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ScienceDirect
Journal of Computational Design and Engineering 2 (2015) 105–112
www.elsevier.com/locate/jcde

A comprehensive approach for managing feasible solutions in production planning by an interacting network of Zero-Suppressed Binary Decision Diagrams

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Received 26 November 2014; received in revised form 5 December 2014; accepted 9 December 2014
Available online 7 January 2015

Abstract

Product Lifecycle Management (PLM) ranges from design concepts of products to disposal. In this paper, we focus on the production planning phase in PLM, which is related to process planning and production scheduling and so on. In this study, key decisions for the creation of production plans are defined as production-planning attributes. Production-planning attributes correlate complexly in production-planning problems. Traditionally, the production-planning problem splits sub-problems based on experiences, because of the complexity. In addition, the orders in which to solve each sub-problem are determined by priorities between sub-problems. However, such approaches make solution space over-restricted and make it difficult to find a better solution. We have proposed a representation of combinations of alternatives in production-planning attributes by using Zero-Suppressed Binary Decision Diagrams. The ZDD represents only feasible combinations of alternatives that satisfy constraints in the production planning. Moreover, we have developed a solution search method that solves production-planning problems with ZDDs. In this paper, we propose an approach for managing solution candidates by ZDDs' network for addressing larger production-planning problems. The network can be created by linkages of ZDDs that express constraints in individual sub-problems and between sub-problems. The benefit of this approach is that it represents solution space, satisfying whole constraints in the production planning. This case study shows that the validity of the proposed approach.

Keywords: Production planning; Production-planning attributes; ZDD

1. Introduction

Product Lifecycle Management (PLM) is known as one of the most effective approaches for product development and management [9]. Production planning is one of the phases in PLM. Production planning can be categorized into several domains, such as process planning, machine layout, production scheduling and so on [2,3,10]. In this research, key decisions in each domain for the creation of production plans are defined as production-planning attributes [4]. Since production-planning attributes correlate complexly in production-planning problems, production-planning problems have traditionally split sub-problems and have been solved by each sub-problem. If a solution in a sub-problem is infeasible in terms of the entirety of production planning, the sub-problem is resolved. Moreover, the orders in which to solve each sub-problem are determined by priorities between sub-problems, such as the first decision being process plans, the second decision being machine layout and so on. Such approaches make solution space over-restricted and make it difficult to find a better solution.

In this research, solution space in production planning is defined as comprehensive. We have proposed a representation of combinations of alternatives in production-planning attributes by using Zero-Suppressed Binary Decision Diagrams (ZDD) [6], which is are special type of Binary Decision Diagram (BDD) [1] used to represent a binary decision tree in graph form and are suitable for representing and processing combinatorial set data [4]. The ZDD was used to represent a

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http://dx.doi.org/10.1016/j.jcde.2014.12.005

set of solution candidates that satisfy constraints in production planning [4]. As a result, the ZDD represented only feasible combinations of alternatives that satisfy constraints in production-planning attributes. Moreover, we have developed a solution search method that solves production-planning problems with ZDDs [5].

In this paper, we proposed an approach for managing solution candidates by ZDDs' network for addressing larger production-planning problems. The network can be created by linkages of ZDDs that express constraints in an individual sub-problem and between sub-problems. The benefit of this approach is to represent solution space, satisfying the entirety of constraints in production planning. Experimental results demonstrate that the interacting network of ZDDs is used for representing feasible solutions in production planning.

2. Production-planning domains and attributes

In this research, we categorized production planning into four domains [4].

- Process planning: creation of product information including operation processes.
- Resource planning: arrangement of equipment and workers for manufacturing execution.
- Execution planning: assignment of jobs to equipment and creation of production schedule.
- Order management: decision of boundary conditions in production processes.

Each domain has production-planning attributes. Table 1 shows the production-planning attributes. As shown in Table 1, 23 production-planning attributes are defined. Each production planning-attribute has alternatives. By combining alternatives in production-planning attributes, a production plan can be created. Each production-planning attribute has relationships to other attributes. A change of alternative may affect other alternatives in other attributes. Such influence may spread to the entirety of production planning. Therefore, the solution space of production planning is defined as comprehensive in this research [4]. For the representation of comprehensive solution space, we have used Zero-Suppressed Binary Decision Diagrams (ZDDs) [6]. The ZDD is described in detail in the next section.

3. Representation of feasible solutions in production planning

3.1. Zero-Suppressed Binary Decision Diagrams

A ZDD is a directed graph representation of a Boolean function and can efficiently represent a set of combinations [6]. ZDDs have two terminal nodes, called 0-terminal node and 1-terminal node, and many decision nodes with two edges, called 0-edge and 1-edge. In order to represent a Boolean function efficiently, the following reduction rules are usually applied [6].

1. Share equivalent nodes.
2. Delete all nodes of which 1-edge directly points to the 0-terminal node, and jump through to the 0-edge's destination.

Fig. 1 shows a ZDD representing Boolean function $F = a\bar{b}c \vee \bar{a}b\bar{c}$, which can be equivalently represented by using a set of combinations $\{ac\}, \{b\}$.

If a variable never appears within any elements in a set of combinations, a node representing the variable is removed from the ZDD.

3.2. VSOP

The Valued-Sum-Of-Products (VSOP) [8] program is for calculating combinatorial item set data specified by symbolic

Table 1
Production-planning domains and attributes [4].

Production-planning domains	Production-planning attributes
Process planning	Product redesign Grouping of process plan Manufacturing method Production process Process sequence Machine type Tool type Tool approach direction
Resource planning	Quantity of resource Available time Resource allocation Control rule
Execution planning	Job sequence Job routing Lot splitting Objective function Dispatching rule Constraint Inventory Placement Quantity of inventory
Order management	Due date Order cancellation Outsourcing

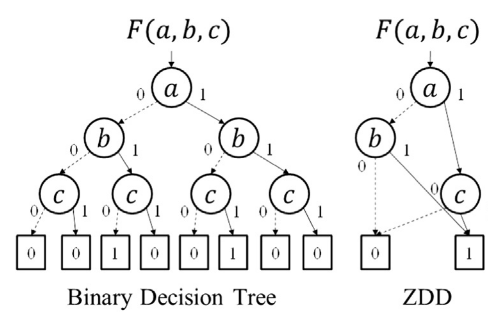

Fig. 1. Binary Decision Tree and ZDD.