Algorithm of Autonomic Shaping of Workflow

Bożena Zwolińska(✉)

AGH Science and Technology, Kraków, Poland
bzwol@agh.edu.pl

Abstract. In the article there is a presentation of the model of shaping level of workflow which is possible to use in formulation of autonomic software of production system. Application with model in intelligent production system is on the second level – level of gathering and processing data. Assumptions of presented models assume customization (personalization) of created product in elastic production system. Flexibility of production system achieved by flexible production sockets with use of economic robots with full cooperation with operator. Exemplary production system have been shaped due to the level of workflow of m input streams and n processing phases. In consideration there is a single production where number of orders k_p in time Δt is deterministic value smaller than 30. The rest of parameters as realization time in consecutive processes are random variables with characteristic designation of probability thickness. Presented model of the whole production system can be used as a system of early warnings before anomaly situations of overstretching or under-stretching single sub-systems of the whole system.

Keywords: Shaping of the level of workflow · Balancing of the production line

1 Introduction

In current production structure based on ERP (Enterprise Resource Planning) systems, most common are ideas of intelligent production compatible with Industry 4.0. Technological development based on artificial intelligence forces changes in production management, basing on so called cyber-physical systems. Those systems enable global communication between autonomic systems which makes integral unity. Inception of those systems in particular economic areas totally changes ideas of production management. New, complex and dynamic systems can assure unreachable level of efficiency with minimal input of human. Factory of future is efficient in terms of costs but also digitalized and automated production structure. Modern systems of production should be elastic without regard for dynamics of changes, variability and customized production. Production compatible with Industry 4.0 idea is remotely steered, autonomic and robotized structure. In these structures it is necessary to process and analyze large amount of data in real time. Putting analytical and calculation system in data cloud with implementation of advanced decisive algorithms enable access and management from everywhere, anytime.

A. Burduk and D. Mazurkiewicz (eds.), *Intelligent Systems in Production Engineering and Maintenance – ISPEM 2017*, Advances in Intelligent Systems and Computing 637,
DOI 10.1007/978-3-319-64465-3_12

New production model resign from “mass production” and focus on “mass customization”. Responsive production – fully customized production forces flexibility from production structure. Flexibility is a pure form of customization with short reaction time from a moment of need. Aforementioned parameters are determinant of changes in production system status. To minimize losses on operational level, it is important to keep stability of production structure. This stability can be define in a few different ways – as a cycle of repetitions in certain frequency or invincibility of particular values in realized processes. In the article there is a elaboration on algorithm of intelligent production line balancing. Balance parameter is a level of workflow in single production sockets in dependence to complex production structure as a whole.

In the article there is a presentation of model of indicating level of workflow for complex production system in which a product fully customized product is created. Final products in production chain are analyzed. Those are not input components for any other production systems. The purpose of this model is to indicate variants of workflow levels in complex structure composed from n independent processes (phases of production). Model is based on random variables and on next steps it will help with shaping decisive variables to indicate optimal conditions of work in dynamic and autonomic production system.

2 Characteristics of Analyzed System

There is a consideration of exemplary production system made of n processes (phases of processing). In the model there is assumption that variable machine resources dependent on process. In first phase of modelling there is general theory of complex systems accordingly to this in which analyzed system has been grouped for n independent sub-systems. In consideration there is another assumption that in separated subsystem there is realization of only one process on m_n machine resources. Figure 1 presents a scheme of analysed system.

Complex production system of h input streams for $l = 1, 2, \ldots, h$ has been modelled and shaped in terms of workflow. In each and every stream there are n independent processes for $i = 1, 2, \ldots, n$. Single final product Y^L consists of N components for $L = 1, 2, \ldots, K$. In each and every process for $i = 1, 2, \ldots, n$ there are k_p elements done, where k_p is a number of single tasks determined by the number of orders from clients for $p = 1, 2, \ldots, s$ in t time and from number of y^N components from BOM (Bill of Materials). structure. Figure 1 presents a scheme of analyzed structure.

