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PROJECT-DRIVEN DECISION SUPPORT: A CLP APPROACH

Abstract: *The paper provides a presentation of a method of balancing the requirements of work orders with given production abilities of a company in a given planning horizon The proposed approach has been illustrated on a sample order including the executing of a* batch of external lever. The ILOG OPL Studio 3.6 software was applied. It allows *for an effective management of a restricted in time access to the resources.*

1. INTRODUCTION

Production adapted to the demands of the customer became a common tendency of the modern market. The ability to evaluate the market demand quickly and to react properly to the demands is one of the conditions for maintaining a position in market and for development of an organization.

The changeable environment which companies work in imposes the necessity of making fast, usually highly risky decisions for taking a new work order. The decisions, related with balancing the needs of the customer and the possibilities of the producer, require taking into consideration lots of factors of a different kind and character, related among others with different technical parameters of a product, production capacity, cost, realization time of specific operations and constraints resulting from the specifics of an order (e.g. volume of the order, time and cost of execution).

In a situation when a company executes its basic production, it is difficult to evaluate the possibility of execution of new work orders, i.e. balancing in any moment the time, required production capacity (related with the execution of the order) in relation with the accessible resources [2]. In work order to evaluate the effect of increasing the burden of resources or the possible time of deliveries with the use of the currently accessible production capacities, it is necessary to answer the question: does a feasible schedule which would meet the resource and logistic constraints exist?

The paper discusses the problem of evaluating the possibility of a timely - not delayed planned cost level realization of a work order based on a limited scope of resources. Its solution requires specifying conditions which guarantee the realization of work orders within the scope of existing resource- time- and price constraints. The analysed conditions include classes of conditions determining: the flows of production batches and transport batches.

ILOG OPL Studio 3.6 [6] was used to solve the problem.

2. STATEMENT OF THE PROBLEM

Given a SMS production enterprise which disposes of free production capacities in a given scope of time. There are known periods of accessibility of the capacities and the cost of their use.

There is a set of work orders determined by price, realization time and volume. Every work order is specified by an acyclic network of activities where the graph nodes refer to the operations of the work order and the arcs represent the sequence of executing operations on specific production positions. The time of preparation and finishing of specific pieces of equipment are constituent items of the duration of an operation. The time of check up and complementing the material reserves has been included in the first operation in the production process of a given product. It is assumed that the sequence of operations results from the adopted variant of technological sequence. Each operation may be executed by one of the system's resources. The operations are indivisible and a once assigned resource cannot be released. It is assumed that there are alternative resources i.e. resources which can be used alternatively at the realization of a given operation. The sequence, number and kind of operations are different for different work orders. It is assumed that a given operation cannot be started as long as all the operations which directly precede it are not finished [8]. The sequence of realization of operations in a company is determined by technological and organizational reasons. Technological operations are preceded by transportation operations. The time of transportation and technological operations is represented by natural numbers. The transportation operations are executed by means of carriage cars along specified transportation routes.

The problem leads to choosing those of the awaiting work orders which can be executed simultaneously in the system without disrupting the currently executed production process. What is therefore sought is such a variant of executing a given work order i.e. schedule of work, which is in accordance with the customer's requirements and technical-organizational possibilities of a given production system.

2.1. Mathematical model of producer-consumer

The following notation is used:

$z = 1,\dots,n$ - production resources,

t_z - periods of availability of a z resource in a time unit t,

$K_{z,t}$ - cost of using a resource z in a time unit t,

t – time unit, $t \in N$,

j= 1,...,m – number of a given operation,

$T_{J,z}$ - time of executing a given J operation on resource z,

T_B - directive deadline for the realization of order B,

$J_{t,z}$ - allocation of operation J to the resource in a given time unit t,

T_k - planned deadline for the realization of order B,

W_w = 1....w - means of transport t,

K - planned cost of realization of the order,

T_p - time of starting the realization of the order,

t_{kJ} - time of finishing the operation J,

t_{pJ} - time of starting the operation J.

