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COMPUTER-AIDED PROCESS PLANNING FOR PRODUCT LAUNCHING IN MANUFACTURING BY THE AVAL METHOD

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Abstract: *Computer-aided process planning is mainly focusing on industrial processes and implies the use of computer technology in manufacturing of products. In the present social-economical context, one of the main components of the competitiveness refers to the time reduction of the preparatory and production launch stages. For this, simple tools such as computer algorithms for establishing the production launch succession can be used. This work, presents a computational algorithm that can easily established the launching into manufacturing sequence in case of several products that belongs to a certain order, based on the AVAL method, as well as a computer application that implements this algorithm. This algorithm is susceptible to industrial application due to its easy, efficient, and rapid utilization.*
Key words: *operational management, AVAL method, CAPP, launch in manufacturing, computer application.*

1. INTRODUCTION

The rapid development of science and technology requires organizations to be ready and able to stop production at any stage, at any time and without losses, and in a very short time, to launch and produce a batch of new products of any size [1].

In order to be able to adapt as quickly as possible to changing market conditions, i.e., to increase business performance, companies adopt new strategies and use new tools in their business planning, including production planning [2].

Thus, given the direct link between innovation and economic performance [3], companies are working hard to optimize their business processes so that very high-quality products can be brought to market as quickly and cheaply as possible [4].

The production planning activity includes interpretation of design data, selection and sequencing of manufacturing operations, selection of machines and tools, determination of work regime parameters, selection of clamping and machining devices and determination of manufacturing process duration and cost [5].

As a phase of planning activity, launching products into production in a very short time is an indispensable requirement for gaining a competitive advantage.

Manufacturing managers face the pressure of launching products into production in record time, due to factors such as accelerating technological development speed, more intense competition due to globalization, fragmentation of markets due to demographic changes, shortening product life cycles and recent not insignificant increases in production costs [6].

During the launching phase of products from an order, companies are under great pressure to deliver the required quantity of products, at an increased level of quality and exactly within the delivery time requested by the customer [7].

The goal of Computer-Aided Process Planning (CAPP) is to create a link between Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) to resolve potential process conflicts and ultimately automate processes.

In recent years, significant steps have been taken to integrate CAD and CAM into product life cycle management.

In this respect, both academia and industry have been looking at how the use of CAPP helps to reduce production planning effort.

Thus, when analyzed from a cost-benefit point of view, when using CAPP, a 58% reduction in production planning effort was estimated [4,5].

The first attempts to use CAPP in production planning were made in the 1970s [4]. Subsequently, the use of CAPP has gained momentum as more and more companies have turned to production planning automation to maintain and increase their competitiveness.

Furthermore, the need for CAPP is the trend towards increasing data management capability in terms of product life cycle and therefore reducing the time required to carry out complicated manufacturing process planning activities.

It is evident that the transition to digital technologies allows significant reduction in manufacturing time and cost, reduction in the number of errors in production planning, which includes the launch of manufacturing, reduction in the time of use of production techniques and a significant increase in the degree of flexibility of the company in the face of tough and often unfair competition [1].

Due to the difficulties faced by companies in this period, only a few of them have the resources and technological capacity to successfully launch a product order into manufacturing [8] in an extremely short time.

Regarding CAPP, there are to main approaches: i) Variant Process Planning (VPP) which refers to generating a new process plan by modifying and continuously adapting an already existing process plan, meeting the proposed objectives that are accordingly to the imposed requests for the launched product and ii) Generative Process Planning (GPP) which basis on algorithms to create a new process plan [4].

In the literature, there are mainly three strategies presented, additional to the strategies discussed earlier: Hybrid Process Planning (HPP) Artificial Intelligence (AI) and Object Oriented (OO). While HPP combines the benefits of both approaches, respectively VPP and GPP, type-AI process planning systems becomes more and more used due to the technology evolution [4].

Thus, Salehi et al. [5] proposed a GA that can obtain optimal/near-optimal solutions, requiring about 10-40s, depending on the number of operations and the number of generations. The genetic algorithm was based on several case studies that were run to sustain its feasibility and robustness.

Chiu et al. [6] proposed a model for evaluating the launch strategy of the new products based on hierarchical fuzzy multi-criteria decision-making (Fuzzy MCDM) method. This model was based on empirical case study to demonstrate its validity.

Meister et al. [7] proposed a model for systematic process solving problems (SPSP) in production launch considering a specific problem.

Moreover, Dobocan et al. [8] proposed an application of the optimal control problem, by considering mainly three objectives of a company: maximization of product image, actuating the launching time and planning the launching. The most important worth of this application is that helps companies to control their investments.

It can be concluded that many of the proposed models presented in the literature [9-14] solves particular cases and, very often, they do not have an increased level of generality.