Formulated model of shaping of level of workflow takes into consideration size of production party. Case for $k_p \leq 30 \; \forall p = 1, 2, \ldots, s$ has been considered. Level of workflow has been set, basing on time necessary to do all the tasks and processes of single final product Y^L. In the article it has been set that all single final products (Y^L) are created from the same number of element y^M. Realization time for the single task is random variable marked as $\tau_{l,i,j}$ compatible with exponential distribution with characteristic parameter $\lambda_{l,i}$ separate for i – process in l – stream for each j – $\tau_{l,i,j} \sim \text{Exp}(\lambda_{l,i})$. of level of workflow

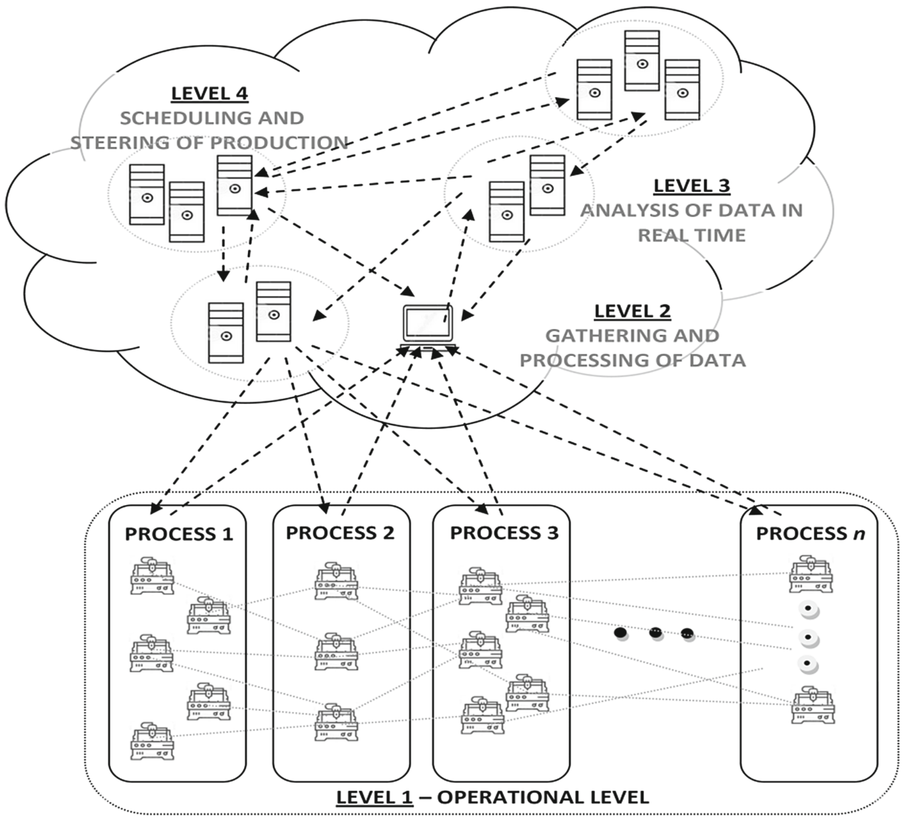

Fig. 1. General scheme of considered production system

for single final product Y^L are expressed with a time necessary to conduct all parts of the processes and can be determined with a formula [1]:

$$P\big(\tau \in \langle \tau_1, \tau_2 \rangle\big) = \left[\prod_{i=1}^{n} \lambda_{i,l}\right] \cdot \int_{\tau_1}^{\tau_2} \sum_{j=1}^{n} \frac{e^{-\lambda_{j,l} \cdot \tau}}{\prod_{\substack{k \neq j \\ k=1}}^{n} (\lambda_{k,l} - \lambda_{j,l})} d\tau \tag{1}$$

where: $\lambda_{i,l}$ – parameter of exponential composition depends on i – process and l – stream.

Shaping level of workflow for the whole production structure should adjust all processes and all tasks realized in time Δt. Level of workflow is determined by implemented in company technology, BOM structure and production schedule which comes from clients' orders. In next part of article, there will be a presentation of model to assign level of workflow for particular processes in time Δt for k_p necessary to execute tasks in i – production process(Fig. 2).