1) Resource availability:

Table 1. Resource availability

resources																	
Z_1	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	K					$K_{z,t}$
Z_2					$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$			$K_{z,t}$	$K_{z,t}$	$K_{z,t}$				$K_{z,t}$
⋮																	
Z_n		$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$	$K_{z,t}$					$K_{z,t}$
	1	2	3	4	5	6	7	8	9	10	11	12	13	...	...	...	T_k
	Planning horizon																

Resource available

Resource not available

2) Transportation means:

Table 2. Means of transport

Means of transport	**An example of route**	**Transportation time [time units]**
W_1	$Z_1 - Z_2$, $Z_2 - Z_5$ Z_2 - Z_4	1
⋮	⋮	⋮
W_w	$Z_5 - Z_3$, $Z_1 - Z_3$	1

Table 3. Means of transport availability

W_1			Z_1-Z_2	Z_2-Z_5	Z_2-Z_4	Z_2-Z_5	Z_2-Z_4	Z_1-Z_2	Z_2-Z_5	Z_2-Z_4				Z_1-Z_2
⋮														
W_w	Z_5-Z_3	Z_1-Z_3	Z_5-Z_3	Z_1-Z_3		Z_5-Z_3	Z_1-Z_3	Z_5-Z_3	Z_1-Z_3	Z_5-Z_3				Z_5-Z_3
	1	2	3	4	5	6	7	8	9	10	...	...	...	T_k
	Planning horizon													

Not available means of transport

Available means of transport

Work orders specification (time, cost, volume):

T_B - directive deadline for the realization of order B,

K - planned cost of realization of the order,

W_o - volume of work order .

Production flow constrains:

1) Every operation must be executed by one of the system's resources:

$$J_{t,z} = \begin{cases} 1 - \text{if operation J is allocated to the resource z in a time unit.} \\ 0 \text{ - in other case} \end{cases}$$

$$\underset{t,z \in N}{\forall} \sum_{J=1}^{m} J_{t,z} \leq 1 \qquad (1)$$

2) The operations can not be preempted:

$$T_{J,z} = t_{k,J} - t_{p,J} \qquad (2)$$

3) Once chosen resource cannot be changed:

$$\underset{j \in (1,m)}{\forall} \sum_{z=1}^{n} \sum_{t=t_{p,J}}^{T_B} J_{t,z} = T_{j,z} \qquad (3)$$

4) The production capacities cannot be exceeded:

$$\sum_{t=t_{p,j}}^{T_B} t_z \geq T_{j,z} \qquad (4)$$

Sufficient conditions resulting from the specifics of a given work order:

1) The condition of meeting the execution deadline of the work order B

$$T_k = \sum_{j=1}^{m} (t_{p,j} - t_{k,j-1}) + \sum_{z=1}^{n} \sum_{j=1}^{m} T_{j,z} \leq T_B \qquad (5)$$

2) The condition of meeting the cost of execution of the work order B

$$\sum_{j=1}^{m} \sum_{z=1}^{n} \sum_{T_p}^{T_k} K_{z,t} \cdot J_{t,z} \leq K \qquad (6)$$

3. ILLUSTRATIVE EXAMPLE

Given is a production order for execution of 100 external circuit levers, which are parts of a lift control system. The order was submitted for a non standard product i.e. not executed within the scope of basic production of a company. The execution time of the work order specified by the customer is 7 working days. The price, which can be paid for the execution of 1 piece of the lever, is 35 PLN. The lever of the external circuit consists of 3 items: lever, external pipe, handle.

The example of executing the external circuit lever has been presented in two stages. The first stage concentrated on the available production capacities (working positions). The second stage took into account the transportation operations, specified the constraints of availability of the means of transport, duration times of the specific transportation operations. The company realizes the basic production plan [6]. It disposes of not fully used production capacities which can be used for following work orders. The remaining production capacities are reserved for processes realized within the system. It is necessary to balance necessary production capacities for the realization of a given work order with the disposed production resources necessary for its realization. It is assumed that there are known periods in which the specific resources remain free. Table 4 presents the disposed production capacities of chosen resources of a given company. The dark fields indicate periods of accessibility of a given resource, whereas values specify the cost of using the resource in a given time unit.

