|) \qquad (1.3)$$

$$\sum_{i=1}^{|I|} x_{i,t} = 1 \qquad (\forall t = 1, \dots, T) \qquad (1.4)$$

$$v_{k,t} + w_{k,t} = \sum_{i=1}^{|I|} p_{i,k}\, x_{i,t} \qquad (\forall k = 1, \dots, |K|);\ \ (\forall t = 1, \dots, T) \qquad (1.5)$$

$$\alpha_{t+k-1} \cdot \hat{v}_{k,t} - v_{k,t} = 0 \qquad (\forall k = 1, \dots, |K|);\ \ (\forall t = 1, \dots, T) \qquad (1.6)$$

$$\hat{s}_{k,t} \geq \hat{s}_{k,t-1} + \hat{v}_{k,t-1} - c \qquad (\forall k = 1, \dots, |K|);\ \ (\forall t = 2, \dots, T) \qquad (1.7)$$

$$\hat{s}_{k,t} \geq \hat{s}_{k-1,t} + \hat{v}_{k-1,t} - c \qquad (\forall k = 2, \dots, |K|);\ \ (\forall t = 1, \dots, T) \qquad (1.8)$$

$$\hat{s}_{k,t} + \hat{v}_{k,t} \leq l_k \qquad (\forall k = 1, \dots, |K|);\ \ (\forall t = 1, \dots, T) \qquad (1.9)$$

$$\hat{s}_{k,t}\,, v_{k,t}\,, \hat{v}_{k,t}, w_{k,t} \geq 0 \qquad (\forall k = 1, \dots, |K|);\ \ (\forall t = 1, \dots, T) \qquad (1.10)$$

$$x_{i,t} \in \{0.1\} \qquad (\forall i = 1, \dots, |I|); \ (\forall t = 1, \dots, T) \tag{1.11}$$

$$\hat{s}_{1,1} = 0 \tag{1.12}$$

In the model, the equivalent objective functions (1.2) are represented by the total work performed (V) and the total work overload (W). Constraint (1.3) requires that the programmed demand be satisfied. Constraint (1.4) indicates that only one product unit can be assigned to each position of the sequence. Constraint (1.5) establishes the relation between the processing times applied to each unit at each workstation and the overload generated in each unit at each workstation. Constraint (1.6) reduces the processing times applied regarding the work pace factor. Constraints (1.7) – (1.9) constitute the set of relative start instants of the operations at each station and the processing times reduced to the products for each processor. Constraint (1.10) indicates the non-negativity of the variables. Finally, constraint (1.11) requires the assigned variables to be binary, and the equality (1.12) fixes the start instant of the operations.

2.1 Function of the Work Pace Factor throughout the Workday

The relationship between an operator's performance and his or her level of "activation" or "arousal", reflected in his level of stress, can be considered curvilinear. (Muse et al., 2003). The "Yerkes–Dodson law" argues that it is an inverted-U.

From this idea in this work, we associate the operator's efficiency with the work pace, by a direct correlation between the work pace factor and the stress. Thus, considering the Yerkes-Dodson's optimum stress curve, we determine a function of the factor work pace throughout time (see figure 1). In this way, on one hand, the first and last product-units sequenced will be processed with less activation of stress and, therefore, with a work speed similar to normal work pace. While, on the other hand, the time periods in which the operator reaches the routine, stress is increased by increasing the work pace factor until reach the fatigue that is a characteristic of the end of the workday.

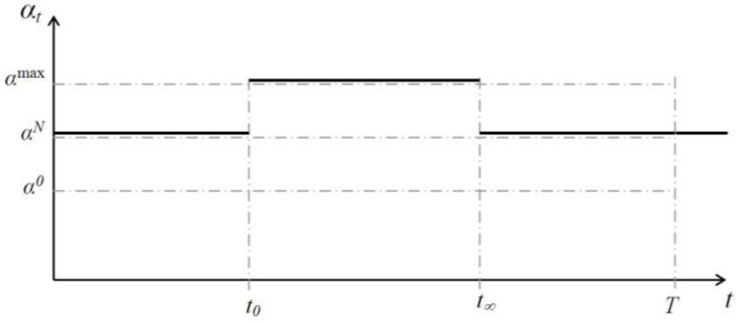

Fig. 1 Function of work pace factor.

In our case, we define a step function of work pace factor, where α^0 is the activity factor corresponding with the MTM_100, α^N with MTM_110 (work pace established as normal by companies) and α^{max} with MTM_121. Thus we set the values of the work pace factor over time. Specifically:

$$\alpha_t = \begin{cases} \alpha^N = 1.0, & if \ \ (1 \leq t \leq t_0) \vee (t_\infty + 1 \leq t \leq T + |K| - 1) \\ \alpha^{max} = 1.1, & if \ \ (t_0 + 1 \leq t \leq t_\infty) \end{cases} \tag{1.14}$$

3 Computational Experience

To evaluate the influence of the incorporation of the work pace factor into the *MMSP-W* on the total work overload generated, we compare the obtained results by the new model $M\_4 \cup 3\_\alpha 1$ with the obtained results by the reference model $M\_4 \cup 3$.