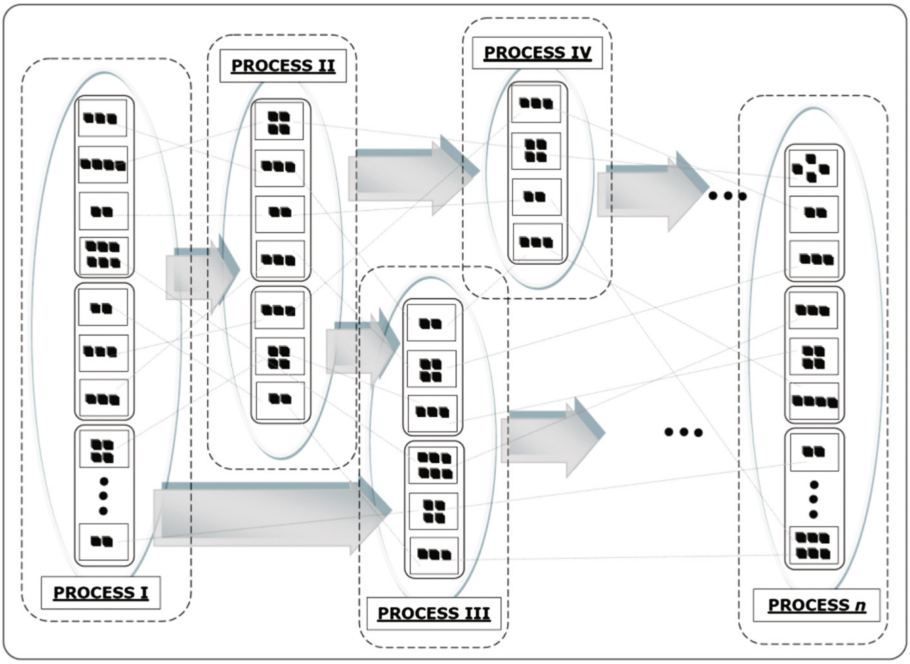

Fig. 2. Scheme of analyzed structure in process

3 Shaping of Workflow of *i* – production Process

In statistic field we can set so called "small trial" for which it can be assumed that amount of elements in considered system is smaller or equal to 30; and also so called "big trial" for which amount of elements in analyzed system is bigger than 30 [2, 3]. Taking into consideration aforementioned examples for considered structure there was a model created which is used to shape level of workflow which assumes that there is k_p for $2 \leq k_p \leq 30$ necessary tasks connected to amount of clients' orders. We do not consider possibility of $k_p = 1$ as value of workflow level will have been a sum of random variables with exponential configuration. Then level of workflow of single separated sub-system will have been marked with a formula (1). Assumption $k = 1$ will mean that in whole production structure in time Δt there are different products Y^K produced (one stock of each). In considered example there is assumption that situation is rare, that is why it has been skipped.

When $k > 30$ – we can use so called "scale effect" which is about shaping level of workflow in big production party. In this example, we can use property of stability in structure of random variable $\tau_{l,i,j} \sim \text{Exp}\ (\lambda_{l,i})$ we can use central border statement (CLT). Basing on CLT specifics – for sum of variety of independent random variables with the same composition with ended variants – we have to assess of analyzed random variable with normal composition with particular standard aberrance σ and approximate value μ [4].

Level of workflow for particular phase (process or characteristic group of processes) in considered production structure is also a level of workflow, assigned due to the theory of complex systems, separated system [5] (in our consideration it is also production department). To assign level of workflow for the process (or group of processes) realized in area of single department there is a need to set sum of all components of elementary times of realization of each sub-products. Figure 3 shows scheme of acting in shaping of the level of workflow for considered production structure.