For this reason, it is increasing the necessity of developing new software application that are used to solve real and actual problems of companies and. But, at the same time, this software application must present a higher level of generality.

Only in this way, the companies are tempted to use this software application and, with small adjustments that are specific to each company, the software application may be implemented.

The direct benefit of using a software application in process planning is the reduction of the preparation time for the launch in manufacturing stage and, further, the reduction of the manufacturing time itself.

This paper presents an algorithm that can easily determine the launching sequence of products in an order, regardless of their number.

The algorithm presented is based on the AVAL method and a computer application for its implementation was developed.

Due to its ease of use, as well as its efficiency, the algorithm is susceptible to industrial application, regardless of the specifics and production capacity of the enterprise.

Several case studies were analyzed to demonstrate the feasibility and robustness of the proposed algorithm, and one of these case studies is presented below.

2. PRESENTATION OF THE METHOD

The launch of products into manufacturing covers all the activities that are carried out for the purpose of preparing, multiplying, and distributing documents to trigger the execution of production tasks at the workplaces [15].

In practice, the AVAL method and the AMONTE method can be used to solve manufacturing release problems.

The AVAL method is the most used and involves going through an algorithm consisting of 4 steps:

In the *first step*, the first production launch of the product to be machined in the first operation on the machine with the shortest (fastest) release time is launched.

If there is more than one product in the same situation, priority will be given to the product with the earliest delivery date.

If even in this situation there are several products, the product with the highest production cost will be launched first.

In the *second step*, the machine release times are recalculated under the conditions of the first product launched into manufacturing using the equations (1) and (2).

For the first machine (the one performing the first machining operation)

$$\delta_{1j} = \delta_{0j} + t_{ij}, \qquad (1)$$

where δ_{1j} is the release time of the machine performing the first operation (new release time for the first machine), δ_{0j} - the release time of the machine performing the first operation before the launch into manufacturing of the first product and t_{ij} is the machining time of product j on machine i that performs the first operation. For other machines (performing next operations)

$$\delta_{ij} = \max\left(\delta_{j-1,i}; \delta_{j,i-1}\right) + t_{ij}, \qquad (2)$$

where: $\delta_{j-1,i}$ is the release time of the machine that performed the previous operation and $\delta_{j,i-1}$ is the releasing time of the machine before start of machining of the launched product.

In the *third step*, after recalculating the release time of the machine that performed the last machining operation, the time reserve for the manufacture of the launched product will be calculated with the equation

$$Rt_i = T_i - \delta m_i, \qquad (3)$$

where, T_i is the maximum delivery time of the product launched into manufacturing and δm_i is the release time of the machine that performed the last machining on the product for which the time reserve is calculated.

Finally, in the *fourth step*, considering the remaining products after the first is launched and the new machine release times, the algorithm is repeated, going through the first 3 steps, until the last product to be released is determined.

If a negative time reserve is recorded for a product, which means that the maximum delivery time cannot be met, step 1 is repeated, listing the products in ascending order of their time reserve, with steps 2 and 3 remaining unchanged. If even in this situation, the maximum delivery times cannot be met, the problem cannot be solved by the AVAL method, which is the major drawback of the method.

Situations in which, by applying this method, it was not possible to determine the launch sequence in manufacturing have not been reported in the literature. Most of the time, after reordering the products in ascending order of their manufacturing time reserve, it was possible to determine, by going through the whole algorithm again, the order of their release into manufacturing.

3. AVAL METHOD APPLICATION

For an easier understanding, the application of the algorithm is sampled by a case study. Thus, in an enterprise, on the basis of an order, 3 products will be processed on 5 machine tools.

Table 1

Case study data

Machine	Time to completion of previous orders [h]	Product 1		Product 2		Product 3	
		Order of operations	Processing time [h]	Order of operations	Processing time [h]	Order of operations	Processing time [h]
M_1	12	4	5	3	10	5	10
M_2	7	1	15	2	15	2	5
M_3	22	5	10	1	20	3	12
M_4	21	2	15	4	30	4	20
M_5	5	3	20	5	10	1	15
Total manufacturing time		-	65 h	-	85 h	-	62 h
Maximum delivery time		180 h		195 h		200 h	
Production cost [RON]		780		1,200		1,300	

Table 1 shows all the information on the completion times of other work on existing machines, the sequence of processing operations and their durations, the maximum delivery time, and the production cost of each product.

In table 1, data on the products to be processed are presented. The order in which each product is processed on the 5 machines is shown in the "Order of operations" column, and the processing time on each machine is shown separately in the "Processing time" column.

The order of launching the 3 products into manufacturing will be determined, and for each product launched, the release time of each machine will be recalculated after the machining of the product i.e., the column "Time to completion of previous orders" will be updated after each product is machined.

