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CP APPROACH TO CIM PROTOTYPING

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Abstract. *Constraint programming (CP) is an emergent software technology for declarative description and effective solving of large combinatorial problems especially in areas of integrated production planning. In that context, the CP can be considered as a well-suited framework for implementation of a computer integrated manufacturing (CIM) concept. The aim of the paper is to present the CP modelling framework as well as to illustrate its application to decision making in the case of a new production order evaluation (PPP – Production Process Planning). Therefore, the contribution emphasises benefits derived from CP-based DSS and focuses on constraint satisfaction driven decision-making rather than on an optimal solution searching.*

1. INTRODUCTION

Constraint programming (CP) is an emergent software technology for declarative description and effective solving of large combinatorial problems especially in areas of integrated production planning. Since a constraint can be treated as a logical relation among several variables, each one taking a value in a given (usually discrete) domain, hence the idea of CP is to solve problems by stating requirements (constraints) specyfing a problem at hand, and then finding a solution satisfying all the constraints.

In that context, the CP can be considered as a well-suited framework for implementation of a computer integrated manufacturing (CIM) concept. Because of its declarative nature, for a use that is enough to state *what* has to be solved instead *how* to solve it. Moreover, the declarative environment for the problem solving is quite natural for non-heterogenic domains of particular variables. Providing such capability the CP may be used to overcome the main obstacle limiting the CIM implementation, i.e. integration of a non-heterogenic data base (including data regarding products design, machine tools, AGVs, warehouses, diagnostics, costs, etc.).

The aim of the paper is to present the CP modeling framework as well as to illustrate its application to decision making in the case of a new production order evaluation (production process planning). Finding an answer to the question whether a given work order can be accepted to be processed in the production system seems to be a fundamental from the customer-driven, and highly competitive market point of view. In that context CIM prototyping regards to the question whether CIM's capability allows to fulfill constraints imposed by the production order requirements, i.e. whether its completion time, batch size, and its delivery period satisfy the customer requirements while satisfying constraints imposed by the enterprise configuration taking into account available resources, know how, experience, and so on. In the case of the response to this question being positive, i.e. there exist a way complete a production order, the next question regards of finding of the most efficient one (e.g. as to be competitive on the market).

The rest of the paper is organized as follows: section 2 describes some issues underlying CIM prototyping, and then provides a problem statement. The CP-based modeling framework aimed at CIM-driven enterprise decision-making is presented in section 3. In section 4 an illustrative example of the approach usage is provided. In section 5 some conclusions are presented.

2. CIM PROTOTYPING

Computer Integrated Manufacturing (CIM) refers to the integrated information processing requirements for the technical and operational tasks of an industrial enterprise [6,7]. The technical activities purport to the following CAx- concepts: Computer Aided Engineering (CAE), Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) including Computer Aided Process Planning (CAP) and Computer Aided Quality Assurance (CAQ). In turn the operational tasks cover area of Production Planning and Control Systems (PPC) including material and capacity requirements planning, cost estimating, master production planning, production and dispatch control [8].

From the decision making point of view CIM can be seen as an integrated framework (based on distributed data base system) allowing one to interact among different domains, function, and activities of an enterprise in order to be both able to respond to customer orders and to compete on the producers market. Despite of many problems regarding the database design (including data consistency and completeness examination) the main question is how to manage CIM potential? How to be able to respond whether capability (including machinery and software flexibility) of the CIM at hand can be enough to accept a new production order? How to obtain such a response in an on-line mode? What mean of production order processing is the most efficient one?

Of course, answers to the above questions have to be given before entering of a production order processing as well as without any previous real object experiments. It means the response should be obtained for example via virtual reality environment (See Fig.1)

