Advances in Production Management Systems

"Competitive Manufacturing for Innovative Products and Services"

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Editors
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PREFACE

Welcome to the IFIP WG5.7 Annual Conference, Advances in Production Management Systems, APMS 2012, being held at Rhodes, Greece, from 24 to 26 September 2012.

Since the first conference that took place in Helsinki back in 1990, APMS is one of the major events and the official conference of the IFIP Working Group 5.7 on Advances in Production Management Systems. Recently, APMS successfully took place in Washington (USA, 2005), Wroclaw (Poland, 2006), Linköping (Sweden, 2007), Espoo (Finland, 2008), Bordeaux (France, 2009), Cernobbio (Italy, 2010), and Stavanger (Norway 2011).

APMS 2012 is sponsored by the IFIP WG 5.7 and co-sponsored by the ATHENA Research & Innovation Centre and the Hellenic Maintenance Society in Greece. In an era of increased globalization and ever pressing needs for improved efficiency, the APMS 2012 theme is "Competitive Manufacturing for Innovative Products and Services”. In this setting, among the key elements of success in modern Manufacturing and Production Management are:

- **Resource efficiency**: the ability to perform in a resource efficient manner throughout the lifecycle of a production process, product use or offered services.
- **Key Enabling Technologies**: the exploitation of the latest materials, manufacturing and production control technologies to support competitive and sustainable production
- **Networked Enterprise** and **Global Manufacturing and Supply Chains**: the ability to operate as a globally interconnected organization and perform at a global scale, both at intra and inter-organizational scale.
- **Knowledge intensity and exploitation**: the efficient use of the enterprise and human resources tangible and intangible knowledge, including efficient knowledge lifecycle management.
- **Innovation**: the ability to efficiently port R&D results into competitive new forms of production, products or services.

The APMS 2012 conference brings together leading experts from industry, academia and governmental organizations to present and debate about the latest developments in Production Management Systems and shape up the future of Competitive Manufacturing. It comprises 7 keynote talks and 36 sessions, including a dedicated Industry Panel Session, to offer the practitioners view on linking research to industry, thus efficiently supporting the innovation process. The keynotes bring up key issues on

- the Business Perspective of Manufacturing Research
- Sustainable manufacturing to support a competitive industrial base in Europe
- Integration and interoperability as a key enabler of production efficiency
- Energy and resource efficiency in operations
- Governmental and non-governmental initiatives to foster greater co-operation between academia, research and industry for the Factories of the Future.

The conference sessions broadly cover the following thematic areas:

- Energy efficient manufacturing and related global research initiatives
- Sustainability in production process, products and services
- Management of international operations
- Emerging and ICT technologies in manufacturing, services, logistics and production management
- Enterprise integration and interoperability
- Mass customization, including design and supply chains for mass-customized products and services
- Supply networks and supply chain management
- Product and asset lifecycle management
- Services and service manufacturing systems
- Towards the products of the future
- Production management, operations and logistics
- Design of manufacturing systems
- Robotics in manufacturing

- Innovation and sustainability in developing countries
- Performance and risk management
- Human factors, innovation, quality and knowledge management
- Modern learning technologies in manufacturing and production management

Several special sessions are organised in the above areas and ongoing research initiatives and projects are presenting their progress and achieved results. A **PhD workshop** organised prior to the conference offers the opportunity to PhD researchers to present their research plans, objectives and achieved results to Scientific Discussants and gain valuable feedback to strengthen their research plan and activities.

Approximately 300 academics, researchers, practitioners and scientists from around the globe have joined the APMS 2012 conference, sharing their expertise and providing insight into what constitutes the currently best practice in Manufacturing and Production Management, while also projecting into the future of Competitive Manufacturing for Innovative Products and Services. The conference involved a high quality International Steering and a Scientific Committee of acknowledged excellence, while the review process involved in total 82 experts, all making key contributions to the Conference success.

