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TOWARDS CP-BASED PRODUCTION FLOW PROTOTYPING FOR SME

The paper addresses the issue of decision-making support for small and medium size enterprises operating within a virtual project-driven enterprise environment. The problem considered here can be defined in terms of finding a feasible schedule that satisfies the constraints imposed by the work order duration, the price, and the time constrained resource availability. In other words, we are looking for an answer whether a given work order can be accepted for processing in a manufacturing system. The problem belongs to a class of multi-mode case problems of project scheduling, where finding a feasible solution is NP-complete. The proposed CP-based approach, implemented in an interactive software package, support the decision maker in the course of the production order requirements and the manufacturing system capacity matching.

ZASTOSOWANIE PROGRAMOWANIA Z OGRANICZENIAMI DO WARIANTOWANIA OBSŁUGI ZLECEŃ PRODUKCYJNYCH W MŚP

Problematyka wspomagania decyzji w małych i średnich przedsiębiorstwach zarządzanych przez projekt, nabiera istotnego znaczenia, w szczególności, w kontekście podejmowania nowych zleceń produkcyjnych. Rozważany problem decyzyjny sprowadza się do odpowiedzi na pytanie: Czy dostępne zdolności produkcyjne przedsiębiorstwa pozwalają na terminowe, zrealizowane po planowanych kosztach, wykonanie danego zlecenia? Problem ten należy do klasy NP-trudnych. Wykorzystanie technik programowania w logice ograniczeń do rozwiązywania tej klasy problemów wydaje się być konkurencyjne w stosunku do aktualnie wykorzystywanych metod programowania matematycznego. Praca poświęcona jest ocenie możliwości budowy narzędzi wspomagania decyzji nowej generacji.

1. INTRODUCTION

The main objective of Decision Support Systems (DSS) aimed at the production flow planning is the coordination of processes and activities related to work order processing, i.e., regarding the transportation, inventory management, warehousing and production. In other words the goal is to achieve a well-synchronized behavior of dynamically interacting components, where the right quantity of the right material is provided in the right place, and at the right time [1].

The problem considered regards of finding of computationally effective approach aimed at scheduling of a new project subject to constraints imposed by a multi–project environment. In other words, we are looking for an answer whether a given production order specified by its cost and completion time can be accepted for processing in a Small and Medium Size Enterprise (SME) specified by available production capability, i.e., the time-constrained resources availability. The problem belongs to a class of multi-mode case project scheduling problems, where the problem of finding a feasible solution is NP-complete [2], [11], [12].

That is worth to note that the currently available software tools allow pre-emption; however, they are not designed to cope with company production capability constraints in terms of resource and time availability. Moreover, they do not permit to consider production planning in a unified way to enable an integrated approach to such different tasks as production and transportation routings, production and batch sizing as well as tasks scheduling.

In that context, Constraint Logic Programming (CLP) languages, by employing the constraints propagation concept and by providing unified constraints specification, seem to be well suited for modelling of a company real-life and day-to-day decision-making {3], [4], [6] process. The rest of the paper is organized as follows: Section 2 describes the modelling framework enabling to state the problem. A concept behind searching for a feasible production flow prototyping is then presented in Section 3. In Section 4, a concept of the CLP-based approach to DSS design in a SME company is investigated. Conclusions are presented in Section 5.

2. CP-BASED PROBLEM SPECIFICATION

Constraint programming (CP) is a framework for solving combinatorial problems specified by pairs: <a set of variables with domains, a set of constraints restricting the possible combinations of the variables' values>. Constraint propagation, i.e., reference engine, is based on the idea of using constraints actively to prune the search space. The scope of propagation techniques, i.e. local consistency checking, is to reach a certain level of consistency in order to accelerate search procedures by drastically reducing the size of a search tree.