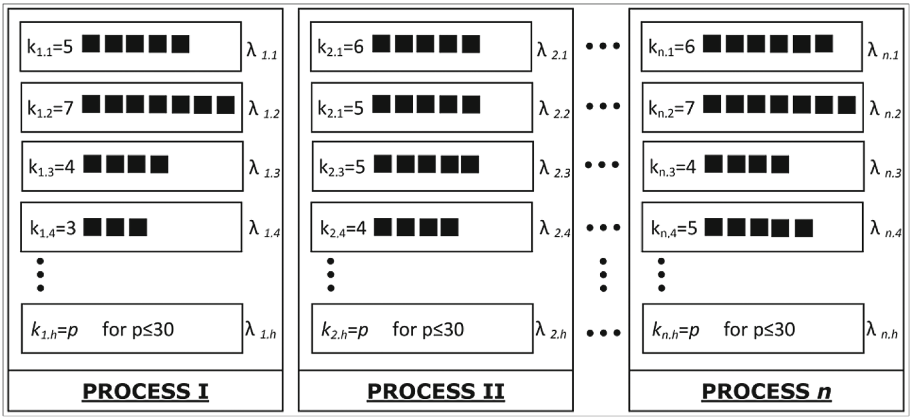

Fig. 3. Scheme of workflow in shaping level of effort

To assess level of workflow for i – process (department), where $k_p \leq 30$ in time t_{i,k_l} there was random variable marked. It is a sum of all realization each $k_{n,h}$ times in i – production process. We know that single realization time for one sub-product $\tau_{l,i,j} \sim \text{Exp}\ (\lambda_{l,i})$ so:

$$t_{i,k_l} = \tau_{i,l,1} + \tau_{i,l,2} + \ldots + \tau_{i,l,k_l} \tag{2}$$

where: t_{i,k_l} – random variable which describes all time of realization k_p necessary elements (tasks) in i – process (phase) of production for l – stream of value. Moreover, we know that if $\tau_{l,i,j} \sim \text{Exp}\ (\lambda_{l,i})$, for all $j = 1,2\ldots k_p$, so $t_{l,i} \sim \text{Erl}\ (k_p, \lambda_{l,i})$. If there are any e x, y: $\lambda_{l,x} = \lambda_{l,y}$, then $t_{l,x} + t_{l,y} \sim Erl\ (x + y, \lambda_{l,y})$. Where the $t_{l,i} \sim \text{Erl}\ (k_p, \lambda_{l,i})$ mean that random variable $t_{l,i}$ is corresponding with Erlang distribution about k_p, and $\lambda_{l,i}$ parameters.

Random variable T_i assess time of k_p tasks in i – process is a sum of independent random variables t_{i,k_l}.

$$T_i = t_{i,k_1} + t_{i,k_2} + t_{i,k_3} + \ldots + t_{i,k_l} \tag{3}$$

where: $T_i \sim Erl\,(k_i, \lambda_{i,l})$, T_i – random variable describing the whole time of production processes realization for i – process; t_{i,k_l} – are random variables which set the realization time for k_p elements (tasks) on i – process.

To assign level of workflow for process (or group of processes) realized in area of single department it is necessary to name formula of thickness which is a sum of random variable with Erlang composition. Basing on [6, 7] there was formula of realization time k_p of grouped tasks in single production department:

$$f_{Ti}(\tau) = \sum_{p=1}^{s} \left(\lambda_{i,l}\right)^{k_p} \cdot e^{-\tau \cdot \lambda_{i,l}} \cdot \sum_{j=1}^{k_p} \frac{(-1)^{k_p - j}}{(j-1)!} \cdot \tau^{j-1} \cdot \sum_{\substack{m_1 + \ldots + m_g = k_p - j \\ m_i = 0}} \prod_{\substack{g=1 \\ g \neq i}}^{s} \binom{k_g + m_g - 1}{m_g} \frac{\left(\lambda_{i,g}\right)^{k_g}}{\left(\lambda_{i,g} - \lambda_{i,l}\right)^{k_g + m_g}} \tag{4}$$

where: $f_{Ti}(\tau)$ – probability density function of a T_i variable random; $\lambda_{l,i}$ – parameter of exponential configuration, k_h – parameter of shape in Erlang composition, $m_1, m_2, \ldots, m_n \in$ N – parameters of combination in which $m_i = 0$ and $\sum_{g=1}^{n} m_g = k_p - j$ for all $i = 1, 2, \ldots, n$ and $j = 1, 2, .., k_p$. Medium of random variable T_i is $\tau > 0$.