Table 4. Part of the state of load of the production resources

R1	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
R2	0	1,05	1,05	1,05	1,05	1,05	1,05	0	0	0	0	0	1,05	1,05	1,05	1,05	1,05	1,05
R3	0	0	0	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
R4	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R5	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0	0,86	0,86	0,86	0,86	0,86
R6	0	0	0	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R7	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	0	0	0	1,05	1,05
R8	0	0	0	0	0	0,75	0,75	0	0,75	0	0	0	0,75	0,75	0,75	0,75	0,75	0,75
R9	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R10	0,86	0,86	0	0	0	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R11	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R12	0	0	0	0	0,75	0,75	0,75	0,75	0	0	0,75	0,75	0,75	0	0	0,75	0,75	0,75
R13	0,86	0,86	0,86	0,86	0,86	0	0	0,86	0	0	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86
R14	0	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0	0	0	0	0,85	0,85
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Planning horizon																	

The work order has been treated as a non-standard product, i.e. not produced within the basic production scope of a company. Due to its uniqueness and a lack of a routine schedule of decision making it may be treated as a project. The time of execution of a batch is calculated in the following way: $t_{pz}+\Sigma(t_j * 100)$.

Table 5 presents the following operations and the times of their execution necessary for the production of 100 pcs of the external circuit levers. The chart presents accessible resources of a production system. There are the following means of transport accessible in the resources of the production system - T_1, T_2, T_3. Table 5 takes into account the duration times of transport between the operations. It was assumed that the volume capacities of the available means of transport and warehouses are unlimited.

A question appears: has the company got sufficient production capacities for the timely execution of the work order?

To solve the presented problem constraint logic programming (CLP) techniques have been used in a work order.

The advantage of the CLP approach is the possibility of a direct declaration of logic conditions in the source code of the programme. There is no need for presenting such conditions by means of binary variables which constitute a source of calculation difficulties in the tasks of mathematical programming. It allows to find a feasible solution in a short time and set out spaces of acceptable solutions which can be searched through by means of mathematical programming.

Table 5. Specification of operations and their durations

Operation	Operation code	Department	Operation time	Preceding operation	Resources
Construction design of the product and preparation of drawings, control and complementing of materials reserves	A1	700	960	-	R1- design position
Execution of the external pipe	A2	403	902	A1	R2- position for the execution of external pipe
Control	A3	401	8	A2	R3- control position no 1
Transport operation	A4	T	7	A3	R4- carriage car
Execution of the lever	A5	403	251	A1	R7- position for the execution of the lever
Control	A6	401	11	A5	R8- control position no 2
Transport operation	A7	T	6	A6	R5- carriage car
Execution of a handle	A8	403	286	A1	R9- Position of the execution of a handle
Control	A9	401	7	A8	R8- control position no 2
Transport operation	A10	T	5	A9	R6- carriage car
Welding	A11	401	82	A4, A7, A10	R10- welding machine
Transport operation	A12	T	7	A11	R5- carriage car
Milling	A13		65	A12	R11- milling machine
Transport operation	A14	T	6	A13	R5- carriage car
Hand treatment	A15	401	95	A14	R12- hand treatment position
Transport operation	A16	T	4	A15	R6- carriage car
Control	A17	401	15	A16	R3- control position no
Transport operation	A18	T	8	A17	R6- carriage car
Assembly	A19	402	50	A18	R13- assembly position
Transport operation	A20	T	12	A19	R4- carriage car
Location in the warehouse	A21	703	45	A20	R14- warehouse

Methods of mathematical programming may make use of constraint programming whereas constraint programming may use the criterion function as one of the constraints. The discussed approaches are in a sense complementary and may be applied interchangeably or alternatively, depending on the specifics of tasks and the complexity of the decision problem. The analysis of the considered problem uses the constraint logic programming with the criterion function *minimize* (minimization of the time of execution of an order) considered as one of the constraints.

The CLP approach is sufficient for modelling and solving planning problems and for scheduling projects. In the planning of the production flow there are frequently problems related with balancing of work orders and the availability resources. Decision support packages in decision making balance resources for certain (long) planning horizons. The accessibility of resources is not checked in any moment of the considered horizon but the established balance is accumulated. CLP allows implementing the considered the problem in the software package. The package can be used for balancing of work orders with the resources capacities in any chosen moment. CLP may be used for setting acceptable and optimum solutions (if they exist). It allows to set a space of allowable solutions which is then searched by means of mathematical programming methods. It is significant to narrow the space by means of eliminating items which do not meet the set constraints.