To do this, we use a case study that corresponds to an assembly line from Nissan's plant in Barcelona. That line has 21 workstations with an effective cycle time of $c = 175\ s$, a time window of $l_k = 195\ s\ \forall k$, and an identical number of homogeneous processors $b_k = 1\ \forall k$. The line assembles nine types of engines $(p_1, \ldots, p_9)$ grouped into three classes: 4x4 $(p_1, \ldots, p_3)$; vans (p_4, p_5); trucks $(p_6, \ldots, p_9)$. Each engine class has different processing times, therefore we use several instances corresponding to different demand plans associated with a single workday of 13.127 hours with 2 shifts. Each one of these instances has a total demand of 270 engines with different production mixes. Specifically, for this manuscript we have selected 7 instances that correspond, each one, to a representative situation of the demand (see table 1).

Table 1 NISSAN-9ENG instances and demand plans.

Demand plan	4x4			Vans		Trucks			
	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9
1	30	30	30	30	30	30	30	30	30
2	30	30	30	45	45	23	23	23	23
3	10	10	10	60	60	30	30	30	30
6	50	50	50	30	30	15	15	15	15
9	70	70	70	15	15	8	8	7	7
12	24	23	23	45	45	28	28	27	27
18	60	60	60	30	30	8	8	7	7

In addition, considering the function of work pace defined in section 2 and the conditions of Nissan, in the computational experience we fixed the values of work pace factor as follows:

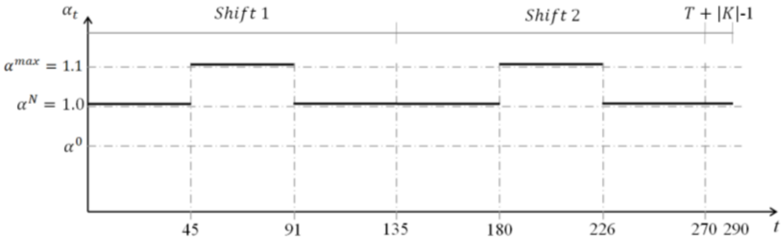

Fig. 2 Function of Nissan's work pace factor.

To implement the two models, the Gurobi v4.6.1 solver was used on a Apple Macintosh iMac computer with an Intel Core i7 2.93 GHz processor and 8 GB of RAM using MAC OS X 10.6.7. The solutions from this solver were obtained by allowing a maximum CPU time of $7200\,s$ for each model and for each of the 7 demand plans selected from the NISSAN-9ENG set. Table 2 shows the obtained results by each model.

Table 2 Work overload (W) of the 7 NISSAN-9ENG instances selected given by Gurobi for models $M\_4 \cup 3$ and $M\_4 \cup 3\_\alpha 1$ with a execution time of $7200\,s$. Optimal solutions are marked with *.

# instance	#1	#2	#3	#6	#9	#12	#18
V_0[1]	807,420	807,370	807,260	807,505	807,615	807,360	807,535
$W_{M\_4\cup3}$	228	384	425	477	782	326	678
$W_{M\_4\cup3\_\alpha1}$	0*	12	0*	84	239	0*	198
$\Delta W(\%)$	100	96.88	100	82.39	69.44	100	70.80

[1] The total work performed can be calculated as $V = V_0 - W$.

From Table 3, we can see how the incorporation of work pace factor decreases the obtained value of overall work overload, regarding the obtained value by the model $M\_4 \cup 3$, at all instances tested. In particular, we see that the fact of passing from a factor of 1 to a factor of 1.1, in the second third of the work shift, reduces the work overload a 96.88%, 82.39%, 69.44% and 70.80% in instances #2, #6, #9 and #18, respectively, and a 100% in instances #1, #3 and #12, reaching, in these three cases, the optimal solution.

4 Conclusions

In this paper we have presented a new model, the $M\_4 \cup 3\_\alpha 1$, from the reference model, $M\_4 \cup 3$, proposed by (Bautista et al., 2012). This new model for the $MMSP\text{-}W$ incorporates variable processing times of operations according to the work pace factor or activity. Specifically, it has set a staggered function of this factor throughout the workday, based on Yerkes-Dodson's optimal stress function. This function sets the normal work pace, fixed by the company $\alpha^N = 1$ at the beginning and end of the work shift, and increases this value to $\alpha^{max} = 1$ in intermediate moments of the shift.

Defined the model and work pace function, we have performed a computational experience linked to the assembly line of Nissan Powertrain plant in Barcelona. We have selected 7 instances that are representative of different demand plans that can be found and the results obtained by the new model have been compared with those obtained with the reference model.

After computational experience, we have observed that an increase in the work pace of 10%, for a third of the work, shift reduces the total work overload generated, on average, 88.5%, a maximum of 100% and a minimum of 69.44%. In addition, by the incorporation of work speed concept into the $MMSP\text{-}W$, we have reached the optimal solution in three instances, the #1, #3 and #12, in which the overload is 0.

Moreover, if we consider that the loss of an engine supposes a cost of $4000\ €/unit$, the cycle time is $175\ s$ and the work schedule contains 225 workdays, we can obtain savings by a maximum of 2.79, a minimum of 1.17 and an average of 2.03 $M€/Year$.

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