Value ET_i marked with a formula (4) of thickness in random variable T_i is expected value in necessary time for execution of k_p tasks in area of one department. In the same time ET_i is nominal level of workflow for i – phase of production (department). ET_i is counted accordingly to the formula:

$$ET_i = \sum_{l=1}^{h} \frac{k_l}{\lambda_{i,l}} \tag{5}$$

To assign differences in level of workflow from average value for separate process it is important to assign variation of random variables T_i. Variant of random variable $VarT_i$ is assigned accordingly:

$$Var\ T_i = Var\ t_{i,k_1} + Var\ t_{i,k_2} + \ldots + Var\ t_{i,k_h} \tag{8}$$

Assigned variants of level of workflow for particular processes informs us about stability (or about lack in stability) which is connected to the fact of the differences in realized tasks. Equipoising level of workflow for all particular processes (or groups of processes) should be adjusted to the expected value (ET) for all production system. That is why in the next part there will be designation of level of workflow for production system considered as a whole.

If with T we assign random variable which is a sum of independent random variable T_i, we are able to assign expected level of workflow for whole production structure. Random variable T is assigned accordingly to the formula:

$$T = T_1 + T_2 + \ldots + T_n \tag{9}$$

Expected value of the random variable and its' variant look like:

$$ET = \sum_{i=1}^{n} \sum_{l=1}^{h} \frac{k_l}{\lambda_{i,l}} \tag{10}$$

$$Var\ T = \sum_{i=1}^{n} \sum_{l=1}^{h} \frac{k_l}{\lambda_{i,l}^2} \tag{11}$$

In reference to assigned level of workflow for whole production system and for single processes (or groups of processes) we can assign sensitive (critical) departments (production sockets) in which there are wastes of 3M – (jap. "*muri*", "*mura*", "*muda*"). Department (production socket) which expected value of level of workflow is significantly bigger than value of level of workflow in comparison to other process (or group of processes) and it is "narrow throat" of whole production structure. On the other hand, department (production socket) in which there are significant lacks in average expected level of workflow can generate over-production or there is unnecessary awaiting in sockets. In this case there is waste of "*muda*" group. We can notice that 3M wastes are dependent and strictly connected. Elimination of one can cause elimination (or decrease) or all the rest [8, 9]. That is why optimization of production processes should adjust analysis of single (separated) processes but not in separation of whole production system [10].

3.1 Balancing Production Line

Balancing production line is this kind of assignment in which there is constant flow in n production processes and indicator of changes of workflow level V_P for grouped processes is near to zero in whole production stream [11, 12]. In complex production structure there are limited technological possibilities in constant decrease of production cycle (C/T). In result – it is important to assign it in particular phases of production, necessary to execute elementary tasks in way in which expected value of designated levels of workflow is the same and stable for whole structure.

Assigned variant of levels of workflow for particular processes enables assignment of probability to execute system of h tasks in area of three standard deviations ($\pm 3\ \sigma$). In next consideration there is a formula which sets probability that value of workflow level for single, particular phases of processing can be set in area of maximum three standard deviations ($\pm 3\ \sigma$) from expected value of the whole production structure – ET. Basing on formula (4) of thickness function in random variable T_i and with formulas (10), (11), accordingly to expected value and variant of random variable T will be set with formula to count probability that random variable T_i will take value from $\left(ET - 3 \cdot \sqrt{VarT}\right)$ do $\left(ET + 3 \cdot \sqrt{VarT}\right)$. Probability is assigned accordingly to the formula:

$$P\left(ET-3\cdot\sqrt{VarT}<T_i<ET+3\cdot\sqrt{VarT}\right)=\int_{ET-3\cdot\sqrt{VarT}}^{ET-3\cdot\sqrt{VarT}} f_{T_i}(\tau)\,d\tau$$
$$=\int_{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}-3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}}^{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}+3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}}\left[\begin{array}{c}\sum_{p=1}^{h}(\lambda_{i,l})^{k_p}\cdot e^{-\tau\cdot\lambda_{i,l}}\cdot\sum_{j=1}^{k_p}\frac{(-1)^{k_p-j}}{(j-1)!}\cdot\tau^{j-1}\cdot\\ \sum_{\substack{m_1+\ldots+m_g=k_p-j\\ m_i=0}}\prod_{\substack{g=1\\ g\neq i}}^{h}\binom{k_g+m_g-1}{m_g}\frac{(\lambda_{i,g})^{k_g}}{(\lambda_{i,g}-\lambda_{i,l})^{k_g+m_g}}\end{array}\right]d\tau \tag{12}$$