Initially, this column contains information about the time of release of machines after completion of parts machining from other previous orders.

Therefore, for each product, it is analyzed on which machine it is processed in the first operation. Thus, product 1 is processed in the first operation on machine M_2, product 2 on machine M_3 and product 3 on machine M_5.

Then, based on above-mentioned release times of the machines M_2, M_3 and M_5, it will be determined which product is launched into manufacturing at first.

If M_5 is released from previous orders after 5 h, M_2 after 7 h and M_3 after 22 h, then the product to be processed in the first operation on the machine with the shortest release time i.e., on the machine M_5, will be launched into manufacturing.

Thus, product 3 is the first to be launched into manufacturing.

For product 3, the machines release times are recalculated: *(i)* for the first machine (first operation on machine M_5), the new release time after processing product 3 is calculated by adding the machine release time until it completes processing a product from a previous order and the duration of processing product 3 on this machine i.e.,

$$\delta_{53} = 5+15 = 20 \text{ h} , \qquad (4)$$

and *(ii)* for next machines, the new release times are determined by adding to the duration of processing product 3 on this machine, the maximum of the machine's release time until it completes processing a product from a previous order and the new release time calculated for the machine on which the previous operation is performed.

Therefore, the second operation for product 3 is performed on M_2. The machine release time until it completes processing a product from a previous order is 7 h (see Table 1), and the new release time calculated for the machine on which the first operation (M_5) is performed is 20 h (see value of δ_{53}).

The maximum between these two times is 20 h, plus the processing time of product 3 on this machine i.e., 5 h. Thus, the new release time of machine M_2 is

$$\delta_{23} = \max(20, 7) + 5 = 25 \text{ h} \quad (5)$$

Next, the third operation for product 3 is performed on M_3.

The machine release time until it completes processing a product from a previous order is 22 h, and the new release time calculated for the machine on which the second operation (M_2) is performed is 25 h. The maximum between these two times is 25 h, plus the processing time of product 3 on this machine, i.e., 12 h.

Thus, the new release time of machine M_3 is

$$\delta_{33} = \max(25, 22) + 12 = 37 \text{ h}. \quad (6)$$

The fourth operation for product 3 is performed on the machine M_4. The machine release time until it completes processing a product from a previous order is 21 h, and the new release time calculated for the machine on which the third operation (M_3) is performed is 37 h. The maximum between these two times is 37 h, plus the processing time of product 3 on this machine, i.e., 20 h. Thus, the new release time of the machine M_4 is

$$\delta_{43} = \max(37, 21) + 20 = 57 \text{ h}. \quad (7)$$

Finally, the fifth operation for product 3 is performed on the machine M_1.

The machine release time until it completes processing a product from a previous order is 12 h, and the new release time calculated for the machine on which the fourth operation (M_4) is performed is 57 h. The maximum between these two times is 57 h, plus the processing time of product 3 on this machine, i.e., 10 h. Thus, the new release time of the M_4 machine is

$$\delta_{13} = \max(57;12) + 10 = 67 \text{ h}. \quad (8)$$

Then, the manufacturing time reserve of this product is calculated by subtracting from the delivery time of the product 3 the release time of the machine on which the last processing operation of this product is performed, i.e.,

$$R_1 = 200 - 67 = 133 \text{ h}. \quad (9)$$

Similarly, the manufacturing time reserve is calculated for the other two products.

Finally, it is found that the order in which the products are launched into manufacturing is: product 3, product 1, product 2.

This way of using the AVAL algorithm is time consuming and, in most cases, causes long delays in the production process.

Therefore, the solution proposed in this paper is to develop and use a computer application to determine the manufacturing launch sequence of the three products, the determination of the launching into manufacturing sequence being achieved in a very short time, in the order of seconds.

4. COMPUTER APPLICATION FOR THE AVAL METHOD IMPLEMENTATION

Given that in industrial practice there may be situations in which the order of launching into manufacturing has to be determined for a large number of products, each of which may require processing at several workstations, the application of the above-mentioned method by analytical calculations can become an extremely laborious activity.

In order to overcome this disadvantage, it was considered useful to develop a computer application, which would automatically solve the problem with a much-reduced time consumption.

The working algorithm of the computer application is presented below.

The Input data are:

- The number of products, *p;*
- The number of workstations (machines) required to manufacture the products, *m* - for

simplicity, in a first step this number was assumed to be the same for all products;

- The vector including workstation times $D = D(i)$, $i = 1, 2, \ldots m$;
- The matrix of the order of operations for all p products, $O = O(i, j)$, $i = 1, 2, \ldots m$, $j = 1, 2, \ldots p$;
- The matrix of processing times required at each workstation (machine), $T = T(i, j)$, $i = 1, 2, \ldots m$, $j = 1, 2, \ldots p$. It should be noticed that no account has been taken of the situation where for two products manufacturing could start on the same workstation.