The analysis of possible realization of a work given order applied the software ILOG OPL Studio 3.6 (using the techniques of mathematical programming methods and constraint programming methods) allowing the user formulate the problem in OPL (Optimization Programming Language) [7].

What is sought is the allowable schedule of execution of a given work order which meets resource conditions of a potential production enterprise and the condition of time and price realization of a work order.

The data specifying durations of operations and resources necessary for their execution were entered in the ILOG OPL Studio 3.6. A directive time deadline for the execution of 100 external circuit levers was entered by means of the function „maxDuration". In work order to define production resources and specifying the variants of resources allocation the *„res"* procedure was applied, whereas the *„precedences"* procedure was used to enter the relations of work order operation sequence. The periods of inaccessibility (periods of being occupied) of a resource were defined in the programme. The procedure *„breaks"* was used to enter the values.

According to the allocated set of resources (taking into account their time accessibility) a schedule of realization of a work order was obtained - it is presented in fig. 1. It takes into account technical – organizational requirements and available production capacities.

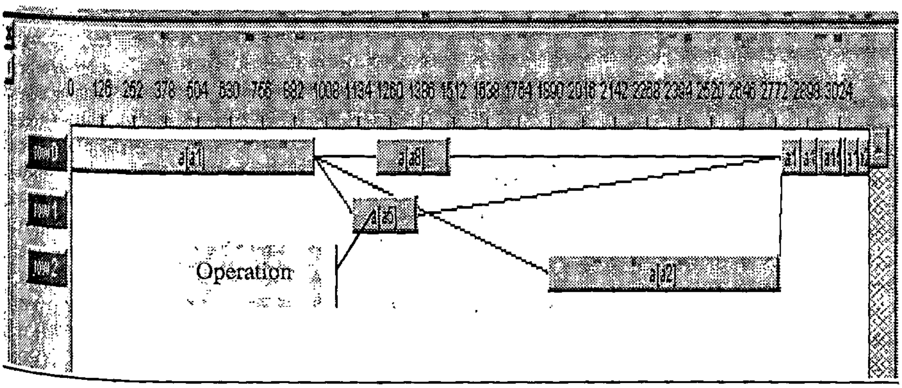

Fig. 1. Schedule of order realization specified in the software ILOG Solver 3.6

In the example, the time of execution of the 100 external circuit levers is 3141 minutes. The cost of execution of the work order is 2493 PLN. The obtained schedule of work order realization does not include transportation operations.

In the following stage it is necessary to answer the following question: can the accessible transportation resources guarantee a timely realization of an work order? It is assumed that there is a collection of means of transport, topology of routes and the duration of the transportation operations. Table 5 presents feasible routes of the means of transport and the transportation time between subsequent production positions. Accessibility constraints of transport resources have been defined. The remaining values in the programme were left unchanged.

As a result of introducing transportation operations a new schedule of realization of a work order has been obtained in the package. The analysis shows that the disposed production capacities are sufficient for the timely realization of the work order. It is therefore necessary to check whether cost constrains allow to execute the work order. The total cost of work order realization should be checked. It should include the cost of resources used in the production.
The cost of production of the specific departments has been presented in table 6.

Table 6. Listing of cost

Department	Operations	PLN/hour gross
401	Mechanical treatment	63
403	Thermo chemical treatment	52
402	Assembly	38
520	Cutting	45
501	Blacking	37
700	Construction design of a product and preparation of design	32
720	Pouring the handle with plastic (in cooperation)	51
703	Storage	26
T	Transport operation	18

Maximum purchase price of the external circuit lever specified by the customer is 35 PLN/ piece. The cost of execution of 100 levers has been calculated according to the values presented in fig. 2. The given values include department and general company cost. The department cost includes among others: depreciation, gas, oil, lubricants, technological materials, stationary, waste, electricity, heating, water, salaries, and tools.