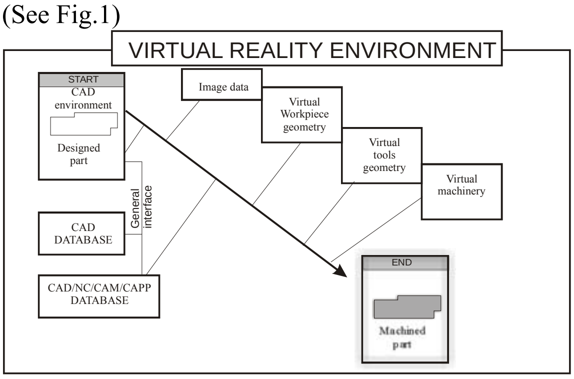
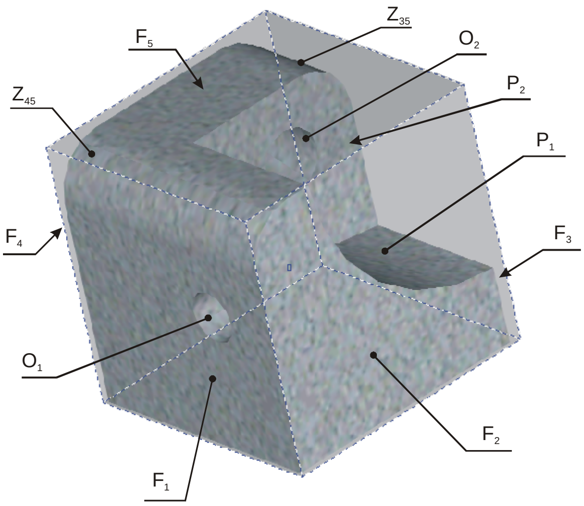


Fig.1 Virtual reality environment

However, the database resources and virtual reality software provide only costly and time-consuming potential to exam few arbitrary assumed versions of work order processing. That is because of combinatorial explosion of possible solutions caused by possible technologies and tools assignment, material handling, transportation and storage facilities assignments, production and transportation lot-sizing, scheduling and pricing, and so on.

For illustration, let us consider the production order regarding to a part of female mould – fig.2. Assuming, that CIM-driven enterprise considered provides such technologies as: milling, grinding, drilling etc., and for all of them there are known machine processing with tooling and cost per hour a set of different connections and solutions should be analysed.



F_i – planes to be machined, P_i- surfaces, O_i –holes, Z_{ij} - fillets

Fig.2 Shape analysis

It's easy to notice, that considering only two processes (based on stock material: casting or bar stock), two technological process variants could be considered. Figure 3 illustrates the framework of the prototype system.

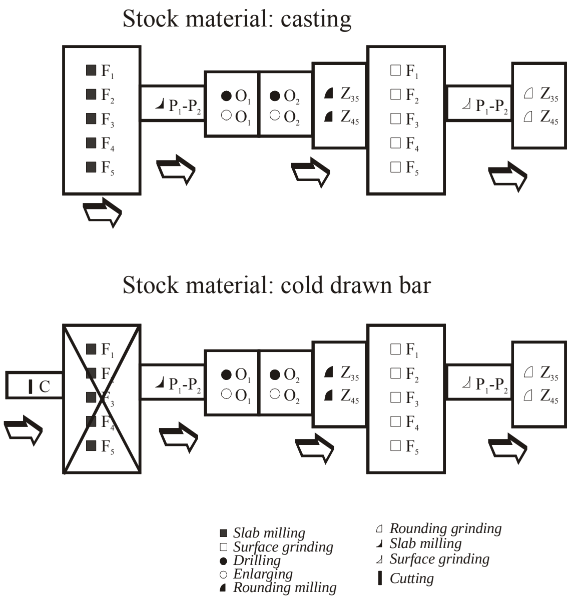


Fig. 3 Example of process part analysis to manufacturing

For the process analysis purpose, part is defined by noncomplex surfaces (planar, cylindrical etc.). This set of generic volumes must assure: for every milled part the material to be removed can be decomposed into the union have disjoint delta volumes. The construction of surface in the object needs to be explicitly stated. The framework is constructed from major modules: feature message, a design models database, machine and tools library and cost database.

On the other hand, assuming that to each partial process two (or more) machines characterized by different exploitation cost and operation time could be assigned, it is easy to notice that the number of variants rapidly grow up (2^n). Adding two devices of materials handling and ways of assigning to technological process, the number of variants increases.

The presented way of estimation of the potential number of variants of the production processes adopts an imposed order (choice of technology, assignment of tools and devices etc.). In general case, some mutual local interactions (corresponding to Concurrent Engineering philosophy) such as: the shape of designed part, choice of technology, the way of production flow (parallel or in series), inter-operating storage system etc. should be taken into account. Not mentioning the simulation.

From the example provided it follows that the tools enabling one to cope with such kind of tasks in an on-line mode are of crucial importance. This need implies requirements for the new approaches and paradigms. The promising perspective seems to be based on CP based framework. In this context the following problem can be considered:

Consider a CIM-driven enterprise providing a given production capability. A given production order is specified by a set of design features, volume, completion time and cost. The problem consists of an evaluation of CP framework to rapid prototyping of admissible ways of production order processing. Solution to this problem provides a way the CP based approach helps to exploit the all capability possessed by the CIM-driven enterprise in an interactive mode.

