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A problem design and constraint modelling approach for collaborative assembly line planning

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ABSTRACT

Assembly line planning is the interface between agents of different professions, competencies, skills and experiences. Each agent is characterized by specific objectives and constraints, that must be considered when different products and processes are merged across multiple levels of various decision making units. A systemic platform for the dependencies of goals, constraining relationships of elements to be assigned and the interdependencies to properties of the elements is designed. Hereby, the objectives and the constraints are evaluated and mapped within the assembly line planning (ALP) process, resulting in a comprehensive graph with the processes, structures, resources and their properties with its dependencies. The dependencies include time criteria but also technical, processual, ergonomic, qualitative, part-dependent along with resource-dependent, structural constraints. The dependency map is integrated within an existing ALP process to achieve a temporal precedence on the incoming and outgoing information resulting in a dynamic process oriented presentation of the objectives and constraints. The elements of the dependency map are categorized and analysed based on the evaluations and a problem model is created for the presented ALP problem. The problem model is solved using a genetic algorithm which is parameterized in accordance to the problem model complexity and characteristic.

1. Introduction

This paper provides a multi-objective approach of assembly line planning within the automotive industry. The approach differs from other approaches in scientific literature by considering collaboration aspects between planning participating actors of different professions, competencies and practical skills. The paper is being divided into four further sections. At first, a basic summary of assembly line planning is given to introduce the considered problem, essential properties and characteristics, as well as possible solution methods. Subsequent, the concept of multi-objective precedence modelling is given. This concept, including solution procedures, will be clarified and explained by a practical example, which is illustrated based on a car model. Remarks are closed by conclusions.

2. Assembly line planning

Assembly lines are flow-line production systems originally developed for mass production of standardized products. In recent times, assembly lines are increasingly important in mass customization. Especially, but not solely in automotive industry an individualization of products must be taken into consideration to respond to different costumer needs. Multi-purpose machines with automated tool swaps allow varying models, yet respectively excluding considerable setup costs [1].

In general, operations are performed by serially aligned production units. Workpieces pass these stations successively as they are moved along the line by using a transportation system, e.g. a conveyor mechanism [1]. These assembly systems are associated with high investment costs. Because of that, the configuration of an assembly line is very important. In this planning process, all decisions regarding equipment, alignment and capacity (number of stations, stroke cycle time, number of workers in a stroke) of stations for a given product or product group with a high number of operations and precedence relations must be made before the production starts. In scientific literature, this configuration problem of assembly systems is called Assembly Line Planning (ALP) or Assembly Line Balancing (ALB). The Simple Assembly Line Balancing Problem (SALBP) describes an assembly line as a one-product-problem, a serial line, one worker per station and the objective of maximization of workload. This problem could be declared as the academic standard problem formalization [1,2].

Boysen, Fliedner and Scholl introduced a classification scheme of the General Assembly Line Balancing Problem (GALBP). It is divided into three elements, which are noted as tuples [α, β, γ]. In this context α

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describes the characteristics of the precedence relation graph, β the characteristics of assembly lines and stations and γ the different planning objectives, e.g. minimal number of stations or minimal costs of assembly line configuration. In this regard, SALB characteristics are chosen as common reference for classification, meaning that only deviations from that basic problem description must be provided by using the tuple notation. The presented classification scheme has been adopted from the machine scheduling scheme of Graham et al., which was used and refined by Brucker et al. for project scheduling [1–3].

The Mixed-Model Assembly Line Balancing Problem (MMALBP), coupled with several variants of the same product is very important within the automobile industry. In general, this problem relates to the operative task of determination of a variant sequence (Mixed-Model Sequencing Problem) [4]. In addition, team organization, parallel tasks and stations, processing alternatives, a very high number of parts and tools as well as a division into production segments must be taken into consideration.

In this context, a wide gap between theoretical discussion and practical applications does exists. Most of the standard optimization models are not able to consider all those practical aspects together with task-station assignment restrictions (combined tasks, assembly high, ergonomic and qualification aspects) and multiple planning objectives. Furthermore, different roles and actors are essential for the planning process. Involved persons or groups can be divided into process and product planners, product developers, logistics, plant and station planners and information as well as material supply planners [1–3].

The depicted problem class can be assigned to Combinatorial Optimization because of the finite solution space. The resulting high complexity of these comprehensive planning problems, interconnected with the problem size, necessitates the use of capable solution methods. For practical occurring problems with more than a thousand operations, the use of exact solution methods is impossible concerning the purpose of computation time. In this case, heuristic methods can be used to get satisfying solutions combined with an acceptable computation time. Such methods can be divided into problem specific heuristics (constructive procedures) and metaheuristics (meta-strategies) [2,4,5].