In other changes we receive difference of incomplete Gamma functions [13]:

$$\begin{gathered}P\left(\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}-3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}<T_i<\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}+3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}\right)\\ =\sum_{p=1}^{h}\sum_{j=1}^{k_p}\frac{(-\lambda_{i,l})^{k_p-j}}{(j-1)!}\cdot\sum_{\substack{m_1+\ldots+m_g=k_p-j\\ m_i=0}}\prod_{\substack{g=1\\ g\neq i}}^{h}\binom{k_g+m_g-1}{m_g}\frac{(\lambda_{i,g})^{k_g}}{(\lambda_{i,g}-\lambda_{i,l})^{k_g+m_g}}\cdot\\ \left[\begin{array}{l}\Gamma\left(j;\left(\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}-3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}\right)\lambda_{i,l}\right)-\\ \Gamma\left(j;\left(\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{\lambda_{i,l}}+3\cdot\sqrt{\sum_{i=1}^{n}\sum_{l=1}^{h}\frac{k_l}{(\lambda_{i,l})^2}}\right)\lambda_{i,l}\right)\end{array}\right]\end{gathered} \tag{13}$$

Finally, after changes we receive:

$$\begin{gathered}P\left(ET-3\cdot\sqrt{VarT}<T_i<ET+3\cdot\sqrt{VarT}\right)\\ =\sum_{p=1}^{h}\sum_{j=1}^{k_p}\frac{(-\lambda_{i,l})^{k_p-j}}{(j-1)!}\cdot\sum_{\substack{m_1+\ldots+m_g=k_p-j\\ m_i=0}}\prod_{\substack{g=1\\ g\neq i}}^{h}\binom{k_g+m_g-1}{m_g}\frac{(\lambda_{i,g})^{k_g}}{(\lambda_{i,g}-\lambda_{i,l})^{k_g+m_g}}\cdot\\ (j-1)\cdot e^{-ET\cdot\lambda_{i,l}}\cdot\left[\sum_{r=0}^{j-1}\left(\begin{array}{l}e^{3\cdot\sqrt{VarT}\cdot\lambda_{i,l}}\cdot\frac{\left(\left(ET-3\cdot\sqrt{VarT}\right)\lambda_{i,l}\right)^r}{r!}-\\ e^{-3\cdot\sqrt{VarT}\cdot\lambda_{i,l}}\cdot\frac{\left(\left(ET+3\cdot\sqrt{VarT}\right)\lambda_{i,l}\right)^r}{r!}\end{array}\right)\right]\end{gathered} \tag{14}$$

Value of three standard deviations has been set after basing on three sigma rule, strictly connected with its' standard deviation. In practice, it is rare tahat there are results which are different than value ±3 σ. It does not mean that their appearance is impossible. Situation in which difference bigger than ±3 σ appears means that circumstances which appeared were anomaly. Figure 4 presents process of balancing production lines in area of level of workflow for single, grouped production tasks in reference to three standard deviations for whole production process.