3. CP-BASED MODELLING

The element 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 [1,2,3].

3.1 Constraint satisfaction problem

Let's consider the constraint satisfaction problem (CSP) formulated as follow: finished set of variables is given $X = \{x_1, x_2, \ldots ,x_n\}$, family domains of variables $D = \{D_i \mid D_i = [d_{i1}, d_{i2}, \ldots, d_{ij}, \ldots, d_{im}], i = 1..n\}$ and finished 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) that extreme objective function definite on chosen decision variables subset.
For simplification lets assume the following notation of constraints satisfaction problem:

$$CSP = ((X,D),C),$$

where: $c \in C$ is a certain predicative $P[x_k,x_l,\ldots,x_h]$ defined on subset of X set.

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.

For this fact illustrative purpose let consider the following problem:

$$CSP = ((X,D),C),\ \text{gdzie}\ X = \{x_1,x_2,\ldots,x_{12}\},$$
$$D = \{D_1,D_2,\ldots,D_{12}\},\ C = \{c_1,c_2,\ldots,c_8\}$$

where:

$c_1 = P_1[x_1,x_2,x_3]$, $c_2 = P2_1[x_2,x_4,x_5]$, $c_3 = P_3[x_4,x_6]$,
$c_4 = P_4[x_7,x_8]$, $c_5 = P_5[x_4,x_7]$, $c_6 = P_6[x_9,x_{10}]$,
$c_7 = P_7[x_8,x_9]$, $c_8 = P_8[x_{11},x_{12}]$.

Two, arbitrarily chosen, admissible decompositions of this problem are shown on fig.4.

Arcs indicate the order of subproblems solving (in arc case, the order of direct preceded subproblems is unrestricted), symbol * indicates elementary subproblems.

Admissible problem decompositions $\leftrightarrow$, could be interpreted as suitable searching strategies, determined by number of definite subproblems and by solution order.

This presented example illustrate:

– operators requirements used in problem solving, in particular requirements connected with elementary problems implementation abilities,
– possibilities of search solving strategy choice which minimize the number of potential returns (the strategies which take into consideration the specifications of each problem instance related to each variables domain size).

3.2. Searching strategy prototyping

Instance of problem decompositions (CSP) featured earlier (fig. 4) of course do not exhaust all potential decomposition possibilities.
Let's introduce the following notation of decomposed subproblems: $CSP^{i'}_{j,k,l}$ means the 1st decomposition of i-th problem (where $i = |\{j,k,l\}|$), is in se-

quence k-th decomposition of $I\text{-}1^{st}$ problem, which is j-th decomposition of initial problem CSP, i' (i) indicates problem for which direct decompositions are suitable mutually independent, that's mean suitable variable subset are not connected with any constraints (dependent). Using this notation, decomposition CSP from fig 4a has a form as it is shown on fig. 5 (in bold)

