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Required buffer capacities in assembly systems

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ABSTRACT

Purpose: The aim of the realised analysis is the determination of the set of conditions. The fulfilment of those conditions enables the synchronisation of the assembly system work into the steady state. It is necessary to specify the rules controlling the assembly system work. Rhythmic concurrent production with wide assortment in the considered assembly system is realised.

Design/methodology/approach: The theoretical roots of the considerations presented in that paper include theory of constraints. The presented approach is consistent with the authority method called Requirements and Possibilities Balance Method (RPBM)

Findings: Two kinds of system buffers: the entrance buffers and the inter-resources buffers are considered in that paper. The number of buffers elements needed for production during first steady state of the given system has been determined. Mathematical formulas specifying the minimal capacity of the buffers allocated in the assembly system have been outworked.

Research limitations/implications: The formulas specifying the minimal buffer capacity constitute the first step towards formulation of the automatic method. That method is designed for the automatic construction of rules controlling the system work during transient phases between two different steady states. The process enables automation of the introduction filling of the system buffers.

Practical implications: The presented formulas can become an integrated part of existing authority software. The developed computer system aids the decision-making process connected with production planning and ensures effective utilisation of production resources. Moreover, the formulas correctness during computer simulations has been verified.

Originality/value: To develop the formulas specifying the minimal capacity of the system buffers is the main achievement of the given paper. The presented approach permits to solve the problem concerning the synchronisation of the assembly system work into the steady state.

Keywords: Production and operations management; Assembly system; Buffer capacity; Rhythmic production

1. Introduction

Market conditions determining business activities of contemporary enterprises force into application by its new production planning and control techniques. Application of the new techniques enables to achieve the company's strategic goals and increase competitiveness in the market. One of many areas required continuous development is computer aiding of the decision-making process connected with order acceptation into realisation in the given firm [1, 2].

Production planning and control problems in assembly systems in the [3-7] articles have been considered. The environment of the analysed assembly systems is changeable. In those systems rhythmic concurrent production with wide assortment is realised. Short system cycles and small batches for that production are characterised. There are the assembly resources (i.e. robots, manipulators) in the assembly systems. In those systems, tasks in the rendezvous-like mode are realised. It means that minimum two pieces must meet at the same time and at the same place in order to be joined into a more complicated element.

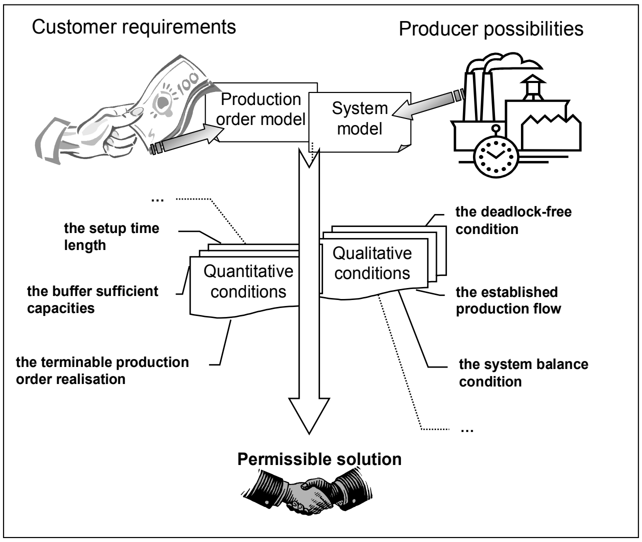

Fig.1. The Requirements and Possibilities Balance Method

The presented approach is consistent with the authority method called Requirements and Possibilities Balance Method (RPBM). According to that method (Fig. 1), the search of the optimal and quasi-optimal solutions consuming time and capital have been given up in favour of finding a solution that is included in the set of permissible solutions. The search of the solution included in the set of permissible solutions boils down to the checking of the sequence of sufficient conditions. The formulated sufficient conditions define the links between the system constraints and the production order parameters. All sufficient conditions can be divided into the qualitative and quantitative ones. Qualitative acceptable production flow characterised by the deadlock-free and starvation-free system behaviour has to be guaranteed at the beginning. A deadlock occurs when during the concurrent production at shared resources the cycle of the mutual expectations takes place. Starvation happens when the process is infinitely long held before shared resource, because access to that resource is impossible as a result of other processes realisation [8]. When the qualitative sufficient conditions are fulfilled in the system and it is certain that production flow in the system is possible, the checking of the quantitative sufficient conditions can take place. That activity heads towards determination whether a new production order can be timely realised in the system. The quantitative conditions concern the number of the final products, the realisation term or the efficiency of resources utilisation. Each condition limits the sufficient conditions set. The first solution meeting the conjunction of all checked sufficient conditions is deemed as a permissible solution and forms a basis of the production plans and the procedures controlling the work of the resources in the system. Moreover, the stages of the production planning and control are integrated [9].

