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PERT METHOD IN MATERIAL'S FLOW CONTINUITY IMPROVEMENT IN CONVERGENT PRODUCTION STRUCTURE

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Abstract: In the article there is a presentation of PERT method in calculation of production tasks beginning time. Main aim was to point out activities which determine production's beginning in convergent production system.In analysis there was an usage of complex systems theory and there were several stages of decomposition into single production streams. In the work there is a presentation of a model which sets the moment of production processes beginning in a production structure which is characterized by high level of processes' repetitions with different production parameters.

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1. INTRODUCTION

Defining mathematical models for issues of setting schedule of production processes implementation is not easy. Level of difficulty is much higher in a situation when we take into consideration elastic systems with dynamic changes (Wiendahl et al., 2007). Level of difficulty is much higher in a situation when we take into consideration elastic systems with dynamic changes (Zwolińska & Kubica, 2017). This kind of tasks is a part of mixed linear programming (PML), in which the number of decisive variables has constant character and some parts of variables are total variables and the others are binary variables (Lange, 2010). In optimization processes there might be a problem of tasks' sizes. Not only character of decisive variables but also its' amount which in some real objects might be higher than two-digits number. Moreover, high amount of border requirements and appearance of a few different aims' functions at the same time make production tasks optimization difficult. Majority of existing algorithms which help with setting schedule is whether time-consuming or guarantee only approximate solution. Often using variety of resources and energy to find optimized solutions is useless (Skołub, 2000). Especially if you make an assumption that acceptable solutions are enough as long as they meet border requirements (Kalinowski et al., 2017).

Aim of this article is to propose rational model to set moment of production's task beginning – for the production structure which is characterized by high level of repetition of processes with variable production parameters. In the article there is a presentation of some ideas of how to eliminate losses coming from waiting time, especially from final setup processes. There is an analysis of convergent production system – one in which in advanced setup through few steps of changes of n semi-products and entry resources one final product appears. Difficult was a high level of final products' customization – it enforces production in MTO system (make-to-order). To be able to achieve final aim – there was an use of one of network programming algorithms. Implementation of presented method will enable companies to minimize losses coming from waiting time for semi-products and also waiting for sub-parts to be processed.

Work (Gawrońska, 2009) includes algorithm to estimate time to process a project with PERT Method. In work (Milian, 2010), author presented a real and exact solutions of PERT problem in mixed times' schedules. However, in article (Jakowska-Suwalska, 2006), author took into consideration problem of bottom and top time estimation, so called "Time at Risk", earliest possible ending time for current project which might be achieved with probability which is no less than originally set. Bendkowski in his work called (2013) proved that realization times are indicator of logistics in production. He discussed a concept to build a production company strategy which is based on logistics on the basis of necessary reduction of complexity and "networking" of logistic processes network. Malik and Stelter in (2013) say that classical production and communication systems are inadequate in environment of production companies where changes are appearing and they proposed an alternative to consider production system as “structured production networks” – directed multigraph. Concept of using blurred sets in projects’ analysis, basing on PERT and simulation of two networks were presented in (Sojda, 2008) work.

Most common algorithms of network programming are CPM – Critical Path Method and PERT – Program Evaluation and Review Technique. Most common algorithms of network programming are CPM and PERT. Both methods are used as tools to plan future projects. CPM and PERT methods are used to estimate project’s realization time (or some part of it) and set moments of beginning and ending of elementary (fragmentary) tasks (Lock, 2009). In the article PERT method was used to set summarized realization time of production tasks for corpus and door which are main elements of analyzed device.

Network optimization methods have been implemented in late 50s – its’ complexity and diversity caused its’ classification. Due to logical structure – network methods might be divided into network methods with determined logical structure (as DAN) or logical stochastic structure (as GAN network). Most common methods of DAN are CPM and its’ extension CPM-COST, PERT (Program Evaluation ad Review Technique) and PERT-COST. Determining methods do not allow considering networks which have undetermined logical structure. CPM method is used when we have enough data to set process timing and when it allows setting consecutive activities which are necessary to its’ realization – so called critical path. Quite similar method is PERT. However, in this method parameters which describe consecutive activities of the process might have probabilistic character. To describe all of the phases of the whole production process, stochastic values are used when probability schedule of different timings is set accordingly to beta-PERT schedule (also known as eta-PERT modified PERT) (Vose, 2008).