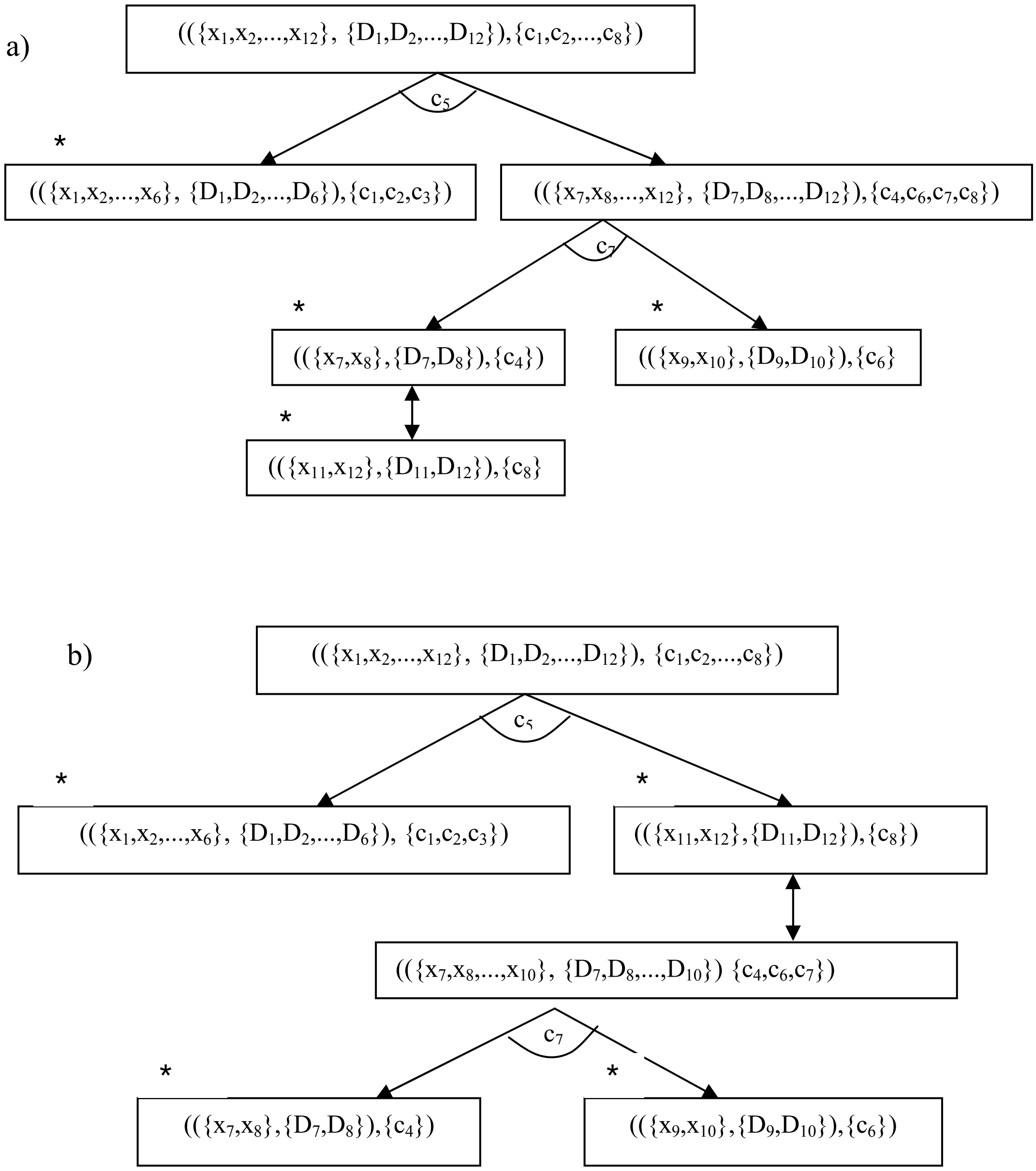


Fig.4. Admissible problem decompositions CSP

Using AND/OR graph notation, the instance mentioned above and the one responding to decomposition (in bold) are depicted on fig.6. Considering unequivocally separate subproblems of each instance this graph allows integrated and easy way of interpreting the representation. Accepted letter indications for each subproblem correspond to subproblems structures (decision variables, domains and constraints). In general case, due to introduced symbols, with every instance one characterized for itself index subproblems symbol is connected $CPS^{i+1}_{j,i}$.

Given graph AND/OR representation of admissible problem decomposition CSP enables the analysis of all potential ways of solving problem (not limited by capabilities of used programming system in CP languages) [4,5].

Resultant representation, including programming tools restrictions, represents the set of admissible (with regards to problem "needs" as well as "capabilities" of used tools) strategies of solution searching. Note, that with AND/OR graph arcs it is possible to bind weight factors determining the necessary number of searches (domain elements), and in this way to chose strategy variant e.g. with least back tracking. This means that each AND/OR graph strategy representations could be initially variant due to different criteria of effective searching.