2. Production flow synchronisation in assembly systems

In the [10 - 12] previous papers concerning the production planning and control in assembly systems only the system steady state has been considered. It means that the system transition state has been omitted. Therefore, the Requirements and Possibilities Balance Method until very recently has been used for the preliminary specification whether the given production order can be accepted for the realisation in the system. That has also enabled the preliminary determination of the procedures controlling the production flow and the preparation of the request for quotation at the customer service facility.

High requirements of customers wanting to buy cheap and fast diversified high-quality products cause that production process rotation is substantial. Production processes eliminated from the system fast are replaced with new processes accepted into the system [13]. In that situation the determination of the rules controlling works during the system transition state is very important. The transition state of the system means that the system does not work in the steady rhythm. There are three possible transition state phases: starting-up, cease and transient. The starting-up phase is connected with production beginning and it precedes the system steady state. The cease phase is applied to the final production completion and follows the system steady state. The transient phase includes the starting-up phase as well as the cease phase. The transient phase consists in the transition from one expected steady state of the system to another also realised in the certain rhythm.

The Requirements and Possibilities Balance Method in automatic assembly systems can be implemented due to the application of the meta-rule conception. There are three parts adequate to the starting-up, the dispatching and the cease phases in each meta-rule. The first part of the meta-rule is the starting-up rule that is executed once and assures the production flow synchronisation into the expected system cycle. The second is cyclically executed and guarantees the steady state of the system. The third is the procedure of the production cease and it is executed once after the cyclic realisation of the local dispatching rule [3]. The following question arises: Which conditions should be fulfilled in the assembly system in order to ensure production flow synchronisation into the expected steady state?

In the real assembly systems working in the steady state elements produced during a given system cycle are needed for the next system cycle realisation. Thus, for the production flow synchronisation into the expected steady state it is necessary to guarantee the production realisation during the first cycle of the system steady state [14]. According to the proposed approach, the production realisation during the first cycle of the system steady state has been guaranteed due to the preliminary filling-up of the system buffers [15]. During the starting-up phase into the system buffers the required number of elements are filled-up. The number of elements should ensure the production realisation during the first cycle of the system steady state without a deadlock. For automatic assembly systems it is characteristic that filling-up of system buffers is realised using the staring-up rules. The staring-up rules are generated on the basis of known dispatching rules. Those rules should guarantee deadlock-free system behaviour and synchronise the production flow into the expected steady state determined by the system bottleneck. Taking into account the presented considerations, the solution of the main synchronisation conditions problem requires a solution to particular problems included in the following questions:

- Which kind of buffers should be in the assembly system allocated?
- How many and which kind of elements should be allocated in the system buffers for the production realisation during the first cycle of the system steady state?
- Which minimal capacities should have buffers allocated in the assembly system?

3. Required buffer capacities

The procedure of determination of the needed number of elements allocated to individual buffers requires introduction of input-data into the system. The input-data are included in two matrices and specify the number of elements forming the assembly units in question. Moreover, information about the realisation repetition of each assembly unit at individual resources within rules controlling the system work is contained. The considered assembly system (Fig. 2) is described by the M_U^M matrix of the system structure and the M_U^L processes links matrix.

The M_U^M matrix of the system structure is $s \times r$, where U is the number of assembly processes realised in the system, s is the number of assembly units realised in the system, r is the number of assembly resources existing in the system. The matrix specifies at which R_a assembly resources given S_b assembly units are realised and how many times those assembly units have to be realised at the given assembly resources during one system cycle in order to the realisation of production orders accepted into the system. The elements of the M_U^M matrix of the system structure are signed as the z_{ba}^M, $b = 1, 2, ..., s$, $a = 1, 2, ..., r$.

The M_U^L processes links matrix is $(n + s) \times s$, where U is the number of assembly processes realised in the system, n is the number of the Pj additional processes realised in the system; the realisation of those processes is equivalent to supply of the elements previously machined or purchased into the assembly system; s is the number of the S_b assembly units realised in the considered assembly system. That matrix specifies the links between the Pj additional processes and the S_b assembly units as well as the number of elements needed for the realisation of the consecutive assembly process steps. The M_U^L matrix also informs which additional processes and/or assembly units enter the given resource and which assembly units exit from that resource. The M_U^L matrix elements are signed in two different ways depending on the occupied matrix position. The z_{jb}^L matrix elements are allocated in the rows corresponding with the Pj additional processes, $j = 1, 2, ..., n$, $b = 1, 2, ..., s$. However, the $z_{(n+x)b}^L$ matrix elements are allocated in the rows corresponding with the S_b assembly units; $x \in (1,2,...,s)$, $x \neq b$.

