Improving Production Flows by Integrating AOA Critical Networks

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Abstract

The main objective of the "AOA critical networks" concept in the manufacturing flow is to support companies that want to improve their processes so that they become more competitive by implementing various tools and techniques for continuous improvement.

At present, it is known that a high level of productivity can be obtained and maintained only by involving all the actors involved in the production process, and to optimize the production flow as a whole, action must be taken to increase flexibility, the means of production and therefore their reactivity. The AON critical networks method can be integrated in the analysis of production systems, especially regarding the optimization of production flows.

The main object of the research is the development of an adaptive production planning system that can optimize the flow of materials, which will lead to an optimal cost of the production project.

Key words: production project, material flow, production costs, AOA network
J.E.L. classification: M11, C20, D24

1. Introduction

The ability of business management to anticipate change in a digital environment and to adapt to new situations in a planned manner leads to the long-term profitability of the industrial enterprise.

The frame of reference, which integrates concepts of materials management, operational management of production, industrial optimization, as a whole, as a factor of synergy between the functions of the industrial enterprise, must be approached in a systemic vision. The objective of this framework is to make a precise transformation of the elements of the system, between which there are a number of causal or functional relationships and connections, so that, at the end of the industrial process, the input elements expressed in value are modified in an amplifying sense.

The systemic approach comprises a very large number of elements, linked together by direct and inverse relationships and connections that allow the scientific explanation of some very complex phenomena, which take place inside this system. In order to place, at least in part, the enterprise as a system, in this frame of reference, it is necessary to know the nature of these relationships, as well as some minimum information elements on how the system behaves at a given time. It can be said that the structure of the enterprise as a system is given by the number of elements that make up the system, the connections and the relationships between them that define the active structure of the system, i.e. those factors that determine the ability to transform input elements.

2. Theoretical background

The object of study of this adaptive system is the management of material flows and information in the production process. The notion of material flow is a distinct entity that is transformed in value amplifier based on an individual technological process from semi-finished product (raw material) to finished product.

The models used to optimize value added in the value chain, at the level of material flow, are based on the following concepts:

- value is added to the flow of materials, as a separate entity, because it is subject to the individual technological process of transformation from semi-finished product to finished product.
- the production costs incurred for the achievement of the added value increase in direct proportion to the added value in each stage of transformation of the material flow and represent about 80% of the cost of the finished product.

Thus, the physical transformation and, at the same time, the value amplification of the material flow determines the dual importance of its optimization within the production. The duality of optimization consists in the analysis of the transformation of the flow of materials from a technological - economic point of view at each level of transformation. A problem with the ordering of the production flow is the establishment of an order to carry out the operations of a production project, so that the interdependencies between them are respected both in terms of technological process, available resources and total execution time. minimizing it.

In order to allow a detailed analysis of the problem of ordering the production flow, a choice of the optimal execution variants and a continuous control of its evolution and added value, we must break down the production project into component parts (operations) at a level that to allow the unitary treatment of each part and the establishment of connections between them. The operation is a distinct part of a production project, a precisely determined sub-process that consumes time and resources.

Among the inter conditions (interdependencies) between activities, we are interested, in particular, the temporal ones, called precedence relations, which can be of three types:

➢ "Finish - start" type - this type is the most common and we say that activity A precedes activity B by an "end - start" interdependence if activity B can only begin after a time interval t_{AB} from the end of activity A.

➢ "Start - start" type - if activity B can only start after a time interval t_{AB} from the beginning of activity A.

➢ "Finish - finish" type - if activity B cannot be terminated until after a time interval t_{AB} from the termination of activity A.

Interdependence intervals can be equal to zero (activity A directly precedes activity B), positive (activity A precedes activity B late), negative (activity A precedes activity B in advance). The decision on the optimal duration of a material flow, as a whole, is taken at the level of production scheduling based on decisions from the level of production planning, according to the graphical networks of analysis AON, AOA.

3. Research methodology. AON-AOA constructions

From a given list of subordination relations (in the sense of hierarchy), at the level of a flow of materials in the sense of subordination relations (of hierarchy), two types of networks of the manufacturing project can be formed. One of them has a trivial construction - AON ("activity-on-node"), and the other non-trivial - AOA ("activity-on-arc").

The trivial construction is a graph that marks the requirements of subordination by identifying the activities in the circles or nodes of the graph while the arcs, by definition, represent graphically (by arrows) the technological succession. The limit between graphs and networks does not exist, because mainly in the literature specific to the programming of manufacturing projects, the second name - network is traditionally adopted. In the language of manufacturing project planning, these networks are "node activity" structures, abbreviated AON ("activity-on-node").