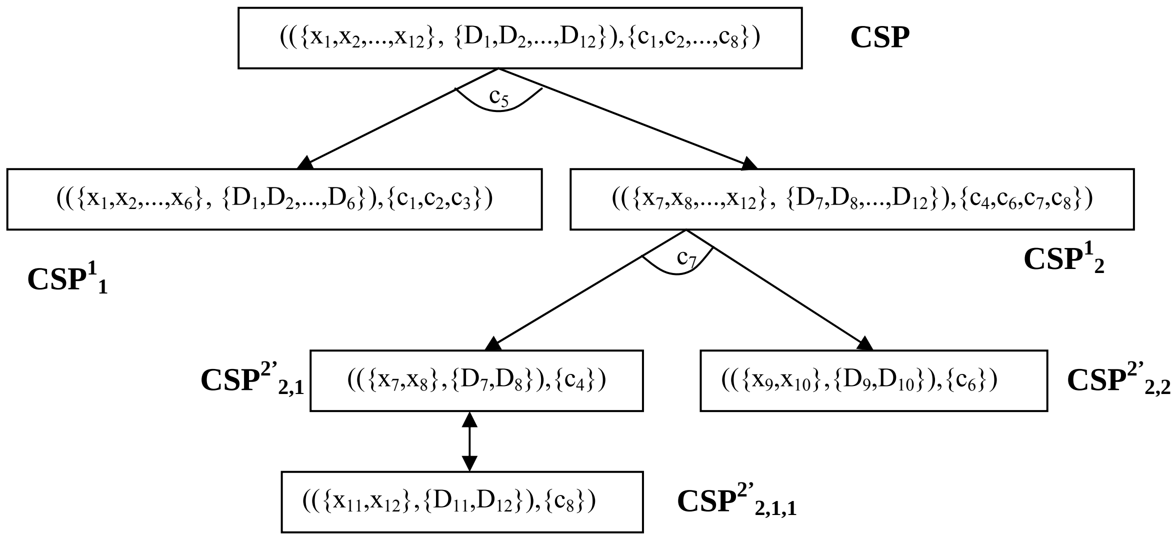


Fig.5. Notification of subproblem decomposition CSP

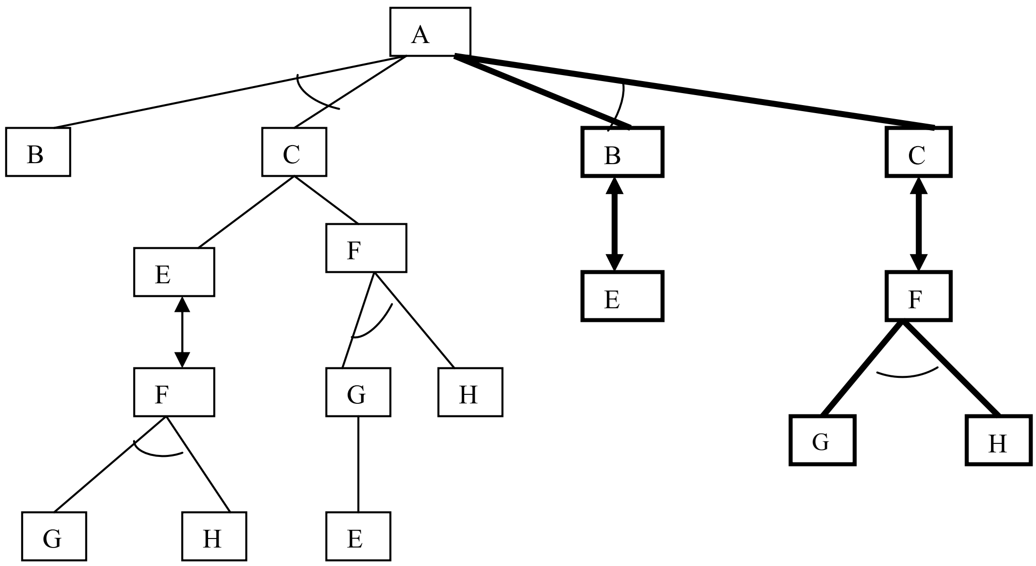


Fig. 6 END/OR graph for three instance problem decomposition.
For figure simplification, letters mark each subproblem were introduced: A – respond to CSP, B – respond to CSP^1_1, C – respond to CSP^1_2, E – respond to $CSP^{2'}_{2,1}$, F – respond to $CSP^{2'}_{2,2}$, G – respond to $PSO^3_{2,2,1}$, H – respond to $PSO^3_{2,2,2}$.

This implies a possibility of abandoning time and cost-consuming experiments. Similar comments also refer to programming system CP variants.

Presented reflections imply the need to work out the reference decomposition model CSP that will be able to solve such problems as:

– the CSP specification, whose CP class kind of language implementation enables a direct arrival at a solution without the necessity of reformulating the problem, is given, acceptance of such searching strategy minimizes the number of potential back tracking,
– the implementation of class CP language is given; for which CSP specifications is dedicated and make possible to search the solution with minimize the number of potential back tracking,
– given are: CSP specification and CP language implementation, what kind of searching strategy minimize the number of potential back tracking.

