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A hybrid genetic algorithm for multi-objective product plan selection problem with ASP and ALB

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ABSTRACT

Facing current environment full of a variety of small quantity customized requests, enterprises must provide diversified products for speedy and effective responses to customers' requests. Among multiple plans of product, both assembly sequence planning (ASP) and assembly line balance (ALB) must be taken into consideration for the selection of optimal product plan because assembly sequence and assembly line balance have significant impact on production efficiency. Considering different setup times among different assembly tasks, this issue is an NP-hard problem which cannot be easily solved by general method. In this study the multi-objective optimization mathematical model for the selection of product plan integrating ASP and ALB has been established. Introduced cases will be solved by the established model connecting to database statistics. The results show that the proposed Guided-modified weighted Pareto-based multi-objective genetic algorithm (G-WPMOGA) can effectively solve this difficult problem. The results of comparison among three different kinds of hybrid algorithms show that in terms of the issues of ASP and ALB for multiple plans, G-WPMOGA shows better problem-solving capability for four-objective optimization.

1. Introduction

In light of the environment of customized requests, design department must design a variety of product to meet market demand, while enterprises must select the optimal product plan considering numerous criteria and constraints. Shehab and Abdalla (2001) have pointed out that over 70% of production cost has been determined at design stage, while the cost of design stage only takes up 6% of the entire production cost. If the cost can be effectively controlled at early stage of production, the following production operation will not have to face the dilemma of discontinued production due to high cost. As a result, the selection of product plan is the crucial segment for the entire production process, where correct assessment can lead to effective production. Therefore, it has become an important issue for enterprises to quickly and effectively select optimal product plan.

The selection of product plan will affect the entire production process. Therefore the selection of product plan must not only evaluate the cost of plan, but also consider the issues related to the entire production process including the product ASP and ALB in order to select the optimal product plan. Marian, Luong, and Abhary (2006) have pointed out that assembly operation will affect 20–50% of production cost and lead time while this proportion can be as high as 90% for high-tech or electronics industries. Therefore the ASP is a very important segment during production operation affecting various aspects such as resources utilization, production line arrangement, assembly efficiency and cost, and even the product design stage. When there are multiple viable product assembly sequences, better assembly sequence will facilitate the progress of manufacturing stage and enhance product profitability. Boysen, Fliedner, and Scholl (2007) and Tasan and Tunali (2008) have all pointed out that enterprises at times must re-establish or re-design assembly lines for large quantity of customized order. Due to the huge establishment cost, decision makers must carefully evaluate and make the right decision. However, process times among work stations may be different during production process. If the idle times for certain work stations are too long, production efficiency will be reduced. Therefore, the effective utilization of ALB technique will allow almost evenly distributed work loads among all work stations such that production efficiency can be enhanced to reach the goal of quickly responding to customers' requests.

Andres, Miralles, and Pastor (2008) have pointed out that when moving from previous task to the next task in the same work station, machine or personnel usually must replace current assembly tool, select new tools from tool box or equipment, and modify them before the next task take place. The time required for tools modifications will vary with different task sequences. These setup times do exist among industrial assembly lines, yet

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they are usually not taken into consideration in general studies. By integrating these issues, we will get a closer look at the practical situations, but this will also make this kind of combination problem more complicated and more difficult to be solved by general methods. ASP is a typical NP complete problem under constraints of assembly process (Laperrière & ElMaraghy, 1996). Wang and Liu (2010) have also pointed out that the search space of assembly sequence is exponentially proportional to the number of product parts, thus the ASP for complicated product is a very difficult issue. Simaria and Vilarinho (2004) have pointed out that genetic algorithm (GA) can effectively solve combinational optimization problems. Tseng (2006) has proposed guided genetic algorithm (G-GA) to effectively solve ASP problems with complicated constraints.

However, most problems in real life are multi-objective optimization problems with multiple objectives usually conflicting with each other, making it impossible for every objective to reach optimal status. Therefore, the unique optimal solution usually does not exist for multi-objective optimization problem. Instead, what exists is the set of multiple satisfying solutions which is called Pareto optimal solutions set (Coello, Aguirre, & Zitzler, 2007). In recent years many scholars have introduced this concept to the studies on multi-objective optimization such as the nondominated sorting genetic algorithm II (NSGA II) proposed by Deb, Agrawal, Pratap, and Meyarivan (2002), the improved strength Pareto evolutionary algorithm (SPEA2) proposed by Zitzler, Laumanns, and Thiele (2001) and the modified weighted Pareto-based multi-objective genetic algorithm (WPMOGA) proposed by Zio et al.