2. CHARACTERISTICS OF ANALYZED CASE

In the article there is an analysis of a product which was one of many offered by exemplary company which creates final products. Variety of offered products in one year cycle was around 450 different items, individually tailored accordingly to customers’ orders. Approximate length of production series was about 4 stocks of one item/device. The longest production series included 22 same products. Analyzing such dynamic, variable production structure – at the first place there was a distribution of final products accordingly to its’ rotation and cyclic requests alongside with theory of complex systems (Mesarovic, 1964). Basing on classification there are four different groups of products extracted:

- group I – characterized by variable orders in the whole clearing cycle, but with a set of minimal monthly requests.
- group II – final products which has a demand variant of more than 60, however medium lapse was no lower than 5.
- group III – for which average was no lower than 10 and variant was higher than 100.
- group IV took into consideration all the devices which did not meet requirements/criteria and were not classified to neither of aforementioned groups.

There is an analysis of final product from Group I – so called "vital few". BOM (Bill of Materials) structure for analyzed device is made of 117 different semi-products and components. As components we consider items bought directly from provider and do not require any further processing (like for example: gasket, hinge, glass). Components constitute around 40% of devices' elements. Remaining 60% (around 70 subassemblies) are semi-products created inside company. Each of the semi-products has its' own (individual) transition path determined by technology. All of the processes are realized in nest production structure. In the next phase of analysis there are two main production streams: door production (D) and corpus production (K). Each of these separated production streams was subassembly in analysis. There was a conjunction of secondary sub-streams.

2.1. Structure of the analyzed product

Analyzed final product has been assign with *Y*, so:

$$Y = (y_1, y_2, \dots, y_{117})$$

where: y_K and y_D are transition paths (production) accordingly for corpus (K) and door (D).

$$K, D \in \{1, 2, \dots, 117\}$$

Single transition stream for corpus is made of 20 phases (activities). Each of activities is analyzed as it was separate process *P*, so:

$$y_K = (P_1^K, P_2^K, \dots, P_{20}^K)$$

Adequately defined transition path for door, made of 19 activities.

$$y_D = (P_1^D, P_2^D, \dots, P_{19}^D)$$

In analyzed production structure, there are resources of machine park enabling assignment of at least two machines for each of the processes. Through $M_{i_{P_j^K}}$ marked *i* – machine for *j* – process if there is a corpus created. While through $M_{i_{P_j^D}}$ marked *i* – machine for *j* – process if door is created. In real objects, very often there is a situation where due to limits (as gauge) there is no possibility to finalize a task on all available machines. Knowing technologic of all created semi-products enable assignment of certain amount of machines (on which it is possible to execute certain process for certain semi-product) to all the processes. Through this, one can assign certain amount of machines from resources. So:

$$P_1^K \subset \left\{M_{1_{P_1^K}}, M_{2_{P_1^K}}\right\}$$

$$P_{11}^K \subset \left\{M_{1_{P_{11}^K}}, M_{2_{P_{11}^K}}, M_{3_{P_{11}^K}}, M_{4_{P_{11}^K}}, M_{5_{P_{11}^K}}, M_{6_{P_{11}^K}}, M_{7_{P_{11}^K}}, M_{8_{P_{11}^K}}\right\}$$

$$P_{20}^K \subset \left\{M_{1_{P_{20}^K}}, M_{2_{P_{20}^K}}, M_{3_{P_{20}^K}}, M_{4_{P_{20}^K}}\right\}$$

Door production:

$$P_1^D \subset \left\{M_{1_{P_1^D}}, M_{2_{P_1^D}}\right\}$$

$$P_{19}^D \subset \left\{M_{1_{P_{19}^D}}, M_{2_{P_{19}^D}}, M_{3_{P_{19}^D}}, M_{4_{P_{19}^D}}, M_{5_{P_{19}^D}}, M_{6_{P_{19}^D}}\right\}$$

Each of single activities (processes) might be done in one particular moment using only one machine and at the same time, on one machine one can only create one semi-product so: $M_{i_{P_j^K}} \ \forall \ {}_j^K \in \{1, 2, \ldots, 20\}$ and $M_{i_{P_j^D}} \ \forall \ {}_j^D \in \{1, 2, \ldots, 19\}$ we get:

$$P_1^K = \left\{M_{i_{P_1^K}}\right\} \text{ and } P_1^D = \left\{M_{i_{P_1^D}}\right\} \text{ where } i \in \{1, 2\}$$

$$P_{20}^K = \left\{M_{i_{P_{20}^K}}\right\} \text{ where } i \in \{1, 2, \ldots, 4\}$$

$$P_{19}^D = \left\{M_{i_{P_{19}^D}}\right\} \text{ where } i \in \{1, 2, \ldots, 6\}$$

2.2. Defining the tasks' realization times

By $t^K_{iP_j}$ and $t^D_{iP_j}$ there were j – processes and i – machines assigned for corpus (K) and door (D). For all single semi-product transition, these times have been measured at least 12 times.Basing on measures there were optimistic values assigned – possibly minimal – corpus (K); - door (D); pessimistically – appearing maximal – K ; - D; as well as for each of the processes there were modal values assigned – corpus; door (formulas 14 to 19).