4. ILLUSTRATIVE EXAMPLE

For the purpose of illustrating the application of the practical capabilities of the presented approach lets consider production order characterized by:

Z – order size,

TZ – dead-line of order realization,

and production system whose capabilities are characterized by:

J – route numbers according which the order may be realized,
I – number of production batch, into which the order is divided,
L – number of transport batch into which production batch are divided,
K – number of operations composed onto a route,
$K+1$ – number of transport operations in each route,
$TJ_{j,k}$ – time of processing per unit for k-th operation in j-th route production,
$TP_{j,k}$ – length of k-th transport operation in j-th route production,
H – planning horizon.

The answer to following question should be given: whether the order could be realized in given term and if so, in what possible way?

Let's consider the following usually considered stage of production process flow planning:

Production batching

$x_{1,i}$ – size of i-th batch production, where: i=1..I
$((\{x_{1,i}\}, \{D_1\}), \{c_1\})$
D_1: 1..(Z-I+1)
c_1: $\sum_{i=1}^{I} x_{1,i} = Z$

Production routing

$x_{2,i}$ – number of route number in which i-th batch will be produced, where:
gdzie i=1..I
$((\{x_{2,i}\}, \{D_2\}), \{c_4\})$
D_2: 1..M
c_2: $M \le J$

Production scheduling

$x_{3,i,k}$ –starting-up time processing i-th batch on k-th stock in technological route, where:
i=1..I, k=1..K
$((\{x_{3,i,k}\}, \{D_3\}), \{c_3\})$
D_3: 1..H
c_3: $x_{3,i,k} + x_{1,i} \cdot TJ_{(x_{2,i}),k} < x_{3,i,k+1}$
c_4: $x_{3,i,k} \le TZ$

Transport batching

$x_{4,i,l}$ – size of l-th batch transport, set apart from i-th batch production, where:
i=1..I, l=1..L
$((\{x_{4,i,l}\}\{D_4\})\{c_9 \div c_{11}\})$
D_4: 1..Z
c_6: $x_{4,i,l} \le (Z-I-L+2)$
c_5: $\sum_{l=1}^{L} x_{4,i,l} = x_{1,i}$

Transport scheduling

$x_{5,i,l,k}$ – transport term of l-th batch transport of i-th batch production to k-th resources in production routing, where: i=1..I, l=1..L, k=1..K+1 (stock K+1 means ready-make production workhouse):
$((\{x_{5,i,l,k}\}\{D_5\})\{c_{12} \div c_{18}\})$
D_5:1..H
c_6: $x_{5,i,l,k} \le TZ$
c_7: $x_{5,i,L,(K+1)} + TP_{(x_{2,i}),(K+1)} < TZ$
c_8: $x_{5,i,l,k} + TP_{(x_{2,i}),k} < x_{5,i,l,k+1}$
c_9: $x_{5,i,1,k} + TP_{(x_{2,i}),k} < x_{3,i,k}$
c_{10}: $x_{5,i,L,k} + T_{i,L,k} < x_{3,i,k} - x_{4,i,L} \cdot TJ_{(x_{2,i}),k}$
c_{11}: $x_{5,i,1,k+1} > x_{3,i,k} + x_{4,i,1} \cdot TJ_{(x_{2,i}),k}$

Two, among from many SCP=$((\{x_1 \div x_5\},\{D_1 \div D_5\}),\{c_1 \div c_{12}\})$ problem potential decompositions are shown on fig.6.

The effectiveness of searching strategy, corresponding to each graph, may be estimated by size of calculated potential outlay needed to obtain the solution.

Cost of using determined decomposition (strategy of solving searching) is estimated. It's simply to notice, the dependence either on the problem decomposition as well as on the size domains of each decision variables.

For the purpose to illustrate the comparison between considered strategies, the following date were assumed:
order size Z=6,
number of possible routings J=2,
number of batch of parts I=3,
number of processing in routing K=2,
number of transport batch on production batch l=2.
planning horizon H=10,
dead-line of realization TZ=9.
Estimated results are shown in table 1.

Table 1

Strategy fig. 4 a)				Strategy fig.4 b)			
	Number of decision variables domains values substitution				Number of decision variables domains values substitution		
x_2	8	8	8	x_2	8	8	8
x_1, x_4	64; 729	46656	$3{,}7 \cdot 10^5$	x_1, x_3	64; 10^6	$6{,}4 \cdot 10^7$	$5{,}12 \cdot 10^8$
x_3, x_5	10^6; 10^{18}	10^{24}	$3{,}7 \cdot 10^{29}$	x_4	729	729	$3{,}7 \cdot 10^{11}$
				x_5	10^{18}	10^{18}	$3{,}7 \cdot 10^{29}$