We wish to acknowledge the support of **Intelligent Manufacturing Systems – IMS** as the USB Sticks & Lanyards for Badges sponsor. We particularly wish to thank the active members of the IFIP WG5.7 community for their contribution and support to the conference, their support to the papers review process and the promotion of APMS 2012 through their networks and collaborating partners. Particular thanks are due to the **ATHENA Research and Innovation Centre** and the **Hellenic Maintenance Society** in Greece for co-sponsoring and supporting the conference.

The conference is hosted in the island of Rhodes, in Greece, a world-class destination, boasting a unique mixture of ancient, modern and holiday attractions, with a continuing history of well over three millennia. According to myth, Rhodes was created by the union of Helios, the sun Titan, and the nymph Rhode. The ancient city of Rhodes hosted one of the ancient wonders of the world, the Colossus of Rhodes, the giant statute of the ancient Greek Titan, Helios. Manufacturing and production management have made giant strides and contributed significantly towards a world of smart, sustainable and inclusive growth but much more needs to be done and a global effort is needed to this end. The APMS 2012 conference constitutes a focused effort to support such aims.

We wish to thank you all for your contribution and participation in APMS 2012.

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Incorporating Ergonomics factors into the TSALBP

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Abstract. Assembly lines with mixed products presents ergonomics risk that can affect to the productivity of the workers and the lines. In this work we propose to incorporate ergonomics factors to the *TSALBP* (*Time and Space constrained Assembly Line Balancing Problems*). So, we present several elements for new models to assign the tasks to a workstation considering technological, management and ergonomics factors.

Keywords: Manufacturing, Assembly Line Balancing, somatic and psychic factors.

1 Preliminaries

In manufacturing systems with mixed-products assembly lines, as in the automotive industry, the fact that circulating units in an assembly line are not identical means a variation in the use of resources (workers, tools, etc.) as well as in consumption of components. Therefore, the need for balancing an assembly line is present in its design.

Obviously, if we talk about real situations, in balancing a line should be taken into account the technological and management constrains.

The Assembly Line Balancing Problem (*ALBP*) is a classic problem [1] related to flow-oriented production systems. The problem deals to assign a set of elementary tasks (which may correspond to the assembly or disassembly of a product: motors, batteries, cars...) to a set of workstations or modules. The workstations are usually associated with teams of workers and/or robots, and they apply some of the work that will serve to complete the final product.

Typically, the workstations are arranged in a row, one behind another, and connected by a transport system, which allows movement of the work in progress at constant speed. Each workstation is given a constant time (cycle time, c) to complete the work that has been assigned.

Baybars [2] divided the *ALBP* into two classes: (1) the Simple Assembly Line Balancing Problem (*SALBP*), and (2) the General Assembly Line Balancing Problem (*GALBP*).

The *SALBP* class contains assembly problems that attempt to minimize the total idle time considering exclusively only two kinds of task assignment constraints: (1) cumulative constraints (associated with the available time of work in the stations); and (2) precedence constraints (established by the order in which tasks can be executed).

Other problems with additional considerations are included in the *GALBP* class [3], as is the case in which the assignment of tasks is restricted [4] or when certain tasks must be assigned in block [5].

Some of the limitations in literature [6-7] take into account factors as: the number of workstations (m); the standard time assigned to each workstation (c), which is calculated through an average of the processing times of all tasks according to the proportions, of each type of product, that are present in the demand plan, and the available space or area (A) to materials and tools to each workstation.

In these conditions we can define a problems family under the acronym *TSALBP* (*Time and Space constrained Assembly Line Balancing Problems*) [6-7] that consist on: given a set J of $|J|$ tasks with their temporal t_j and spatial a_j attributes ($j = 1,\ldots,|J|$) and a precedence graph, each task must be assigned to a single station, such that: (1) all the precedence constraints are satisfied, (2) no station workload time is greater than the cycle time and (3) no area required by the station is greater than the available area per station (A).