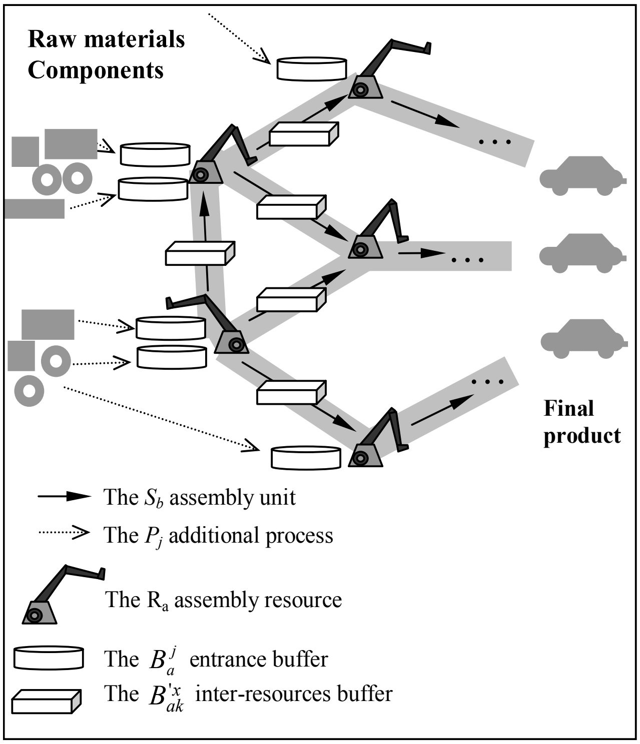

Fig. 2. An exemplary assembly system

There are two kinds of buffers allocated in the considered assembly system: entrance buffers and inter-resources buffers. The entrance buffers are allocated at the beginning of the production route. There are the B_a^j entrance buffers before each R_a assembly resource, $j = 1, 2, ..., n$, $a = 1, 2, ..., r$. They collect elements machined during previous steps of the technological process or purchased from suppliers. The B'^x_{ak} inter-resources buffers are allocated between each (R_a, R_k) pair of neighbouring resources at which the S_x assembly unit is realised, $x \in (1,2,...,s)$, $a = 1, 2, ..., r$, $k = 1, 2, ..., r$, $a \neq k$. Note that for the same elements forming different assembly units the separate inter-resources buffers are indispensable.

The required number of elements allocated to the entrance buffers in order to the production realisation during the first cycle of the system steady state is determined in accordance with the interdependence (1):

$$c_a^j = \begin{cases} \sum_{b=1}^{s} z_{ba}^M \cdot z_{jb}^L, & \text{if the } P_j \text{ is used in assembly at the } R_a \\ 0, & \text{in the opposite case} \end{cases} \tag{1}$$

where c_a^j is the required number of elements coming from the Pj additional process to the B_a^j entrance buffer which occurs before the R_a resource, $a = 1, 2, ..., r$, $j = 1, 2, ..., n$.

The required number of elements allocated to the inter-resources buffers for the production realisation during the first cycle of the system steady state is determined in accordance with the interdependence (2):

$$c'^x_{ak} = \begin{cases} \sum_{b=1}^{s} z_{bk}^M \cdot z_{(n+x)b}^L, & \text{if the } S_b \text{ is assembled at the } R_a \\ 0, & \text{in the opposite case} \end{cases} \tag{2}$$

where C'^x_{ak} is the required number of elements coming from the S_x assembly units to the B'^x_{ak} inter-resources buffer which occurs between the (R_a, R_k) pair of neighbouring resources, $x \in (1,2,..., s)$, $a = 1, 2, ..., r$, $k = 1, 2, ..., r$, $a \neq k$.

The elements allocation into the entrance buffers according to the (1) interdependence and into the inter-resources buffers according to the (2) interdependence guarantees the system synchronisation into the expected steady state. Deadlock-free system behaviour during the starting-up phase is ensured if the minimal required capacities of the entrance buffers is equal c_a^j and the minimal required capacities of the inter-resources buffers is equal c'^x_{ak}. On the basis of that information the rules controlling the assembly system work should be formulated.

4. Conclusions

In that paper problems occurring during production planning and control in the assembly systems have been considered. There are two kinds of system buffers: the entrance buffers and the inter-resources buffers. To develop the formulas specifying the minimal capacity of the system buffers is the main achievement of the given paper. Those formulas constitute the first step towards the formulation of the automatic method. That method is designed for the automatic construction of rules controlling the system work during transition state of the system when the system does not work in the steady rhythm. The presented approach permits to solve the problem concerning the synchronisation of the assembly system work into the expected steady state determined by the system bottleneck.

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