The non-trivial construction is more interesting and closer to optimal values referring to the AOA ("activity-on-arc") structures, here the activities being represented by springs while the nodes play their natural role of defining the points of divergence and convergence of springs.

The analysis performed in the construction of an AOA network for the manufacture of an industrial product presents the situation of the subordination requirements for the ten operations for the manufacture of an industrial product, given in the form of a list of dependencies (conditions) between the operations of the industrial product.

Table no. 1 Activity times

T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
–	T_1	$T_1T_5T_4$	–	T_4	T_4	$T_1T_2T_3T_5T_4$	T_4T_6	$T_5T_8T_6T_4$	$T_5T_8T_6T_4$

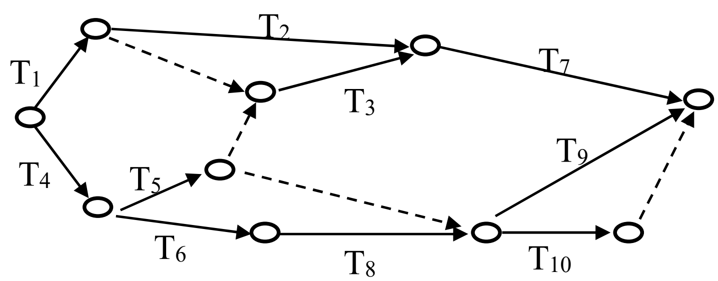
Source: own processing

The requirements that can be deduced through transitivity are introduced, that means, we show $T_4 \prec T_8$ and $T_6 \prec T_8$ when only the latter is needed because $T_4 \prec T_8$ is involved by $T_4 \prec T_6$ which was indicated earlier in the list.

The AOA network has introduced arcs (those with dashed lines) that do not represent actual activities but some fictitious ones (do not require time and resources), useful for the representation of subordination (Figure 1).

It is obvious that for a given AOA structure, the corresponding AON representation is formed by the line diagram of the AOA network.

Figure no. 1 AOA flow chart for industrial product manufacturing



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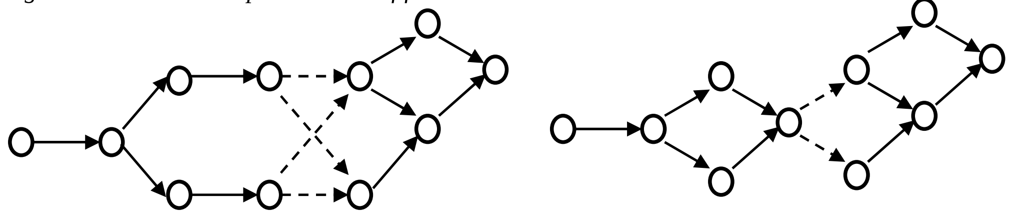
There are several ways to build a successful AOA network from a list of subordination requirements. This is due to the alternative possibilities of using the fictitious activity. In Figure 2 both networks show the same subordination structure but use a different number of fictitious activities. In this respect, a realistic hypothesis is to prefer a representation with minimal dimensions of the AOA network, important being the one that indicates a smaller number of fictive activities.

Figure no 2. Variants representation of fictive activities



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An efficient and general method of building AOA networks with minimal fictitious activities appears to be a difficult "hard N-P" problem. Because this problem is looking for a graph $G = (V, E)$, an existence decision of a subset $V' \subset V$ cu $V' \cap \{i, j\} \neq \emptyset$ for al the sides $\{i, j\}$ from E, and which has the upper bounded dimension of a certain input limit value k, the graphical mapping is done as follows: noting the G peaks with $v_1, v_2,..., v_n$ and the E sides with $e_1, e_2,..., e_m$, a set of activities is created $\{v_1, v_2,..., v_n, e_1, e_2,..., e_m, x\}$.

The relations of subordination are given by the pairs $\{(e_i, v_j) \mid e_i \textit{ is incident in } v_j \textit{ from } G\} \cup \{(e_i, x) \mid 1 \leq i \leq m\}$. Thus, G has an appropriate number of peaks only when the number of requirements of that AOA network does not exceed a number that represents $(2 \cdot |E| + k)$ fictive activities.

For the graph in Figure 3(a), the subset of vertices {v2, v4} is a coverage and is minimal in this regard Thus, as shown in Figure 3 (b), an appropriate AOA network can be drawn using a number of (3 $|E|$) fictive activities (a number of 2 $/E/$ of these are required in any construction).