A constraint satisfaction problem can be stated as follows. Consider a set of n variables $x_1,x_2,\ldots,x_n$, their domains $d_1, d_2,\ldots,d_n$, and a set of constraints of this variables. Each constraint, i.e. an n-ary relation on $x_1,x_2,\ldots,x_n$ and can be treated as a subset of the Cartesian product $d_1 \times d_2 \times\ldots\times d_n$ of the domains. The solution is a value assignment of the variables such that all constraints are satisfied. In order to illustrate this kind of inference engine, let us consider a set of the following variables x, y, z and their domains $d_x = \{1,2,3,4,5,6\}$, $d_y = \{1,2,3,4,5,6\}$, $d_z = \{1,2,3,4,5,6\}$. Suppose the following constraints:

$$\alpha: X \geq Y + 1, \quad \beta: Y \geq Z + 2, \quad \gamma: Z < X - Y.$$

One of possible ways of constraint propagation is shown below:

$D_X = \{1,2,3,4,5,6\}$ $D_X = \{2,3,4,5,6\}$

$D_Y = \{1,2,3,4,5,6\}$ $\xrightarrow{\alpha}$ $D_Y = \{1,2,3,4,5\}$

$D_Z = \{1,2,3,4,5,6\}$ $D_Z = \{1,2,3,4,5,6\}$

$D_X = \{2,3,4,5,6\}$ $D_X = \{4,5,6\}$

$D_Y = \{1,2,3,4,5\}$ $\xrightarrow{\beta}$ $D_Y = \{3,4,5\}$

$D_Z = \{1,2,3,4,5,6\}$ $D_Z = \{1,2,3\}$

$D_X = \{4,5,6\}$ $D_X = \{5,6\}$

$D_Y = \{3,4,5\}$ $\xrightarrow{\gamma}$ $D_Y = \{3,4\}$

$D_Z = \{1,2,3\}$ $D_Z = \{1,2\}$.

The resulting set of feasible solutions consists of the following combinations of value assignment of the variables:

X, Y, Z X, Y, Z X, Y, Z

(5 , 3 , 1), (6, 3, 1), (6, 4, 1),

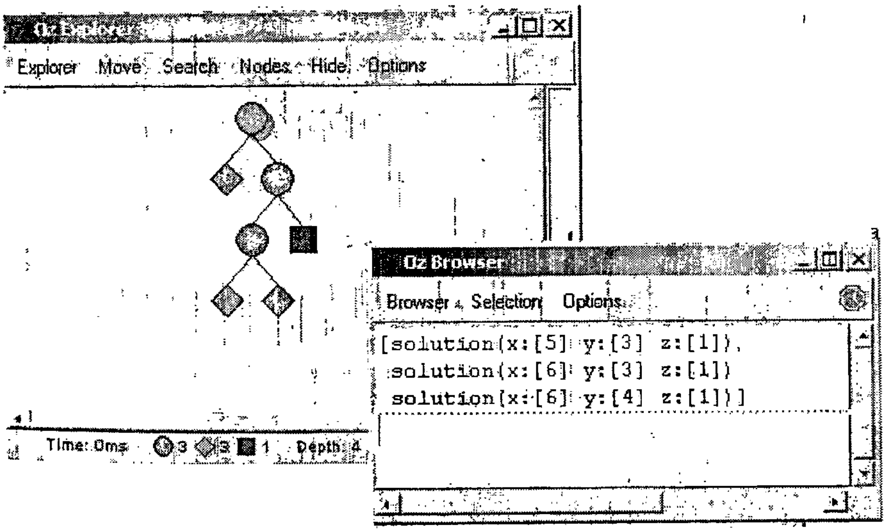

Fig. 1. Solution obtained in Oz language

So, the task is to find values of the variables satisfying all the constraints, i.e., a feasible valuation. Note, that the constraints are not restricted to linear equalities and/or inequalities. They can express arbitrary mathematical or logical formula as well as bind variables with different non-numerical event domains. Taking into account this advantage, the following problem is considered.

Given a manufacturing system providing a production capability while processing some other work orders. So, only a part of the production capability (specified by the time-restricted resource availability) is available for use in the system. The work order is specified by project duration deadline T_h, which is equivalent to a presumed completion time (the work order cycle), as well as a total project cost constraint K_h (selling price). Each activity may be executed in one out of the set of $M_{i,j}$ modes (system resources). Also, each activity may not be pre-empted and the mode once selected may not be changed. Considering a time horizon, which an upper bound on the project's makespan, there is an amount of p units of available renewable resources in the considered period. The cost of using a resource unit is specified in the map of accessible renewable resources.

The question is whether there exists a makespan-feasible schedule that fulfils the constraints imposed by precedence relations, by time-constrained resources availability, as well as the duration deadline. In other words, the question: does there exist a work order schedule respecting the assumed production cycle and cost limits?