From aforementioned points of view, we understand that enterprises must provide a variety of products in the environment of customized requests. Therefore, there can be many different combinations of assembly sequences among numerous product plans. If the convenience and feasibility of future assembly task can be considered at initial stage of planning, the production cost can be reduced and production efficiency can be enhanced. By integrating assembly line balance technology to balance the work load for every work station, the work efficiency can be improved. The main objectives of this study is (1) to establish multi-objective optimization mathematical model for the selection of product plan; (2) to solve the model by the integration of G-GA and WPMOGA into G-WPMOGA in order to find most appropriate production plan; (3) to compare the problem solving capabilities by integrating other multi-objective algorithms.

The structure of this study is as described below: Section 2 is about literatures exploration with respect to ASP, ALB and multi-objective optimization. The multi-objective optimization mathematical model for this multiple plans selection problem is introduced in Section 3. In Section 4, G-WPMOGA is introduced to solve this problem. Section 4 is about solving cases using the proposed methods, and the comparison of results. Conclusions are listed in Section 5.

2. Literature review

2.1. Assembly sequence planning

Product assembly is about assembling product components into final product through assembly operation procedure, while ASP means the planning of certain priority of assembly based on individual-specific assembly rule of thumb of the organizer with the consideration of related assembly constraints. Tseng, Li, and Chang (2004) explore ASP problems based on connector considering four engineering characteristics such as combination, assembly tools, assembly directions and precedence relationship. These four characteristics are described as the followings:

(1) Combination: There are four basic types of combinations according to the types of component fasteners such as fixed fastener and disassembled (FD), fixed fastener and not disassembled (FND), movable fastener and disassembled (MD) and movable fastener and not disassembled (MND).
(2) Assembly tools: There are four types of assembly tools based on the degree of difficulty of assembly and disassembly operations such as: (T1) easy assembly method without tools; (T2) assembly by simple hand tools without interference from too many other parts; (T3) assembly by using simple tools with the help of other tools; (T4) assembly requiring special tools.
(3) Assembly directions: There are six directions such as $+X$, $-X$, $+Y$, $-Y$, $+Z$ and $-Z$ taken into consideration.
(4) Precedence relationship: The precedence of connector is determined by expertise of engineer in accordance with the engineering characteristic of connector or the geometric information of related parts.

Tseng (2006) has pointed out that GA is not capable of obtaining optimal solution while solving ASP problems with more complicated constraints and sometimes even the feasible solution is not available. There are three factors causing this situation: initial population, crossover and mutation operator. G-GA is developed with respect to these three factors, and the results of studies indicate that G-GA has superior problem solving capability than general GA such that it can effectively solve assembly arrangement problem with over-complicated constraint equation. Tseng, Wang, and Shih (2007) utilized G-GA to conduct local search and to solve assembly sequence constraint problems and developed memetic algorithm with integration of global search method for the applications of assembly problems of staplers, fans and laser printers in order to effectively solve assembly sequence arrangement problems with huge amount of constraints and obtain good results.

2.2. Assembly line balance

An assembly line is a process-oriented production system developed by Henry Ford in 1912. In an assembly line, production parts are transported by conveyors, technicians or robots before assembled into final products through certain operations (Gu, Hennequin, Sava, & Xie, 2007). ALB problem was first introduced by Helgeson, Salveson, and Smith (1954) followed by different methods from all kinds of perspectives introduced by different scholars for solving this problem. Among them, Ghosh and Gagnon (1989) divided ALB problem into four types according to the number of products and characteristics of working time explored in the problem: Single model deterministic (SMD), Single model stochastic (SMS), Multi/mixed model deterministic (MMD) and Multi/mixed model stochastic (MMS).

In general there can be four kinds of conditions for ALB such as SALBP-1, SALBP-2, SALBP-E and SALBP-F. Actually there is this dual relationship between SALBP-1 and SALBP-2 because SALBP-1 is aimed at pursuing minimized number of work stations with fixed cycle time while SALBP-2 is aimed at pursuing minimized cycle time with fixed number of work stations. SALBP-E is very common among line efficiency problems mainly for simultaneously pursuing the minimized value between the correlation between number of work stations and cycle time. SALBP-F is a feasibility problem for verification of the existence of feasible line balance with given number of work stations and cycle time.

In recent years, GA has been widely applied to the field of ALB. Chen, Lu, and Yu (2002) have studied multi-objective assembly planning including problems such as minimized cycle time, frequent changes of minimizing tools, complexity of