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Iterated Local Search for dynamic assembly line rebalancing problem

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Abstract: This research presents an iterated local search (ILS) based technique to address the dynamic assembly line rebalancing problem. The goal is to find a new assignment of tasks to workstations when disturbances occur. The solution must respect a desired cycle time (takt time) and the precedence constraints. The problem was formalized as an integer linear programming model. To solve it an exact approach and the heuristic approach ILS were used. Computational experiments are conducted on different industrial cases to evaluate and to compare the performances of the proposed approaches. The results confirm the effectiveness of the ILS approach.

Keywords: iterated local search, dynamic line rebalancing problem

1. INTRODUCTION

Assembly lines are flow-oriented production systems. They are still typical in industrial production systems of high quantity standardized products. In these systems, sequences of tasks are achieved in stations which are usually interconnected by a conveyor, and which are processed by human/robot operators using machines and/or tools. A task is a basic indivisible activity of work that is performed in standard cycle time. The desired cycle time called takt time determines the maximum work time that can be assigned to a station in order to meet the product demand. Due to the machines and/or operators availability conditions, precedence conditions among the tasks are determined. The assembly line balancing problem (ALBP) consists of optimally partitioning (balancing) the assembly work among the stations with respect to some objective. Several classifications were proposed for this kind of problem (Battaïa and Dolgui, 2013). This classification links the industrial problems and the academic resolutions and highlights the gap between real problem and academic ones. The vast majority of studies deal with the line balancing of a yet-to-be-built assembly line instead of the reconfiguration of an existing line. Faced to changes on productions or processes, tools and resources of the existing lines are reused or adapted. For this reason rebalancing problems are more common than line design from scratch.

Therefore and in addition to line design, balancing problem covers many planning horizons depending on the disturbances nature (Scholl 1999), see Figure 1. Thus, for example, the substantial changes on the structure of the line or the introduction of new products (re-engineering level) correspond to long-term decisions. The re-balaning problem as discussed in (Grangeand 2012) could concern the production demands changes, and some structural changes (removing or adding workstations) and corresponds to medium term horizon. Dealing with short-term disturbances (delays, breakdowns, temporary supply shortages...) has been mainly resolved by sequencing modifications (Miltenburg (2002)).

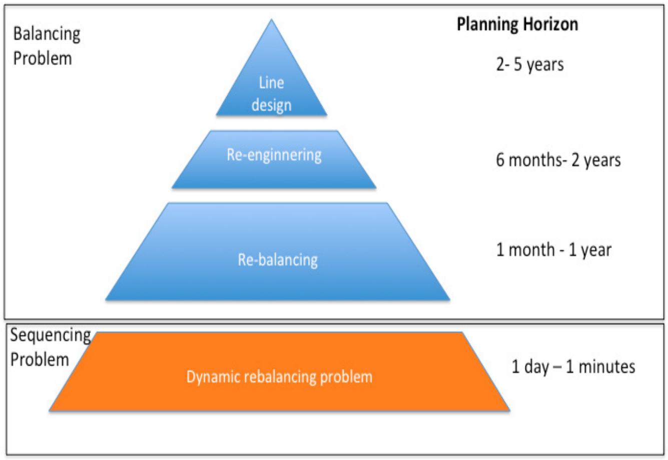

Figure 1: Balancing problem through planning horizons

In the Intelligent Manufacturing Systems context (IMS) where resources and products could share and update their own data, the real-time information about the work in progress and the resources are available. Thus, an on-line balancing algorithm could be relevant. We called this problem, Dynamic Assembly Line-Rebalancing Problem (DALRP).

The objective here is to propose a new tasks allocation for a short time horizon to keep the line well balanced when disturbances occur (shortage, a shutdown), or when theoretic production duration is different from the realized ones. We assume that the manual assembly line is initially balanced (computed by a predictive balancing process) and the sequencing is fixed. The aim is to quickly react to disturbing events with an on-line algorithm even if the new obtained balancing is not optimal.

To solve this problem, this paper explores the use of the

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metaheuristic approach "ILS" (Iterated Local Search). In Section 2 a formal description of the problem is presented. Then, a state of the art about the resolution approaches is used to justify the choice of the considered method. The studied problem is formalized as an integer linear program in Section 3. The proposed resolution approach is detailed in Section 4, and evaluated with a case study in Section 5. Finally, Section 6 concludes and displays some future works.

2. STATE OF THE ART

Since 1950, many exact and heuristic approaches were proposed in the literature to solve the ALBP. For exact methods, a branch and bound approaches are well-used to solve ALBP (Scholl 1999), (Hackman et al., 1989). As the ALBP is NP-hard and the computing time of exact methods is long, many heuristic approaches were proposed. These methods are classified into two categories: constructive and incremental approaches. Their respective performances are compared in several studies (Capacho et al., 2007).