3. PRODUCTION FLOW PROTOTYPING

The approach proposed can be seen as an alternative to the one based on a computer simulation. On one side, it allows to respond to the same question "what if", providing detailed plan of production flow if a balance holds. On the other side, it provides suggestions (e.g., how to change consumer requirements and/or a producer capability) supporting negotiation aimed at a production order acceptance. The core technology of CP is therefore hidden in constraint propagation combined with sophisticated search techniques [5]. Depending on the order, the constraints propagation take a number of backtracking steps and the efficiency of the applied searching strategy may differ dramatically (see Fig. 2).

Taking this into account, our objective is to develop a task oriented searching strategy, the implementation of which in a CLP based language could be successfully applied in project-driven SME companies, i.e., to make possible on-line decision making under real-life task sizes and constraints.

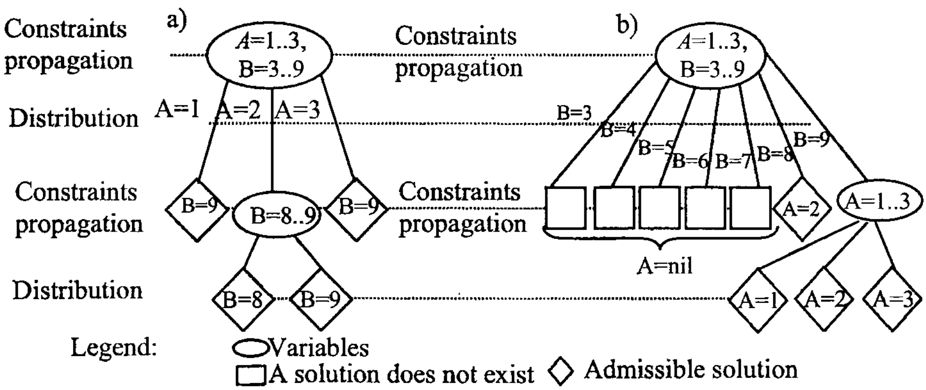

Fig. 2. Decision variables distribution, a) B follows A, b) A follows B

The factor guaranteeing competitiveness of an enterprise on the market is its ability to make prompt and appropriate decisions relating to customer needs and production possibilities of the producer. Decision making problems occur, particularly often in small and medium-sized enterprises and are connected to acceptance of a new production order. Usually, the first solution, which satisfies the set of limits, is search. This set connects decision variables, which specify manufacturer abilities, variables that characterize order realization conditions and decision variable between consumer and manufacturer.

Decisions taken, are usually formulated in Constraint Satisfaction Problem (CSP) form, for which dedicated programming languages with constraints are elaborated (Constraint Programming CP), in particular Constraint Logic Programming CLP. Declaratory character of CP languages and high efficiency of implemented decision aided packets creates an attractive alternative (enabling on-line work) to accessible computer integrated management systems.

The constraint satisfaction problem CSP = ((X,D),C) is defined for: a finite set of variables $X = \{x_1, x_2, \ldots, x_n\}$, family domains of variables $D = \{D_i \mid D_i = [d_{i1}, d_{i2}, \ldots, d_{ij}, \ldots, d_{im}], i = 1..n\}$ and a finite set of constraints $C = \{C_i \mid i = 1..L\}$, which limits decision variables values. Request is either admissible solution, that means solution in which values of all variables satisfy all constraints (one, soon obtained, either or all possible) or optimal solution (in general set of solutions) there exists or not.

It's easy to notice, that problem formulated in such a way in natural decomposes into subproblems, in particular to elementary subproblems, which are not further decomposed. This observation leads to a concept of a CSP decomposition model encompassing an object-like nature of the CSP structure. In general case each CSP can be seen as a composition of subproblems. Composition consists of subproblems which are CSP's direct decompositions being either mutually independent (that's mean suitable variable subset are not connected with any constraints) or dependent subproblems.

Since each subproblem corresponds to a standard constraint problem problem structures, i.e., decision variables, domains and constraints, hence some object-like modified AND/OR graph notation can be used in the course of analysis of the potential ways a CSP problem my be resolved.

Since with AND/OR graph arcs it is possible to bind weight factors determining the necessary number of searches, hence such representation provides a way to chose the best searching strategy, i.e. a variant with least number of backtrackings. This means that each AND/OR graph strategy representation could be initially variant due to different criteria of effective searching. For the detailed discussion of possible applications of the reference model aimed at solving of production flow planning problems see the papers: [7], [10].