Especially in the last two decades, a large variety of heuristic approaches for different specifications of ALBP was developed. Constructive procedures, like priority rule based approaches or incomplete enumeration approaches, as well as metaheuristics, like, Genetic Algorithms (GA), Ant Colony Optimization (ACO) or local search strategies (LS), are used for searching feasible solutions to the assembly line balancing problem. As stated in Table 1 Genetic Algorithms are mainly used to solve the assembly line planning problem. Therefore, the problem formalization as well the modelling system is created with respect to use a genetic algorithm as solution search.

Table 1
Solution approaches for assembly line planning.

Author	Year	Problem type	GA	LS	ACO	ABC	MA	PSO	Source
Rubinovitz	1995	ALBP	x						[6]
Tsujimura	1995	GALBP	x						[7]
Plans	1999	SALBP-E		x					[8]
Pastor	1999	ALBP		x					[9]
Ponnambalam	2000	GALBP	x						[10]
Bautista	2000	ALBP	x	x					[11]
Rekiek	2001	ALBP	x						[12]
Bautista	2005	TSALBP		x	X				[13]
Rekiek	2006	MMALBP	x						[14]
Vilarinho	2006	ALBP-I			X				[15]
Zhang	2007	SALBP-1			X				[16]
Su	2007	MALBP	x						[17]
Zhang	2008	ALBP-wa	x						[18]
Guo	2008	FALBP	x	x					[19]
Cao	2008	MALBP	x						[20]
Bautista	2009	TSALBP		x					[21]
Kao	2009	ALBP-1		x					[22]
Khaw	2009	ALBP/ U-Type ALBP		x	X				[23]
Chica	2009	TSALBP			X				[24]
Jonnalagedda	2010	MALBP-2		x					[25]
Brudaru	2010	ALBP/ U-Shaped	x						[26]
Tang	2010	SALBP	x						[27]
Chica	2011	TSALBP			X		x		[28]
Chica	2011	TSALBP	x						[29]
Qian	2011	MALBP	x	x					[30]
Sulaiman	2011	SALBP-1			X				[31]
Hu	2011	Two-sided ALBP		x					[32]
Zhuo	2011	U-Type ALBP	x						[33]
Noushabadi	2011	SALBP-2	x						[34]
Razali	2011	ALBP	x						[35]
Chica	2012	TSALBP					x		[36]
Nilakantan	2012	Robotic ALBP		x				x	[37]
Liao	2012	MALBP		x					[38]
Adham	2012	ALBP	x						[39]
Jaturanonda	2013	ALBP PL Smoothness		x					[40]
Yu	2013	MMALB	x						[41]
Liu	2013	ALBP		x				x	[42]
Saif	2014	SALBP				x			[43]
Davidrajuh	2014	ALBP		x					[44]
Triki	2014	ALBP	x						[45]
Chica	2015	r-TSALBP-m/a		x					[46]
Sikora	2015	ALBP-2	x						[47]
			21	17	7	1	2	2	

3. Collaborative precedence modelling

According to the presented problem models, various objectives can be aimed for within the assembly line planning process. The most obvious objective is the minimization of costs. The question of optimizing the costs hereby is, as always, limited to the direction it is aimed at. An assembly line with minimal costs for logistics is most certainly not equal to an assembly line with minimal production costs (i.e., labour costs, machinery, manufacturing site), and not equal to an assembly line designed with minimal production planning costs. Besides the optimization objective(s) following basic input parameters are used for assembly line design [48]:

- precedence relations between a set of elements (structural, processual),
- cycle time as time limit for structural element where process elements are assigned to,
- assignment constraints for tasks related to stations, competencies, logistics elements and technology.

Those input parameters, especially the precedence relations and the restrictions, are related or are extracted by decision makers, using a wide variety of information exemplified in Table 1. The evaluation of ergonomic aspects is carried out after the first assembly line is designed based on the assembly height and the assembly zone, as well as the manufacturing equipment and possible product handling technology.

In industrial practice, it is not common that all the precedence relations are either known when the assembly line design process is initiated, nor will one planner state all the precedence relations. Therefore, it only seems obvious to carry out investigations regarding the potential of collaborations within the assembly line design process. So far, merely the construction process takes the collaborative assembly into consideration. Reviewing the process's perspective, no efforts have been made to establish a collaborative planning process. In accordance to the concept presented before (as presented in [49]), an approach for collaborative precedence modelling will be presented on behalf of automotive assembly line planning.

The pool of information is created by the decision makers and