Constructive methods solve an optimization problem step by step. Concerning the ALBP, tasks are allocated one by one after the constraints are checked. Some of known approaches are COMSOAL (COmputer Method for Sequencing Operations for Assembly Lines) proposed by (Arcus, 1965) and RPW (Ranked Positional Weight) (Helgeson and Birnie, 1961). (Arcus, 1965) proposed a heuristic combined with stochastic variables. Ranked Positional Weight heuristic (RPW) is based on the assignment of a weight to each task and their decreasing order classification. These weights take into account the task duration its predecessor and its successor. The more weight a task has, the more priority it has. The allocation is done using this priority order.

Incremental approaches were also investigated. For example (Bautista and Pereira, 2007) used Ants algorithms to solve an ALBP. Genetic algorithms were proposed by (Kim et al., 1996; Pierreval et al., 2003; Falkenauer, 1992) (Gambrini et al., 2009), swarm optimization approaches by (Kalayci and Gupta, 2013; Chutima and Chimklai, 2012), and Tabu searches (Özcan and Toklu, 2008).

For the dynamic assembly line rebalancing problem, a quick resolution is more important than an optimal one. The aims is to react quickly in order to reduce negative impacts of disturbing events and define a new solution that is close to the initial line balancing. Those two requirements lead us to choose an incremental approach for resolution based on ILS.

Despite simplicity of ILS, the algorithm has proven to be a very successful approach to solve combinatorial optimization problems (Stutzle, 2006; Voudouris and Tsang, 1999; Vansteenwegen et al., 2009). A detailed explanation of the ILS metaheuristic can be found in (Lourenco et al., 2003). To our knowledge, ILS methods were not investigated to solve the ALBP in the literature. This paper proposes an ILS approach for the dynamic line-rebalancing problem. This method is evaluated and compared with an exact approach using three case studies.

3. FORMALIZATION

In this section, we propose an integer linear model for the dynamic assembly line-rebalancing problem.
Before solving the model, a pre-processing step is done in order to fix the allocation of all tasks executed before a disturbance time t_0. Therefore, the DALRP concerns how to reassign the tasks that must be executed after t_0, to candidate workstations, under constraint of the tack time.
The following assumptions are stated to clarify the setting in which the problem arises:

(1) The initial line balancing has been done previously
(2) Task processing time is constant
(3) Each task can be assigned to any station.
(4) The precedence graph is given.
(5) When a disturbance occurs on a workstation at t_0, only the remained tasks for the product will be considered for the new rebalancing.
(6) The delay induced by the disturbance is known and estimated by an Intelligent Manufacturing System application.

Notations used for the formulation of the problem are as follows.

3.1 Parameters and Sets

n: number of tasks, $n \in \mathbb{N}^*$;
m: number of workstations, $m \in \mathbb{N}^*$;
I: set of the tasks: $I = \{1,2,\dots,n\}$;
J: set of the workstations: $J = \{1,2,\dots,m\}$;
i: a single task: $i \in I$;
j: a single workstation: $j \in J$;
I^*: set of tasks which need to be re-assigned for rebalancing: $I^* \subseteq I$ (I^*will represent the dynamic part of tasks and $I \backslash I^*$ the fixed one) ;
J^*: set of workstations where tasks in I^* can be re-assigned: $J^* \subseteq J$ (J^* will represent the dynamic part of workstations and $J \backslash J^*$ the fixed one);
$\left(A_j\right)_{j \in J}$: initial assignment of tasks: $\left(A_j\right)_{j \in J}$ forms a partition of I;
$\left(t_{ij}\right)$: $\left(t_{ij}\right) \in \mathbb{R}_{+*}^{n \times m}$ matrix of the task processing times: t_{ij} is the processing time of a task $i, i \in I$ assigned to a workstation $j, j \in J$;
$\left(\Delta t_{ij}\right)$: $\left(\Delta t_{ij}\right) \in \mathbb{R}_{+}^{n \times m}$ matrix of task delays: Δt_{ij} is delay of a task $i, i \in I$ on a workstation $j, j \in J$;
$(p_{ii'})$: $(p_{ii'}) \in \{0,1\}^{n \times n}$ precedence matrix: $p_{ii'} = 1$ if task $i, i \in I$ must be finished immediately before $i', i' \in I$;
T_t: takt time, value of the cycle time initially fixed by the decision maker: $\mathrm{T}_t > 0$.

Remarks

- A value Δt_{ij} is estimated at disturbance time t_0 if any (in this case t_{ij} is judged to be exceeded). Before any disturbance occurs all delays are zero.
- T_t is an important indicator to manage flow in lean manufacturing. The classic calculation of this indicator is available production time divided by the customer demand.