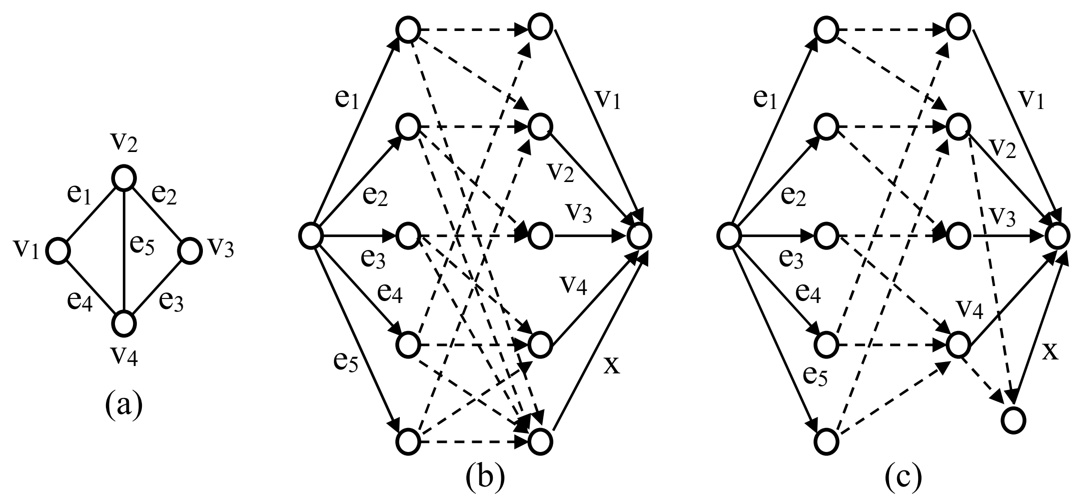
On the other hand, the structure in Figure 3 (c) uses only ($2/E/ + 2$) and, more importantly, any smaller number is invalidated, leading to a false subordination structure. It is obvious to identify the fictitious activities in the AOA network in figure 3 (c) with optimal assurance of the peak in G.

The complex state of the problem of minimizing fictitious activities attracts the usual interpretation that comes with the perspective of the most unfavorable case.

Thus, while there are very complicated examples of the problem, there are many others in which the number of fictitious activities is easily minimized or at least reduced to a number that is verified to complete the optimization.

In fact, it is very easy to formulate heuristic (methodological) rules for building AOA networks and with which relatively efficient structures are obtained.

Figure no.3 AOA chart with minimal fictive activities „hard N-P"



Source: own processing

3. Basic critical material flow scheduling

In the context of the AOA network, the activity is represented by the arc (i, j) and its duration with τ_{ij}. The problem in scheduling the flow of materials at the level of a production project refers to how short the duration of the production project is.

For the production project network $G = (V, A)$, is defined for each peak $i \in V$, a variable, s_i, which indicates the start time of any activity (arc) coming out of the top of i peak.

Also, that the peaks are marked a cyclically, ie for each arc $(i, j) \in A$, $i < j$ and that the network has only one initial peak marked with the number 1 and only one final peak, noted $n = |V|$. Under these conditions the next linear programe will operate, P_{CP}:

P_{CP}: min $s_n - s_1$
s.t. $s_j - s_i \geq \tau_{ij},\ (i, j) \in A$

It is obvious that the minimum value for the completion of all operations in the production project is determined by the size of the longest flow in the production project network. The length of the flow represents the total duration of all operations in the flow. This is the critical flow that results from the critical states associated with how operations are scheduled. Of course, if they are delayed from starting as soon as possible, then the duration of the entire production project is also delayed.

Determining the size of the longest path in an acyclic network is especially straightforward with labeling methods.

Using the project network $G = (V, A)$, matrix construction $Q = (q_{ij}),\ 1 \leq i, j \leq n$ is realised:

$$q_{ij} = \begin{cases} \tau_{ij}, & (i,j) \in A \\ 0, & i = j \\ -\infty. & \text{în rest} \end{cases}$$

Fictive activities have 0 duration and thus we construct a vector $S^0 = (s_i^0), 1 \leq i \leq n$:

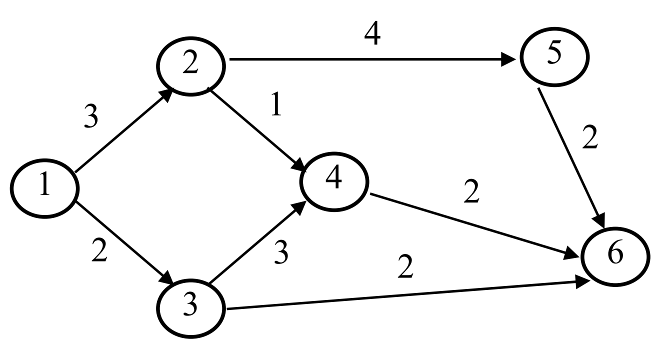
$$s_i^0 = \begin{cases} 0, & \text{dacă vârful } i \text{ este final (nesuccedat)} \\ -\infty, & \text{în rest} \end{cases}$$

Now, starting with S^0 we will form the S^k vectors by reccurence:

$$S^k = S^{k-1} \cdot Q, \quad k = 1, 2, \ldots, \bar{k} \leq n,$$

Recursion stops when either two successive vectors are identical or when k = n, regardless of which event occurs first. Thus,its value $s_n^{\bar{k}}$ provides the length of the critical flow and hence the minimum duration of the production project. The matrix Q is formed for the network in figure 4, the calculation of the vector S is given below and the minimum duration of the project is 9 units of time.