Then, if we take into account the types of limitations defined above, we have eight types of problems, according to the objective of each one of them [6]. As example, the model to the *TSALBP-1* is the following:

$$\min \; z_1 = m \tag{1}$$

Subject to:

$$m - \sum_{k=1}^{m_{\max}} k x_{j,k} \geq 0 \qquad (j = 1,\ldots,|J|) \tag{2}$$

$$\sum_{j=1}^{|J|} t_j x_{j,k} \leq c \qquad (k = 1,\ldots,m_{\max}) \tag{3}$$

$$\sum_{j=1}^{|J|} a_j x_{j,k} \leq A \qquad (k = 1,\ldots,m_{\max}) \tag{4}$$

$$\sum_{k=1}^{m_{\max}} x_{j,k} = 1 \qquad (j = 1,\ldots,|J|) \tag{5}$$

$$\sum_{k=1}^{m_{\max}} k(x_{j,k} - x_{i,k}) \geq 0 \qquad (1 \leq i, j \leq |J| : i \in P_j) \tag{6}$$

$$x_{j,k} \in \{0,1\} \qquad (j = 1,\ldots,|J|) \wedge (k = 1,\ldots,m_{\max}) \tag{7}$$

Where, $x_{j,k}$ is a binary variable that is equal to 1 if a task j ($j = 1,\ldots,|J|$) is assigned to the workstation k ($k = 1,\ldots,m_{\max}$), and to 0 otherwise; P_j is a parameter that indicates the set of precedent tasks of the task j ($j = 1,\ldots,|J|$) and the objective is to minimize the number of workstations ($m = |K|$).

2 The Ergonomic in assembly lines

One of the main objectives of the ergonomic is to adapt the operations that the workers must perform to guarantee their safety, welfare and to improve their efficiency.

In the case of manufacturing assembly lines with mixed products, the ergonomic risk is present and may affect the performance of workers and the line. In such environments, ergonomic risk is given basically by the components related to somatic comfort and psychological comfort.

The somatic comfort determinates the set of physical demands to which a worker is exposed throughout the working day. To analyze this type of ergonomic risk, three factors, among others, can be analyzed. These are (1) Postural load: During working hours the workers may adopt repeatedly, inappropriate or awkward postures that can result in fatigue and musculoskeletal disorders in the long run [8]; (2) Repetitive movements: A workstation may involve a set of repeated upper-limb movements by the worker. This may cause long term musculoskeletal injuries [9]; (3) Manual handling: Some tasks involve the lifting, moving, pushing, grasping and transporting objects [10].

3 The TSALBP with ergonomic

Our proposal is to incorporate into the *TSALBP* or in other assembly lines problems the factors that imply these ergonomics problems.

Otto and Scholl [11] employ several techniques to incorporate the ergonomic risks to the problem *SALB-1*.

In a first approximation, given the set K of stations, to each workload S_k assigned at workstation k ($k = 1,\ldots,|K|$), the ergonomic risk $F(S_k)$ is determined. Moreover, a maximum value is established for that ergonomic risk, *Erg*. Consequently, we can add to the original models the following constraints, satisfying: $F(S_k) \leq F(S_k \cup \{j\})$ $(\forall S_k, \forall j \in J)$.

$$F(S_k) \leq Erg \qquad (k = 1,\ldots,|K|) \tag{8}$$

Alternatively to the conditions (8), [11] propose to the *ErgoSALBP-1* a new objective function composed by two terms; that is:

$$\min \quad K'(x) = K(x) + \omega \cdot \xi(F(S_k)) \tag{9}$$

Where $K(x)$ is the number of workstations; ω is a weight non-negative and $\xi(F(S_k))$ is a function that includes the ergonomic risk factors $F(S_k)$ $(k = 1,\ldots,|K|)$.

Logically, the constraints (8), presented by [11], can be completed if we take into account, in the design of the line, a minimum value to the ergonomic risk. In addition we can consider that this risk depends on the factor (somatic or psychic) that we want. In this situation, we have:

$$F_\phi^{\min} \leq F_\phi(S_k) \leq F_\phi^{\max} \qquad (k = 1,\ldots,|K|)(\forall \phi \in \Phi) \tag{10}$$

Where Φ is the set of factors, $F_\phi^{\min}$ y $F_\phi^{\max}$ correspond to the minimum and maximum ergonomic risk to the factor $\phi \in \Phi$, and $F_\phi(S_k)$ is the ergonomic risk at workstation $k \in K$.

