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CAPACITY PLANNING IN OPERATIONS PRODUCING HEAVY PLATE CUT SHAPES

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The present approach to capacity planning in operations producing heavy metal shapes causes problems in fulfilling the required financial and volume indexes in production, as well as in meeting the work order completion dates. The article represents the methodology for optimal production scheduling in operations producing heavy plate cut shapes, which significantly eliminates the above-mentioned problems. The methodology is based on the application Generalized Assignment Problem (GAP).

Key words: capacity planning, production of heavy plate cut shapes, production scheduling, optimization, Generalized Assignment Problem (GAP)

Planiranje kapaciteta kod rezanja teških limova. Postojeći pristup planiranju kapaciteta u proizvodnji metalnih proizvoda od limova uzrokuje probleme kod ispunjavanja zahtjeva financijskih indeksa, razine produktivnosti te kompletiranja isporuke u danim rokovima. Članak daje metodologiju za optimiziranje terminiranja proizvodnje kod rezanja limova, koja značajno eliminira naprijed navedene probleme. Metodologija je temeljena na primjeni Općeg problema pridruživanja (OPP).

Ključne riječi: planiranje kapaciteta, proizvodnja rezanja teških limova, terminiranje proizvodnje, optimizacija, Opći problem pridruživanja (OPP)

INTRODUCTION

A wide product range is typical for operations producing cut shapes from heavy plates. The production capacity of these operations depends on the producing ability of the basic technological machines, which are the flame-cutting machines. The product range of the flame-cutting machines is primarily stated by a combination of the sizes and shapes of the cut shapes, which represent as many as numerous thousands of product items. Based on the product range, the producing ability of the single flame-cutting machines may, however, move within a very large range. The lower limit of this range is close to only few kilos per hour, whereas the upper limit normally achieves several tons per hour. Processing of various product ranges thus significantly affects the production capacity of the operation.

Capacity planning under these conditions is very difficult. Based on authors' detailed survey of available professional publications it is possible to state that there has not been proposed any comprehensive methodology of capacity planning for operations producing cut shapes from heavy plates so far. With regard to the specific characteristics of the monitored work places no so far known solutions from other production areas can be applied here.

The present approach to the capacity planning, applied in the mentioned operations, is based on very rough heuristics. Therefore, situations when the production either does not fill the production capacity or makes it impossible to reach the required amount within the usable production time are very often. Due to this fact, the required financial and volume indexes are not achieved in the production, and as a result the work order completion dates are not fulfilled too.

The objective of the authors' research is to find such methodology in the area of capacity planning in operations for the production of cut shapes from heavy plates which would enable optimizing the schedule of work orders for single flame-cutting machines and eliminating the above-defined problems.

EXPERIMENTAL WORK

Generalized Assignment Problem (GAP) was chosen as the basic approach to optimize the work orders' schedule for single flame-cutting machine. The GAP was introduced by Ross and Soland [1]. Ferland has presented a general overview and discussion of assignment type problems and their generalizations [2].

The aim of GAP is to find the optimal assignment of *n* jobs into *m* agents where each of them are with a fixed capacity availability. Each job must be assigned exactly to one agent. The capacity of each agent has an up limit,

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which must not be exceeded. More than one job may be assigned to an agent. It is assumed that the capacity requirements of any job are known and that they depend on the agent the job is assigned to. In addition, it is assumed that the profit from assigning a job to an agent is also known and it is required that the total profit from assigning the n jobs is to be maximized.

As a consequence of practical capacity-cost relationships, the profit from a job-agent assignment would be expected to be increased if the corresponding capacity utilization is increased in practical instances of the problem [4].

Many applications of the GAP appear within the scheduling problems [5]. However, in the frame of the application GAP the following problems had to be particularly solved in the area of capacity planning in operations for the production of cut shapes from heavy plates:

- It has to be possible to assign work orders to several flame-cutting machines simultaneously what enables to speed up the time of their processing significantly. Therefore, the constraints ensuring that each job is assigned exactly to one agent must be changed.
- In practice, the volume of production (in tons) is used as an optimization criterion but it does not ensure maximization of the economic effect as for the reached capacity plan. Therefore, an economic criterion was proposed as the contribution to the settlement.
- The GAP does not take into account a fulfillment of completion dates, i.e. the sequence of single work orders on the given flame-cutting machine. Therefore, the proposed methodology has been extended by the technique of planning by means of buffers defined by Goldratt in his Theory of Constraints [6].

RESEARCH RESULTS

The methodology frame of the capacity planning in operations for the production of cut shapes from heavy plates is the first result of authors' research work:

If the operation has m flame-cutting machines with various technical parameters or various cutting technologies, we can recommend the following methodology for compiling an optimum capacity schedule:

1. Compile a set of n work orders; the required completion date which is within the given planning period, and the weight is given, i.e. we know the weight of the i-th work order planned to be completed in the given planning period m_{zi} (t). The completion date is derived from the supplying date by deduction, i.e. the supplying buffer. The supplying buffer determines such timing in advance which should sufficiently protect the supplying date against any eventual delay in production. When determining the above-mentioned supplying buffer, it is always required to consider the costs of the buffer maintenance and the eventual consequences of the "buffer over-utilization". Within the work, it is suitable to express the size of the buffers in a certain number of days.
2. Sort the obtained files by the required production completion date in ascending work order.
3. Determine the j-th flame-cutting machines which are able to process the required work order ($j = 1, 2, \dots m$). The reasons for the non-completion of the given work order on a flame-cutting machine may, for instance, include cut shapes with a size and/or length exceeding the usable surface of the cutting table or cut shapes with a thickness that cannot be processed by the stated cutting technology.
4. Determine the processing time of the i-th work order on the j-th flame-cutting machine related to a ton of product t_{ij} (min/ t). If the work order can be implemented on the flame-cutting machine, the processing time of the i-th work order is calculated from the producing ability of the j-th flame-cutting machine P_{ij} (t /h):

   $$t_{ij} = \frac{60}{P_{ij}}, \quad \text{(min/t)} \tag{1}$$

   $i = 1, 2, \dots n$
   $j = 1, 2, \dots m.$
   For determining P_{ij}, we can recommend a procedure for analyzing floating bottlenecks in metallurgical production [7].
5. Determine the usable time of the j-th flame-cutting machine C_{tj}:

   $$C_{tj} = C_{nj}\left(1 - \frac{b_j}{100}\right)k_s \quad \text{(min)} \tag{2}$$

   C_{nj} – nominal time of the j-th machine (min), i.e. calendar time C_k (min) reduced by the amount of time resulting from breaks by virtue of nonworking days
   b_j – time of planned downtimes of the j-th machine in % of nominal time
   k_s – shift working coefficient
   $j = 1, 2, \dots m.$
6. Define the criteria for optimizing the schedule of work orders for flame-cutting machines in the planned period. In the work, this mainly includes the maximization of the economic result of the completed production measured by the operation margin to the settlement of i-th work order c_i:

   $$c_i = p_i - v_i, \quad (€\,/\text{t}) \tag{3}$$

   p_i – price of the i-th work order (€)
   v_i – costs of the i-th work order (€)
   $i = 1, 2, \dots n.$
7. Compile an analytical model of the scheduling task, i.e. determine the basic variable of the model, the set of constraints and the objective functions:
   – basic model variable - volume of the i-th work order assigned to the j-th flame-cutting machine x_{ij} (t),

– constraint by the usable time of the flame-cutting machines – the total time consumed for the production of single work orders on the *j*-th flame-cutting machine must not exceed its usable time C_{tj}:

$$\sum_{i=1}^{n} t_{ij} x_{ij} \le C_{tj}\,, \quad \text{(min)} \tag{4}$$

$j = 1, 2, \dots m$

– constraint by work order weight – the sum of the partial weights of the *i*-th work order assigned to the single flame-cutting machines must not exceed the total work order weight m_{zi}:

$$\sum_{j=1}^{m} x_{ij} \le m_{zi}\,, \text{ (t)} \tag{5}$$

$i = 1, 2, \dots n$

– conditions for non-negativity:

$$x_{ij} \ge 0, \tag{6}$$

– the objective function for cases is the criterion for optimization of the total profit maximization:

$$\max \sum_{i=1}^{n} \sum_{j=1}^{m} c_i x_{ij}\,, \text{ (€)} \tag{7}$$

8. Optimize the compiled model – the output of the model solution is a schedule of the work orders for the single flame-cutting machines optimized according to the selected criterion, including the sequence and time for processing on the related machines t_{zij} (processing time of the *i*-th work order on the *j*-th flame-cutting machine in min).
9. Compile the time schedule for work using the flame-cutting machines based on the output of the model solution and verify the fulfilment of the supplying dates (not exceeding the supplying buffer).
10. Carry out the capacity balancing in the case that the requirements of the production capacity – given by the volume of work orders with the required completion date in the given planning period – are not compliant with the available operational capacity.

CONCLUSION

The proposed methodology frame is the base for creating of a comprehensive methodology of the capacity planning in operations for the production of cut shapes from heavy plates. In the consequential scientific work the following areas will be examined in particular:

- The analytical model for work order assignment to flame-cutting machines can be considered as NP-Hard. There is no polynomial time algorithm which finds a feasible solution. The known exact solution approaches can solve only small-size task. To overcome the limitation of exact methods, a new heuristic or metaheuristic algorithm will have to be proposed.
- Heuristic algorithms for determining flame-cutting machine producing ability will be created.
- The analytical model does not consider business priorities (completion of work orders for strategic customers). The set of constraints is assumed for further modification.
- The methodology frame is fully deterministic. The next step will bring creation of its stochastic version.

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List of symbols

m – Number of flame-cutting machines
n – Number of production work orders
m_{zi} – Weight of the *i*-th work order (t)
t_{ij} – Processing time of the *i*-th work order on the *j*-th flame-cutting machine related to a ton of product (min / t)
P_{ij} – Producing ability of the *j*-th flame-cutting machine (t/h)
C_{tj} – Usable time of the *j*-th flame-cutting machine (min)
C_{nj} – Nominal time of the *j*-th machine (min)
C_k – Calendar time (min)
b_j – Time of planned downtimes of the *j*-th machine in % of nominal time
k_s – Shift working coefficient
c_i – Operational margin of *i*-th work order (€/t)
p_i – Price of the *i*-th work order (€)
v_i – Costs of the *i*-th work order (€)
x_{ij} – Weight of the *i*-th work order assigned to the *j*-th flame-cutting machine (t)
t_{zij} – Processing time of the *i*-th work order on the *j*-th flame-cutting machine (min)

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