The working steps are:

- Identify in each column of the matrix O (i.e., for each product) the index corresponding to the first operation to be performed, $i_{min}(j)$;
- Identify the column of matrix O (product) where, for the first operation, the waiting time until the release of the corresponding workstation is minimum - $D(i_{min}(j)) = \min$; the index of this column is denoted by j_{min};
- For column $O = O(i, j_{min})$ an auxiliary vector, $V = V(i)$, $i = 1, 2, \ldots m$, is constructed for which the components are the indexes of the work items (according to matrix O) in the order in which they are to be performed;
- Recalculate the values of the components of the vector D, taking into account the completion times for the product j_{min};
- The current position of a vector called *Launch* shall hold the value of index j_{min};
- The j_{min} column is removed from the O and T matrices;
- repeat the above steps until the matrix O becomes empty.

The *output data* are:

- The vector $Launch = Launch(j)$, $j = 1, 2, \ldots p$, which contains the product indexes in the order in which they are to be launched into manufacturing;
- The vector $D = D(i)$, $i = 1, 2, \ldots m$, the components of which denote, at this moment, the release times of the workstations, measured from the initial time to the completion of the last product.

The developed computer algorithm was implemented in the MatLab environment and is listed below:

```
jmin_old=100; z=1;
for q=1:p
for j=1:p
  for i=1:m
    if O(i,j)==1
      X(j)=D(i);
    end
  end
end
minx=min(X);
for i=1:m
  if D(i)==minx
    imin=i;
  end
end
V(1)=imin;
for j=1:p
  if O(imin,j)==1
    jmin=j;
  end
end
for k=2:m
    for i=1:m
      if O(i,jmin)==k
        V(k)=i;
      end
    end
end
D(V(1))=D(V(1))+T(imin,jmi
n);
for k=2:m
  D(V(k))=T(V(k),jmin)
  +max(D(V(k),D(V(k-1)));
end
if jmin<jmin_old
    Launch(q)=jmin;
else Launch(q)=jmin+z;
    z=z+1;
end
    O(:,jmin)=[];
    T(:,jmin)=[];
    X(p)=1000;
    jmin_old=jmin;
    p=p-1;
    end
```

5. CONCLUSION

The development of technology and the implementation of its solutions in the industry makes innovation meaningful. All major companies do their utmost to ensure the fastest possible production flow.

This means, first and foremost, a substantial reduction in manufacturing preparation time, including the manufacturing launch into manufacturing phase.

As conventional release methods are time-consuming, new tools have to be developed to organize production and determine the launch into manufacturing sequence of products.

The computer application developed in this study proposes a very fast, split-second way of determining the order in which products in an order are launched into manufacturing.

Using the AVAL method, which was the basis for the development of the computer application and considering the imposed delivery deadlines on the one hand and, the other production activities on the other hand, it was found that the order in which the products are to be released for production is product 3, product 1 and, finally, Product 2. As expected, this result is coincident to the one obtained in Section 3.

This model can very easily be extrapolated to the case of the full production volume of the production section of a large industrial enterprise.

By using the proposed computer application, manufacturing preparation time will be considerably reduced, and the company's production department will work without interruptions caused by the establishment of the launching into manufacturing of orders or products within an order.

The computer application has been developed to assist production planning in a company with a very high production volume.

Although the case exemplified in this paper comprises an order with 3 products to be machined on 5 machine tools, this computer application can be used to determine the sequence of launching into manufacturing of an infinitely large number of products, respectively machines.

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PLANIFICAREA PRODUCŢIEI ASISTATĂ DE CALCULATOR PENTRU LANSAREA ÎN FABRICAŢIE A PRODUSELOR PRIN METODA AVAL

Planificarea producţiei asistată de calculator se concentrează, în principal, pe procesele industriale și implică utilizarea tehnologiei computerizate în fabricarea produselor. În contextul socio-economic actual, una dintre componentele principale ale competitivității se referă la reducerea timpului etapelor pregătitoare şi de lansare în fabricaţie. Pentru aceasta, pot fi folosite instrumente simple precum algoritmii computerizaţi la stabilirea secvenţei de lansare în fabricaţie. Această lucrare prezintă un algoritm de calcul care poate stabili cu ușurință secvenţa de lansare în fabricaţie în cazul mai multor produse care aparţin unei anumite comenzi, având la bază metoda AVAL, precum și o aplicație informatică care implementează acest algoritm. Algoritmul este susceptibil de aplicare industrială datorită utilizării sale ușoare, eficiente și rapide.

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