Figure no. 4. AOA network



Source: own processing

$$Q = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{pmatrix} 0 & 3 & 2 & -\infty & -\infty & -\infty \\ -\infty & 0 & -\infty & 1 & 4 & -\infty \\ -\infty & -\infty & 0 & 3 & -\infty & 2 \\ -\infty & -\infty & -\infty & 0 & -\infty & 2 \\ -\infty & -\infty & -\infty & -\infty & 0 & 2 \\ -\infty & -\infty & -\infty & -\infty & -\infty & 0 \end{pmatrix} \end{array}$$

	1	2	3	4	5	6
$s^0 =$	$\{0$	$-\infty$	$-\infty$	$-\infty$	$-\infty$	$-\infty\}$
$s^1 =$	$\{0$	3	2	$-\infty$	$-\infty$	$-\infty\}$
$s^2 =$	$\{0$	3	2	5	7	$4\}$
$s^3 =$	$\{0$	3	2	5	7	$9\}$
$s^3 =$	$\{0$	3	2	5	7	$9\}$

It should be noted that the explicit identification of the critical flow, and thus of the critical operations, is easily determined in the usual way by following the calculation of the *S* marking presented above. We will start with the label of the final peak *n* (the network contains a single final peak and a single start peak) after which we proceed by recurrence; at a given peak *j* which is known as the longest flow, we need to determine only those peaks *i* for which inequality $s_j^{\bar{k}} - q_{ij} \geq s_i^{\bar{k}}$ is mandatory.

For those peaks (at least one peak must satisfy this inequality) that exist, respectively the arc / operation *(i, j),* must be the longest flow at *j* peak. The process is repeated in this way until the initial peak is reached. Thus, the calculation provides a single critical flow given by the sequence of peaks {1, 2, 5, 6}. The calculations described above provide the starting times of the activity without delay, starting from the initial peaks of the project network and increasing the longest flow, from them to the final peaks. The process can be assimilated with an earlier calculation (without delays).

If we consider at the origin the moment of start without delay of an operation that starts from *j* peak as being ES_{jk}, then $ES_{jk} = \max_i (EF_{ij})$ wehere EF_{ij} represents the moments of end without delay of the activities that end in the *j* peak. So: $EF_{ij} = ES_{ij} + \tau_{ij}$.

If we consider, in analogy, the calculation considering delays or the calculation with delays, the time of delayed end of an operation starting at the top *j*, then reducing the moment of duration of that operation would generate the time of delayed start. If we mark the start time late LS_{ij} and late end time with LF_{ij}, then $LS_{jk} = LF_{jk} - \tau_{jk}$ where $LF_{ij} = \min_k(LS_{jk})$.

If we know the delayed and no delayed start times of an operation, we have a measure of the stagnation moment.

Noted with S_{ij}, the stagnation moment of an operation is $LS_{ij} - ES_{ij} = LF_{ij} - EF_{ij}$. This is the interval at which the start of an operation can be delayed and the duration of the minimum production project cannot be exceeded. One form of stagnation used is the determination of free stagnation, FS_{ij}, which measures the delay that an operation can maintain before the start time of any operation increases.

So $FS_{ij} = ES_{jk} - EF_{ij}$. Free stagnation can never exceed the value of conventional stagnation for an operation, and when it is different from zero at certain peaks of the project logic network, then the peaks have a degree greater than 1 so they are not on the critical flow.

4. Conclusions

The method is used as an alternative and fast way to establish the critical flow at the level of a logical network of the production project and as a variant of determining the minimum total stagnation interval. Balancing the flow of materials in the logical network of the production project, through adaptive programs, leads to the existence of an adaptive system of production planning and thus production management will have a remarkable ability to adapt to continuous changes from a complex and dynamic environment.

The existence of an adaptive system for planning the production of a balanced and orderly flow of materials, has as objectives: identifying the critical flow and thus identifying critical operations and free stagnation, optimizing the tasks allocated to available resources and optimizing the number of resources involved in the project. production. Thus, the adaptive production planning system will optimize the flow of materials, depending on the number of parallel production projects and will lead to the establishment of an optimal cost of the production project.

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