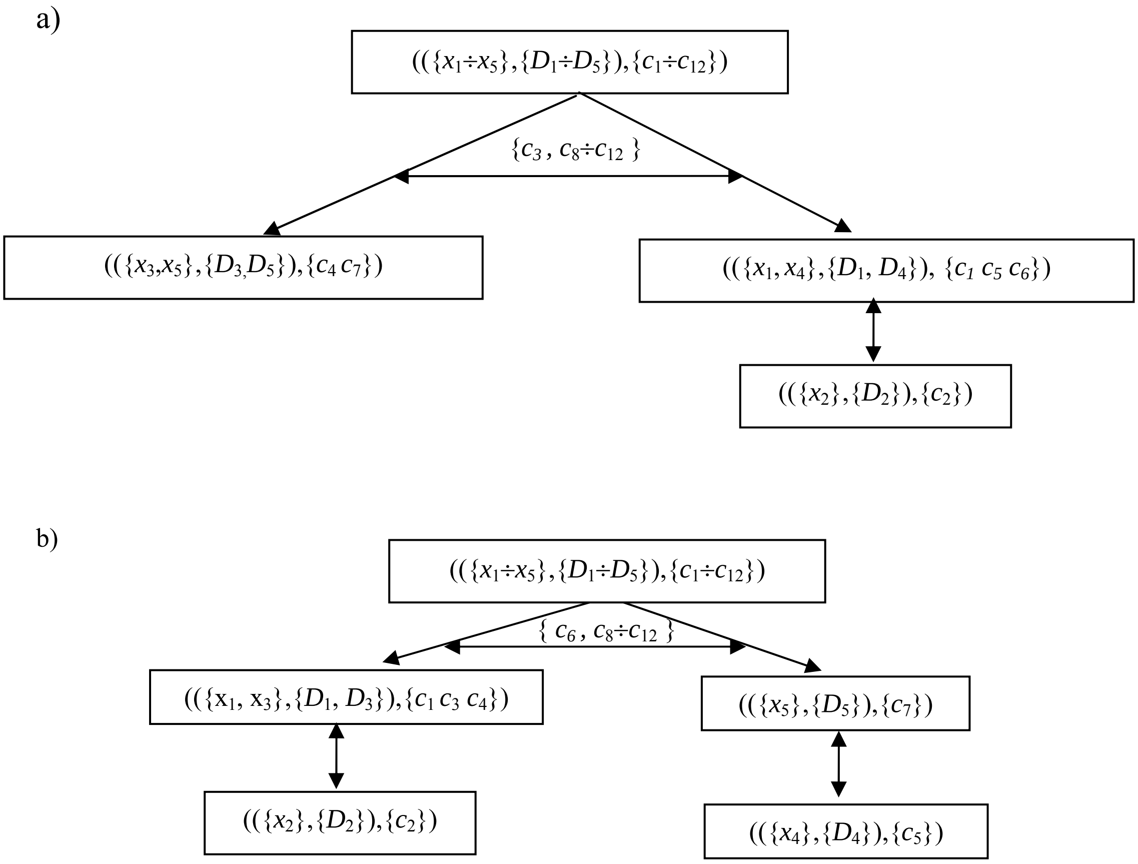


Fig 6. Examples of SCP decompositions; replayed to intuitive way of flow production decomposition problem on transport and manufacturing planning a) and non-standard decomposition b)