Other way to treat the problem is to classify the workstations in several categories (e.g. from 1 to 4) depending on different factors, as movements, loads, duration, etc. From this point, we can condition the design of the line to the different categories of workstations that are present in a minimum and a maximum percentage.

Then, if we define H as the set of ergonomic risk components in our case, somatic (σ), psychics (φ) or both ($\sigma \cup \varphi$), we can find a new classification for the *TSALBP*, that is (see table 1):

Table 1. *TSALBP_erg* typology. The suffixes 1, 2, and 3 refer to the minimization of *m*, *c* and *A*, respectively. The suffix F refers to a feasibility problem. The post-suffix η refers to the type of the restriction linked to the human aspects, psychic and somatic, being the element $\eta \in \mathrm{H}$ where $\eta = \{\varnothing, \sigma, \varphi, \sigma \cup \varphi\}$. The column "Type" indicates if the problem is one of feasibility (F), mono-objective (OP) or multi-objective (MOP).

Name	*m*	*c*	*A*	Type
TSALBP-F- η	Given	Given	Given	F
TSALBP-1- η	Minimize	Given	Given	OP
TSALBP-2- η	Given	Minimize	Given	OP
TSALBP-3- η	Given	Given	Minimize	OP
TSALBP-1/2- η	Minimize	Minimize	Given	MOP
TSALBP-1/3- η	Minimize	Given	Minimize	MOP
TSALBP-2/3- η	Given	Minimize	Minimize	MOP
TSALBP-1/2/3- η	Minimize	Minimize	Minimize	MOP

4 An example

Given a set of eight tasks ($|J| = 8$), whose operation times, t_j ($j = 1, \ldots, |J|$), required space, a_j ($j = 1, \ldots, |J|$), ergonomic risk $F(\{j\})$ ($\forall j \in J$) and which precedence graph are shown in figure 1 (left), each task must be assigned to a single stations satisfying the limitations: (1) $c = 20$ s; (2) $A = 20$ m; and (3) $F^{\max} = 60$ e-s (ergo-seconds).

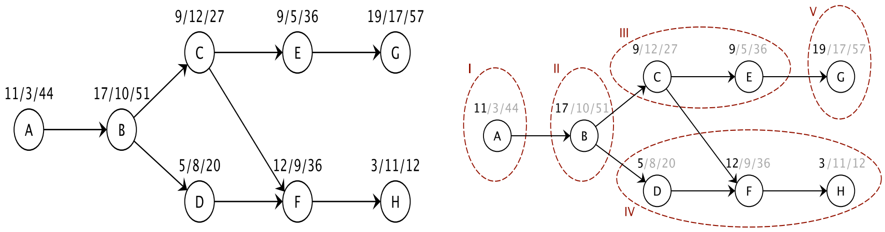

Fig. 1. Precedence graph of tasks. At each vertex we can see the tuple $t_j / a_j / F(\{j\})$ corresponding to the task (left). Solution obtained by SALBP-1 ($m = 5$) (right).

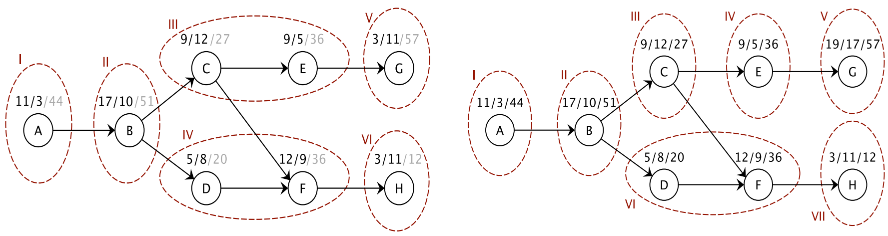

Fig. 2. Solution by TSALBP-1-$\varnothing$ ($m = 6$) (left). Solution by TSALBP-1-σ ($m = 7$) (right).

Considering the *SALBP-1* the obtained result is (see figure 1) a number of workstations of 5. By other hand, taking into account the *TSALBP-1-*$\varnothing$ the obtained result is one workstation more that with the *SALBP-1* (figure 2, left). Finally, if we consider that the ergonomic factor are additive, we can group tasks taking into account, in addition to the cycle time and the area, this factor. Then, we can obtain a result for the *TSALBP-1-*σ (figure 2, right).