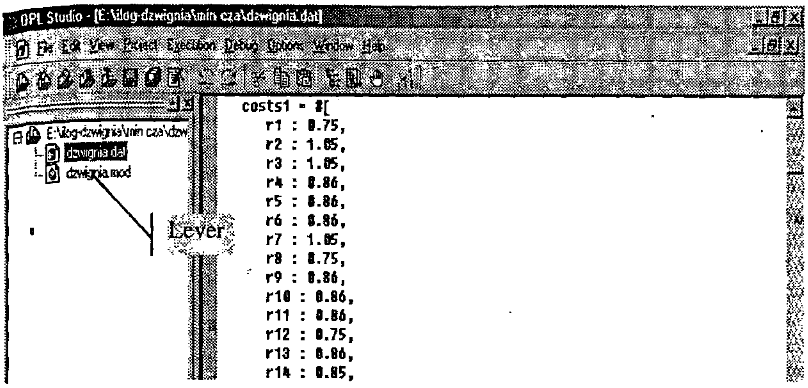

Fig. 2. Window for entering the cost of using specific resources

The cost of material for the execution of specific parts is (100 pieces) is 607 PLN :

- lever (2,23 PLN*100),
- handle (1,36 PLN*100),
- external pipe (2, 48 PLN*100).

Cost of execution of 100 pieces of lever, obtained in the programme is 2509,7 PLN. The maximum purchase price specified by the customer is 35 PLN per piece, the cost condition for the realization of the work order is therefore satisfied. Taking into account the conditions imposed by the customer it is possible to state that the production capacities of the company allow for a timely and not exceeding the planned cost execution of a work order.

The paper presents an approach which supports decision making for taking or rejecting a work order in a situation of not fully occupied production capacities of a company. The proposed approach is one of the possible exaples of solving the presented problem.

An alternative approach has been proposed in the paper [4]. The method based on the branch and bound scheme and on the critical path (CPM) method. The searching procedure is driven by an upper bound evaluation policy. The heuristic rule applied are treated as a set of sufficient conditions. If they hold for the given work order and manufacturing system specifications then there exists a feasible work order schedule. The method is computational efficiency and allows to find a feasible solution in short time.

The proposed solutions enable making fast decisions (in an on-line mode), in situations when the available software packages require a direct interference of the operator (at every stage of the planning process), or are too expensive or require a highly qualified operator.

The available packages such as: MS Project, Project Scheduler, ProAlpha 4.1d. are insufficient for solving the problem. The packages do not allow for generating a solution in every moment of the considered time horizon. The user has no possibility to choose a search strategy for the spaces of potential solutions. A strategy of search which is proper for the given problem allows for generating a solution in a very short time and the solution does not always meet the set restrictions. The analysed case applies strategy Depth First Search, which allowed to generate the solution in the on line mode (i.e. 0,3 sec).

Studying the process of decision making it can be noted that in the choice of decision the decision maker uses not one but several criteria at the same time. For example he/she aims at creating production plans which are characterised by a minimum cost and shortest possible execution time.

Commercial packages do not facilitate solving the problem of optimisation and do not take into account the alternative character of resources.

Unlike systems such as: MS Project, Project Scheduler, ProAlpha 4.1d, the Ilog enables to find an optimum solution. However the programme does not allow for a multicriterion optimisation. It does not enable an analysis of several criteria simultaneously (e.g. time and cost).

The proposed approach does not take into account alternative resources. In general case an introduction of modal resources may influence prolonged time of search for an acceptable solution.

4. SUMMARY

Due to the prevailing unique character of work orders in small and medium size enterprises it is necessary to be able to evaluate quickly and precisely the possibility of balancing production capacity of a company with the requirements set in an agreement with the employer.

In the paper has been presented a supportive approach in decision making for taking or rejecting a production order in a situation of not fully used capacities of a company. The main issue is balancing the needs related with the realization of the work order with the production capacities of an enterprise.

Accessible decision making support tools allow scheduling realization of a project when the volume of resources availabilities are known in the considered planning horizon. The software tools are not able to cope with the resource time-availability constraints assumed. [6]. This means that the obtained solutions refer to average in a given time horizon balance of resources. They therefore do not guarantee that in every moment of the realization of a project the balance is maintained i.e. the amount of resources necessary for its execution will be sufficient.

The presented problem has been analysed with the use of the software package ILOG OPL Studio 3.6. in trial version which works on the basis of propagation of constraints and distribution of variables. The applied programme facilitates automatic, i.e. not requiring an intervention of an operator solutions, both allowable and/or optimum. ILOG OPL Studio 3.6 trial version is a fully accessible and free package which gives a possibility of using the programme by small and medium size enterprises, without the necessity to cover additional financial expenses related with a purchase of integrated computer systems.

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