Table 1. Parameters of realization times for corpus production

Lp.	Action	Preceding activity	Action name	min	mod	max	${}^K T_c^{iP_j}$
1	A	–	cutting PK	4	7	11	7
2	B	–	cutting G	29	34	39	34
3	C	–	cutting L1	37	39	49	40
4	D	–	cutting L2	62	67	81	69
5	E	–	cutting L3	40	43	52	44
6	F	–	cutting L4	50	54	61	55
7	G	–	cutting L5	46	49	63	51
8	H	C	bending K1	3	4	10	5
9	I	C	cutting M	29	33	43	34
10	J	I	bending K2	5	7	12	8
11	K	D	bending K3	3	4	15	6
12	L	F	bending K4	6	8	13	9
13	M	F	bending K5	7	9	14	10
14	N	G	bending K6	4	6	12	7
15	O	H, J	soldering K1	5	7	10	7
16	P	L	welding	8	10	16	11
17	Q	P	etching	5	11	20	12
18	R	M, P	soldering K2	14	17	22	17
19	S	O, K, E	painting	40	45	53	46
20	T	A,B,R,N,S	isolation K	150	160	210	167

Tables 1 and 2 present a list of realized activities and certain times values based on measures – Table 1 for corpuses and Table 2 for doors.

$$ {}^K t_{min}^{iP_j} = min\left\{t_1^{iP_j}, t_2^{iP_j}, \dots, t_{12}^{iP_j}\right\} \qquad {}^D t_{min}^{iP_j} = min\left\{t_1^{iP_j}, \dots, t_{12}^{iP_j}\right\} $$

$$ {}^K t_{max}^{iP_j} = max\left\{t_1^{iP_j}, t_2^{iP_j}, \dots, t_{12}^{iP_j}\right\} \qquad {}^D t_{max}^{iP_j} = max\left\{t_1^{iP_j}, \dots, t_{12}^{iP_j}\right\} $$

$$ {}^{K}t_{mod}^{\ iP_j} = mod\left\{t_1^{\ iP_j}, t_2^{\ iP_j}, \ldots, t_{12}^{\ iP_j}\right\} \qquad {}^{D}t_{mod}^{\ iP_j} = mod\left\{t_1^{\ iP_j}, \ldots, t_{12}^{\ iP_j}\right\} $$

On tables 1, 2 there were also times ${}^{K}T_c^{\ iP_j}$ and ${}^{D}T_c^{\ iP_j}$ presented. These times were assigned accordingly and alongside with beta-PERT schedule (Vose, 2008).

$$ {}^{K}T_c^{\ iP_j} = \frac{{}^{K}t_{\min}^{\ iP_j} + \gamma \cdot {}^{K}t_{\mathrm{mod}}^{\ iP_j} + {}^{K}t_{\max}^{\ iP_j}}{\gamma + 2} $$

$$ {}^{D}T_c^{\ iP_j} = \frac{{}^{D}t_{\min}^{\ iP_j} + \gamma \cdot {}^{D}t_{\mathrm{mod}}^{\ iP_j} + {}^{D}t_{\max}^{\ iP_j}}{\gamma + 2} $$

where: γ - is a digit which sets fold of „mody" appearance for certain set of gathered measures. In elementary, basic schedule PERT γ =4.