As we can see from the examples, depending on the limiting factors that we consider, the resulting number of stations will be one or other. Obviously, a greater number of conditional factors, means a greater number of workstations.

5 Case study

To evaluate the proposed model and to contrast the influence of constrains relative to the ergonomic factors on the number of workstations of the line, required for *SALBP-1* and *TSALBP-1*, we have chosen a case study that corresponds to an assembly line from Nissan's plant in Barcelona. In fact, the 378 tasks (including the rapid test), that are required in the assembly of a motor (Pathfinder), have been grouped into 36 operations. After to set consistently the potential links, predecessors and successors, between the 36 operations, considering the potential links of the 378 original tasks, and taking into account a cycle time of 180 s; an available longitudinal area of 400 cm; and a maximum ergonomic risk of 400 e-s, we have solved, using the CPLEX solver, the three problems that are the focus of this study (*SALBP-1*, *TSALBP-1* and *TSALBP-1-*σ). In table 2 we can see the optimal solutions obtained, and the need of more workers when are taken into account more realistic conditions in the assembly line problems. In addition we can see the process time of the operations (t), the required area (a), the risk factor (F) and the workstation where each task has been assigned, for each problem.

In our case, are necessary 19 work teams when only is taken into account the limitation of the cycle time, 21 when the constraints of the area are included and 24 when a maximum ergonomic risk must be respected at each workstation.

Table 2. Solutions obtained by CPLEX from SALBP-1, TSALBP-1 and TSALBP-1-σ.

j	*t*	*a*	*F*	*P*	SALBP-1	TSALBP-1	TSALBP-1-σ
1	100	400	200	-	1	1	1
2	105	400	210	1	2	2	2
3	45	100	90	1	3	3	3
4	113	300	226	1, 2	3	3	3
5	168	400	336	1, 2, 4	4	4	4
6	17	150	34	2, 4, 5	5	5	5
7	97	250	194	6	5	5	5
8	50	200	100	2, 3, 7	5	6	6
9	75	200	150	2, 8	19	6	6
10	30	100	90	8	6	7	7
11	65	300	195	8, 10	6	7	7
12	35	350	105	10, 11	6	8	8
13	65	50	195	11, 12	7	8	8
14	115	300	345	12, 13	7	9	9
15	60	50	180	14	8	9	10
16	115	100	345	14, 15	8	10	11
17	60	150	120	13, 14, 16	9	10	12
18	105	250	210	16, 17	9	11	12
19	60	150	120	18	10	11	13
20	100	400	200	18, 19	10	12	14
21	100	400	200	19, 20	11	13	15
22	75	200	150	21, 22	11	14	16
23	75	175	225	21, 22	12	14	16
24	105	150	315	23	12	15	17
25	15	100	45	23, 24	17	15	17
26	35	150	105	24, 25	19	15	20
27	175	250	350	24	13	16	18
28	5	0	15	27	14	17	18
29	165	250	330	27, 28	14	17	19
30	5	0	15	27, 28	14	17	19
31	115	150	230	5, 29	15	18	20
32	60	200	120	29, 30, 31	15	18	21
33	85	200	170	5, 31	16	19	22
34	70	200	140	32	16	19	21
35	160	375	320	31, 33, 34	17	20	23
36	165	150	330	35	18	21	24

6 Conclusions

From the family of problems *TSALBP*, we propose an extension to these problems attending to the need to improve working conditions of workers in production and assembly lines. The result of this extension is the family of problems *TSALBP_erg*. Specifically, we formulate the problem TSALBP-1-σ, corresponding to the somatic risks, that considers the constraints of cycle time, available area and, in addition, the maximum ergonomic risk to which the workers, assigned to each station, may be subjected.

Through a case study linked to Nissan, we observe that the improvement of the working conditions increases the minimum number of required workers to carry out the same work. By other hand, the reduction of the maximum ergonomic risk admissible, supposes a reduction of the labor cost due to injuries and absenteeism, whose valuation will be object studied in future research.

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