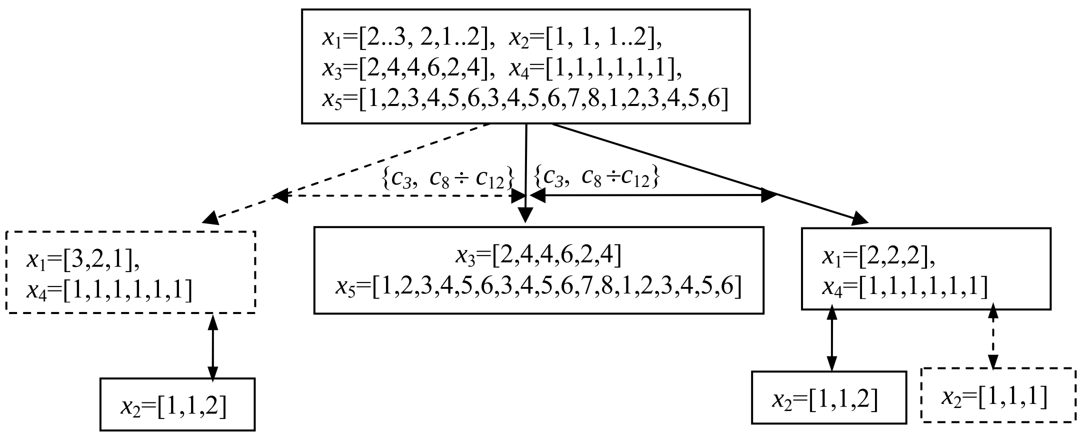
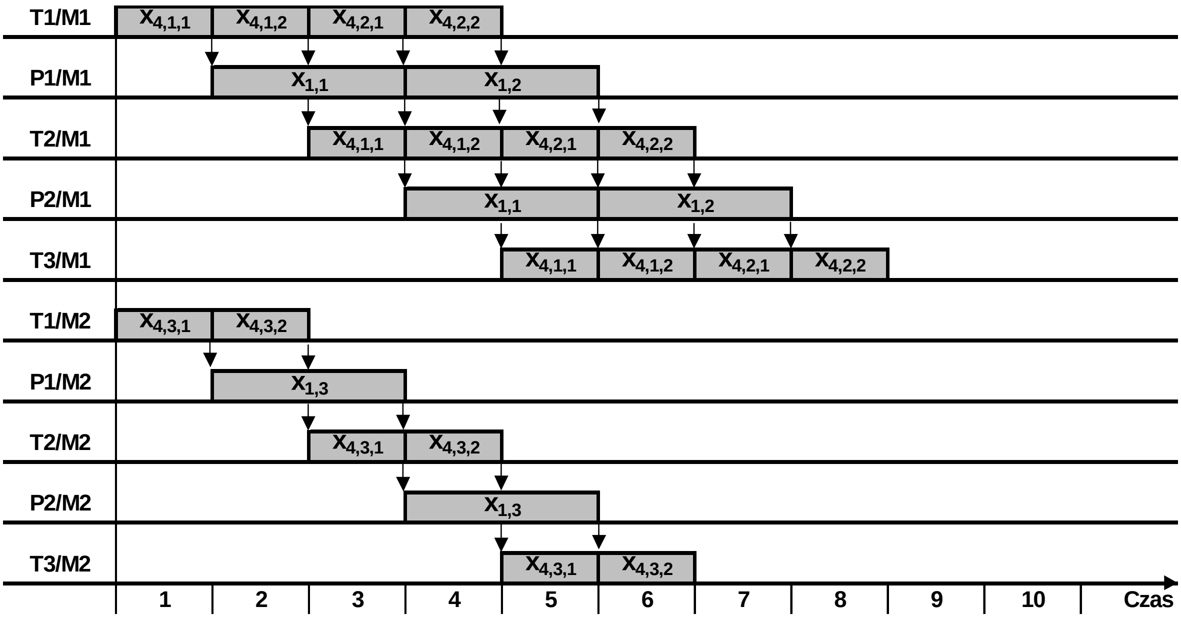


Fig 7. Examples of solution due to strategy from fig. 6 a). Dashed lines – inadmissible solution

For presented instance, strategy shown on fig 6a is better. The results are a consequence of sequence of elementary subproblems consideration. The strategy from fig 6a is characterized (in contradistinction to strategy on fig.6 b) by subproblems solving from least complicated to most. As a result of it, the potential return number is limited. Fig. 7 illustrate solution searching based on strategy from fig. 6 a.

Obtained solution satisfy flow production presented on Gantt chart – fig. 8.



Legend: T_i/M_j – *i*-th transport operation in *j*-th routing; P_i/M_j – *i*-th production operation in *j*-th routing; $x_{1,i}$ – *i*-th batch production; $x_{4,i,j}$ – *j*-th batch transport of *i*-th batch production

Fig 8. Admissible solutions of production flow in Gantt chart

5. CONCLUDING REMARKS

The presented reference model allows to make analyses of admissible searching strategies to solve problems of flow production planning (fig. 4a).

It's possible to estimate the number of decision variables domains values substitution. The influence of data structure, sequence of elementary subproblems solution and domain size on decision making time is also convenient (appoint the solution– table 1).

Possibilities of verifying the effectiveness of traditional approach to problems concerning the flow production planning arise. Strategy presented in fig 4a belongs to the traditional strategy which separates manufacturing problems from transport. On the other hand, the strategy presented on fig 4 b) belongs to that strategy in which some elementary problems with transport are connected to some elementary manufacturing problems. Such solution has the effect of increasing efficiency (for certain domain sizes).

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