Table 2. Parameters of realization times for doors production

Lp	Action	Preceding activity	Action name	min	mod	max	${}^{D}T_c^{\ iP_j}$
1	A	–	cutting L6	50	56	70	57
2	B	–	cutting L7	46	50	67	52
3	C	–	cutting L8	61	63	70	64
4	D	–	cutting L9	26	32	44	33
5	E	–	cutting L10	34	45	49	44
6	F	–	cutting PD	6	8	21	10
7	G	B	bending D1	9	11	22	13
8	H	C	bending D2	8	10	14	10
9	I	H	bending D3	6	7	10	7
10	J	I	bending D4	5	8	13	8
11	K	D	bending D5	7	9	15	10
12	L	E	bending D6	4	7	9	7
13	M	G, J	welding D1	3	4	13	5
14	N	M	grinding D1	3	6	11	6
15	O	K, N	soldering D	17	20	28	21
16	P	O	welding D2	4	5	9	6
17	Q	P	grinding D2	2	4	9	5
18	R	A, Q	painting	37	46	50	45
19	S	F, L, R	isolation D	120	145	185	148

Assigned timings of realization of tasks within certain processes enable approximating probability of finishing elementary phases as well as whole project within deadline. Times ${}^{K}T_{c}^{iP_j}$ and ${}^{D}T_{c}^{iP_j}$ are named to be „non-determined" values assigned accordingly to 20 and 21. Advantage of PERT method is a graphic presentation of project's results. In the next phase of analysis there was a creation of arrow diagram to consider cases. In the last phase, there were variants assigned for critical path of corpus and door.

$$D^2\left({}^{K}T_{c}^{iP_j}\right) = \frac{\left(K_{T_c^{iP_j}} - K_{T_{\min}^{iP_j}}\right)\left(K_{T_{\max}^{iP_j}} - K_{T_c^{iP_j}}\right)}{\gamma + 3}$$

There will be assigned variant of realization times for door. Processes in which there will be identification of highest variant's value should be taken into consideration as first with regards to improvement and stabilization.

3. MODELLING OF THE REAL OBJECT

Graphic form is a clear presentation which helps with precise definition of connections between certain tasks (processes) and which sets critical path. Basing on the data from Table 1 there was graph created – it shows connections between processes within corpuses production (Fig. 1).

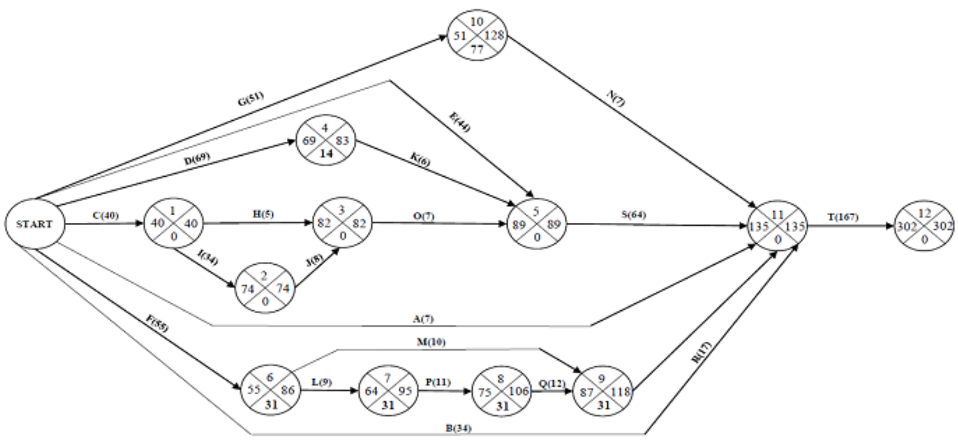

Fig. 1. Graph presenting connections in corpuses production

Identically, there were graph created for door production (Fig. 2).