4. DEDICATED DECISION SUPPORT TOOLS

Since the reference model, i.e. an object-like AND/OR graph framework, provides the possibility to estimate the number of decision variables domains values substitution, hence the influence of data structure, sequence of elementary subproblems solution and domain size on decision making time may be evaluated as well. In other words, the model considered provides a well suited framework for development (taking into account the ways of possible problem specification, available CP/CLP languages, and searching strategies) of a CP-based programming methodology as well as the development of the task oriented software tools aimed at the SMEs decision support, e.g. regarding production flow planning.

Programming methodology proposed takes into account the constraints imposed by a programmer experience (possible problem statements), by a set of available software tools (CP/CLP languages), and a set of searching strategies (build-in the software tools as well as those proposed by programmers) (see Fig.3).

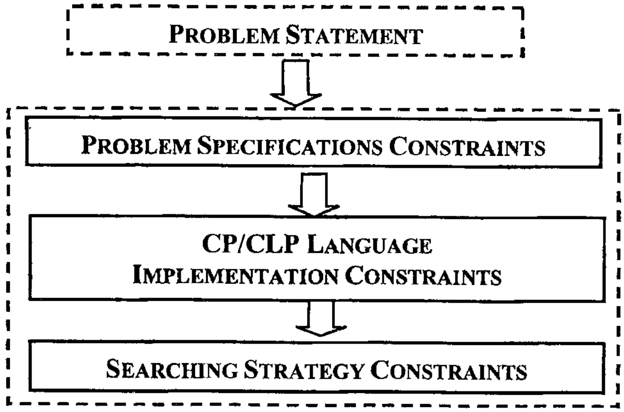

Fig.3 Stages of the CP-based programming methodology

The illustration of the possible implementation of the methodology considered into the task oriented software tools supporting the SME in the course of decision making is shown in Fig. 4. The admissible way of problem resolution is underlined by the bold frames and arcs.

Since efficiency of programming (i.e. a size of resolved problem) depends on selected problem specification, a software tool employed and a chosen searching strategy, hence designing of the task oriented tools seems to be the only reasonable approach to set-up a CP-based decision support software. It means, for a given class of CSPs (e.g. production flow planning ones) and a CP/CLP language assumed, on the base of an experience gathered both from the analysis of the reference model of CSP decomposition, and multiple experiments that is possible to develop searching strategy optimal in the sense of minimal number of potential backtrackings.

5. CONCLUDING REMARKS

A CLP – based modeling framework provides a good platform for checking consistency between the production order completion requirements and a workshop capability offered. The CP methodology presented here is a promising alternative for commercially available tools based on other technologies, such as a class of ERP systems. Their application in solving a real-life problem is quite limited [8], [9].

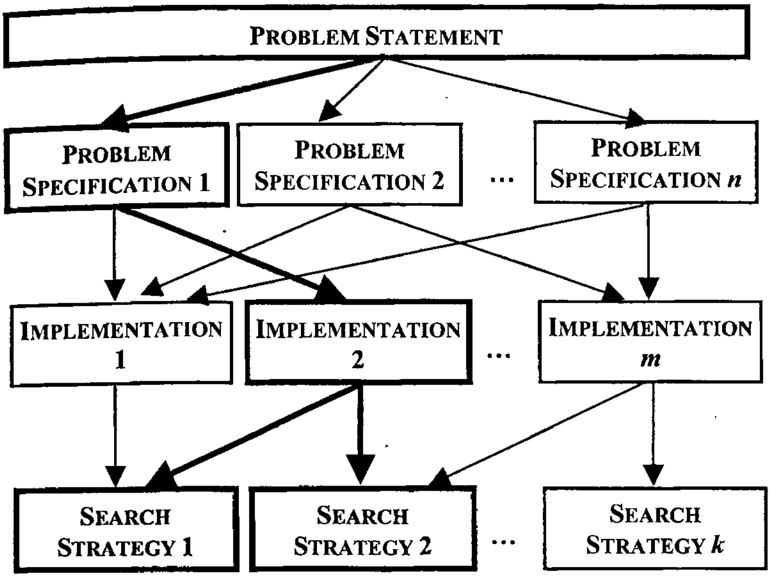

Fig.4 The tree of possible ways of a CSP programming.

Also, the proposed approach can be considered as a contribution to project-driven production flow management applied in make-to-order companies as well as for prototyping of the virtual organization structures. That is especially important in the context of cheap and user-friendly decision support in SMEs. further research is aimed at developing task oriented searching strategies, implementation of which will support the SME's decision making process.

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