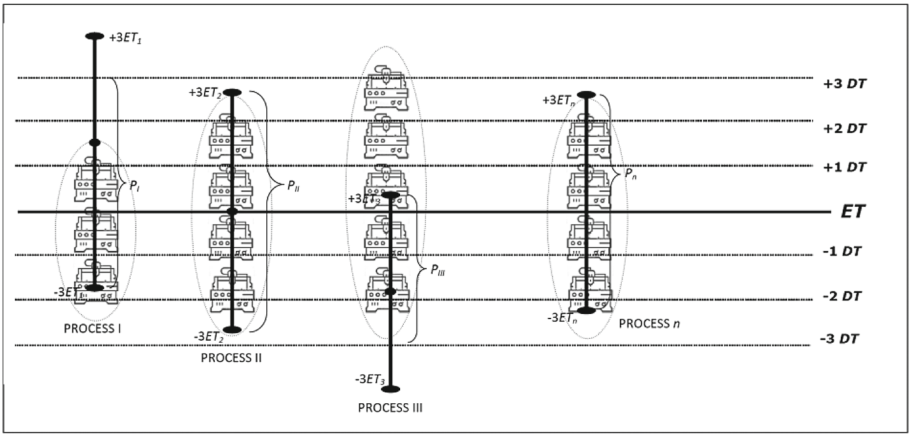

Fig. 4. Scheme of balance in the level of workflow

If probability of realization time is not in area of three standard deviations of whole production structure means that production system was overstretched or under-stretched. In case of overstretch – it will result with losses like awaiting for components for all of the next processes – process 1 Fig. 4. In case of under-stretch – process 3 Fig. 4 – we have a situation in which there are too many resources to execute tasks (processes). In this phase of processing (process 3) there is permanent expectation. Optimization based on balancing of workflow in real time Is obliged to permanent expectation of resources. It is possible to achieve with use of digitalization of whole production process and interaction of physical objects (machines) with virtual (software).

In intelligent production systems aforementioned algorithm of shaping workflow of separated areas in complex production structure will help with programming the steering process of assigning the production resources. Presented model enables control of workflow levels of assigned tasks in single production processes. Use of advanced counting algorithms based on formula number (14) enables assignation of optimal parameters customized to resources and fully-correlated to clients' needs.

4 Conclusion

Level of workflow in particular production subsystems is different and depends on implemented technology, type of product, level of its' complexity and phases necessary to process. Moreover, depending on availability of resources (or their lack), single elements can be produced unto different technologies. This situation significantly change level of workflow in considered time. In the article there is a presentation of a model of shaping level of workflow for production structure which consists of *n* phases. In optimized, autonomic production system decomposition of tasks for single machines must be correlated with all mechanical and human resources. In consideration there is an assumption that cooperation between robot and operator is necessary (when operator has universal abilities of operating with variety of machines and operator is able to execute a lot of tasks in different processes). Presented model assumes flexibility of separated subsystems in area of realized processes in which tasks are assigned accordingly to autonomic decisive systems.

Wrought software with the use of presented model can be an element of intelligent production system in area of analysis and calculations. Exceeding borders in range of three standard deviations in whole production system can be an alert of early warning before critical situation.

References

1. Singh, L.N., Dattatreya, G.R.: Estimation of the hyperexponential density with applications in sensor networks. Int. J. Distrib. Sens. Netw. **3**, 311–330 (2007)
2. Devore, L.J.: Probability and Statistics for Engineering and the Sciences. Books/Cole, Boston (2012)
3. Durrett, R.: Probability: Theory and Examples Cambridge Series in Statistical and Probabilistic Mathematics. Cambridge University Press, New York (2010)
4. Lange, K.: Applied Probability. Springer Texts in Statistics. Springer, New York (2010)
5. Gniedenko, B.W., Kowalenko, I.N.: Wstęp do teorii obsługi masowej. PWN, Warszawa (1966)
6. Jasiulewicz, H., Kordecki, W.: Convolutions of Erlang and Pascal distributions with applications to reliability. Demontratio Math. **36**(1), 231–238 (2003)
7. Akkouchi, M.: On the convolution of exponential distributions. J. Chungcheong Math. Soc. **21**(4), 501–510 (2008)
8. Wiegand, B., Langmaack, R., Baumgarten, T.: Lean Maintenance System Zero Maintenance Time – Full Added Value Workbook. Lean Institute, Portsmouth (2005)
9. Zwolińska, B.: Use of the method VSM to the identify muda. Res. Logist. Prod. **6**(6), 513–522 (2016)
10. Grzybowska, K., Gajdzik, B.: Optymisation of equipment setup processes in enterprises. J. Metal. **51**(4), 563–566 (2012)
11. Nyhuis, P., Windhal, H.P.: Fundamentals of Production Logistics. Theory, Tools and Applications. Springer, Heidelberg (2009)
12. Lenart, B., Grzybowska, K., Cimer, M.: Adaptive inventory control in production systems. In: Corchado, E., et al. (eds.) Hybrid Artificial Intelligent Systems, Proceedings, Part II, pp. 222–228 (2012)
13. Di Salvo, F.: The exact distribution of the weighted convolution of two gamma distributions, pp. 511–514 (2006). http://old.sis-Statistica.org/files/pdf/atti/Spontanee%202006_511–514.pdf