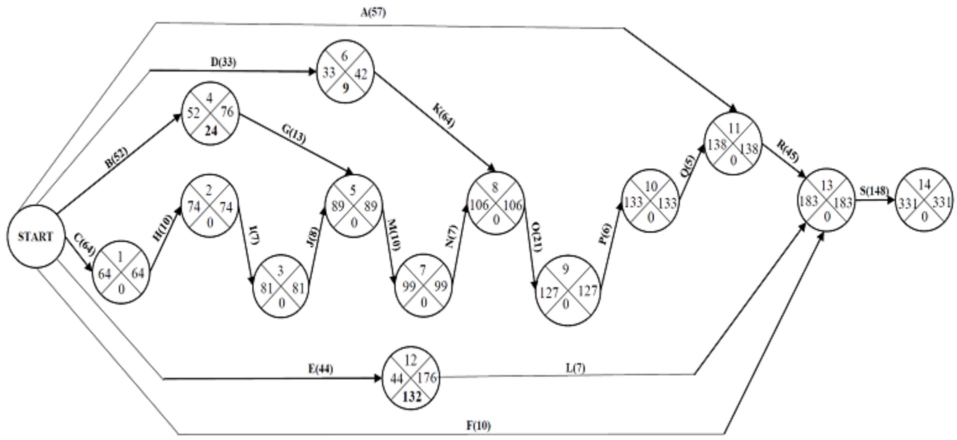

Fig. 2. Graph presenting connections in door production

4. CONCLUSION

In the article used PERT method to set production processes' realization times for corpus and door of cooling devices. Considered streams were extracted to be significant because of a process of final setup. Production process of analyzed product is a complex system made of a few hierarchical sub-processes. Setting main production streams (door – D and corpus – K) helps with defining amount of tasks for each of the streams separately and cumulative time to complete the processes, according to final setup process. Using theory of complex systems, analyzed production system has been decomposed into a set of correlated tasks' sub-systems. Production structure of analyzed item is a set built from a few hierarchical sub-processes. Timing measurements, going along value stream enable setting realization times for certain tasks and setting production lead tie for each semi-product. Moreover, schedule of initial tasks in analyzed case takes into consideration: operational resources, amount of machines to realize certain processes, production abilities (which come from time consuming activities) and realization times for each elements, achieved levels of quality. Implementation of presented method might help company to minimize losses coming from waiting time for semi-products from operator as well as waiting time of sub-assembly for next processing.

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REFERENCES

Bendkowski J. (2013), Logistyka jako strategia zarządzania produkcją, Zeszyty Naukowe Politechniki Śląskiej, z.63, Zabrze, pp. 2–25.

Burduk A. (2013), Modelowanie systemów narzędziem oceny stabilności procesów produkcyjnych, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

Durrett R. (2010), Probability: Theory and Examples Cambridge Series in Statistical and Probabilistic Mathematics, Cambridge University Press, New York.

Gawrońska D. (2009), Szacowanie czasu trwania przedsięwzięcia metodą PERT na podstawie rozmytych ocen czasów trwania zadań, Zeszyty Naukowe Politechniki Śląskiej, z.49, Zabrze, pp. 46–60.

Grzybowska K. & Gajdzik B. (2012), Optymisation of equipment setup processes in enterprises, Journal Metalurgija, 51 (4), pp. 563–566.

Jakowska-Suwalska K. (2006), Ryzyko w sieci PERT, Zeszyty Naukowe Politechniki Śląskiej, z.38, Zabrze, pp. 69–76.

Kalinowski K., Grabowik, C., Ćwikła G., Gwiazda, A. & Monica, Z. (2017), Harmonogramowanie operacji w uwzględnieniem wymagań wielozasobowych w grupach kompetencji, Innowacje w zarządzaniu i inżynierii produkcji, R. Knosala (ed.) Opole: Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, pp. 552–561.

Lange K. (2010), Applied Probability, Springer Texts in Statistics.

Lock D. (2009), Podstawy zarządzania projektami, Wydawnictwo, PWE Warszawa.

Malik F. & Stelter D. (1990), Kriesengefahren in der Weltwirtschaft – Ueberlebensstrategien fuer das Unternehmen, Stuttgart.

Mesarovic M.D. (1964), The Control of Multiverible Systems, New York, Wiley

Milian Z. (2010), Dokładne rozwiązania problemu PERT z mieszanymi rozkładami czasu realizacji zadań, Wydawnictwo Politechniki Krakowskiej, Kraków.

Skołub B. (2000), Planowanie wieloasortymentowej produkcji rytmicznej, Zeszyty Naukowe Politechniki Śląskiej, Mechanika z. 136, Gliwice.

Sojda A. (2008), Zastosowanie zbiorów rozmytych w ustalaniu harmonogramu na bazie sieci PERT, Zeszyty Naukowe Politechniki Śląskiej, z.45, Zabrze, pp.359–371.

Wiendahl H.P., ElMaraghy H.A., Nyhuis P., Zäh M.F., Wiendahl H.H., Duffie N. & Brieke M. (2007) Changeable Manufacturing – Classification, Design and Operation, Annals of the CIRP, Vol. 56/2/2007, pp. 783–809.

Wiegand B. Langmaack R. & Baumgarten T. (2005) Lean Maintenance System Zero Maintenance Time – Full Added Value Workbook, Lean Institute, Portsmouth U.S.A..

Zwolińska B. & Kubica Ł. (2017), Forming of the dynamics of the changes in convergent production system depending on size of production party. LogForum, no. 3, pp. 301–311.

Vose D. (2008), Risk Analysis. A quantitative guide. John Wiley & Sons, Ltd., USA

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