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The selection of the production route in the assembly system

A. Dobrzańska-Danikiewicz*, D. Krenczyk
[a] Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology, ul.Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: anna.dobrzanska@polsl.pl

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ABSTRACT

Purpose: The aim of the conducted research is the outworking of the methodology enabling the selection of the fastest production route from the set of the alternative production routes. The presented approach is applied to the assembly system described by the following matrices: the assembly process matrices specified for each assembly process, the processes links matrix specified for the entire system and the alternative routes matrix specified for the entire system. In the considered assembly system rhythmic concurrent production with wide assortment is realised.
Design/methodology/approach: The considerations presented in that paper have the theoretical roots in theory of constraints as well as critical path scheduling techniques.
Findings: The result of carried out works is the three-step methodology enabling the determination which production route from the set of the alternative production routes enables the fastest customer order realisation. The proposed methodology enables production planning in the way ensuring the satisfaction of the customer needs as soon as possible.
Research limitations/implications: The future research will concern the assembly system behaviour in a starting-up phase and a cease phase as well as transient phases. That work boils down to meta-rules determination for the considered class of the system.
Practical implications: The proposed three-step methodology can become the integrated part of existing authority software. The outworked computer system aids the decision-making process connected with production planning and ensures effective utilisation of production resources.
Originality/value: The main achievement of the given paper is to outwork the three-step methodology permitting to solve the decision problem concerning the selection of the fastest production route from the set of the alternative production routes, which are possible for the realisation in the assembly system.
Keywords: Production and operations management; Assembly system; Production route

1. Introduction

The activity strategies of the industrial firms have been oriented at customer needs, demand changes and requirements defined by marketing staff. The contemporary enterprises often produce complex product in various forms, which differ from each other with components, parts or sub-assemblies. There are rapid developing branches of industry dealing mainly with assembly processes, i.e. computer, furniture, audio-video and motor industry. Hence, the competitiveness of that group of enterprises depends on the rate, costs and quality of assembly processes [1].

One of the important problems concerning the production organisation in the assembly systems working in changeable environment is the production routes determination. One kind of a product can be produced in different ways, thereby using some alternative production routes. Hence, the logical function "OR" has been considered. That approach ensures the flexibility of the production route selection depending on an current situation and facilitates the administration of the production routes. Information about alternative ways of the customer order realisation can be used in order to select the production route enabling the fastest realisation of that customer order. The issue of the selection of the fastest production route in the assembly system is the subject matter of the detailed considerations conducted in that paper.

2. Contemporary assembly systems

Recently, more and more often core business of modern enterprises is production including different kinds of assembly processes. The enterprises mainly dealing with assembly are called assembly systems. Generally, there are manual assembly systems; manual and automatic assembly systems; and automatic assembly systems. The manual assembly system is characterised by the important role of an operator in the maintenance and decisions making [3]. The manual assembly can be realised within the confines of manual single-station assemblies and manual assembly lines. The manual and automatic systems are characterised by partial automation of the assembly processes. However, an operator making decisions plays an important role [4]. The rapid technical development causes that automatic assembly systems started to be popular in contemporary enterprises. The automatic assembly systems are divided into following three main categories [5]: short-cycle assembly machines; flexible, modular assembly systems; and flexible, assembly systems with industrial robots. Short-cycle assembly machines are designed for one special assembly task realisation and they are used in mass production. The main feature of flexible, modular assembly systems is that all subsystems are constructed in a modular way [6]. The modularity of the assembly systems ensures: the easy system reconfiguration [7], tasks realisation thought many alternative ways, a high level of reusability, the fast development of the control technology and the reduction of the investment risk [8]. The flexible, modular assembly systems are used for a wide range of assembly tasks realisation. Flexible, assembly systems with industrial robots is the last group of the automatic assembly systems. There are three basic types of flexible, assembly systems with industrial robots: flexible assembly lines, flexible assembly cells and flex-link assembly systems. The largest number of industrial assembly robots is used in flexible assembly lines [9,10]. Flexible assembly cells are complex automated assembly stations with one or two assembly robots, many periphery devices and task-specific assembly devices [11]. Flex-link assembly systems are characterised by the transport realised by a use of workpiece carriers equipped with special lifting and holding devices. The application of those assembly systems makes sense when product has more than twenty parts and the demand for the finished goods is high.

3. Description of the considered system

The subject matter of the analysis carried out in that paper is the A assembly system existing in changeable environment. In that system rhythmic concurrent production with wide assortment is realised. The A system is in steady state, meaning that the earlier accepted production orders are realised in a certain rhythm and a starting-up phase and a cease phase have been omitted [12,13]. The considered A system is defined by the formula (1):

$$A = \Big(\{R_a, a = 1,2,...,r\}, \{S_b, b = 1,2,...,s\}, \{P_j, j = 1,2,..., n\}, \{C_a, a = 1,2,...,r\}\Big) \quad (1)$$

where R_a is the ath assembly resource (e.g. robot, manipulator, station of manual assembly); S_b is the bth assembly unit being the part of the N_u assembly process; N_u is the uth assembly process corresponding with the Z_u customer order realisation as well as the completion of the finished product ordered by the customer, $N_u \in \{N_1, N_2,..., N_U\}$, $Z_u = \{Z_1, Z_2,..., Z_U\}$; P_j is the jth additional process supplying the indispensable elements of realising the assembly; the set of those elements includes materials, components, parts, semi-finished goods and sub-assemblies which were previously machined in the system or purchased into the system; C_a is the inter-resources buffer allocated to each R_a assembly resource. The considered assembly system is described by the following matrices: the set of the M^{N_u} assembly process matrices, the M_U^L processes links matrix and the M_U^A alternative routes matrix.

The M^{N_u} assembly process matrix is $3 \times s_u$, where s_u is the number of assembly units belonging to the N_u assembly process, $s_u \le s$. The elements of the M^{N_u} processes links matrix are signed in the threefold way depending on the occupied matrix position. It has been assumed that $\Psi_b \in \{\Psi_1, \Psi_2, ..., \Psi_{S_u}\}$ and $N_u \in \{N_1, N_2,..., N_U\}$. The elements of the M^{N_u} matrix are signed as $z_{1\Psi_b}^{N_u}$, if they are allocated in the first row of the matrix. Those elements are the figures of the S_b consecutive assembly units belonging to the N_u assembly process. The elements of the M^{N_u} matrix are signed as $z_{2\Psi_b}^{N_u}$, if they are allocated in the second row of the matrix and inform about most likely processing time. Finally, the elements of the M^{N_u} matrix are signed as $z_{3\Psi_b}^{N_u}$, if they are allocated in the third row of the matrix and they inform about most likely set-up time.

The M_U^L processes links matrix is $(n+s) \times s$, where n is the number of the P_j additional processes realised in the system; those processes realisation is equivalent to supply of the elements previously machined or purchased into assembly resources; s is the number of the S_b assembly units realised in the considered assembly system [14]. Depending on the occupied matrix position the M_U^L matrix elements are signed in the twofold way. The z_{jb}^L matrix elements are allocated in the rows corresponding with the P_j additional processes. However, the $z_{(n+x)b}^L$ matrix elements are allocated in the rows corresponding with the S_b assembly units; $x \in (1,2,..., s)$, $x \ne b$. The M_U^L processes links matrix determines the links between the P_j additional processes and the S_b assembly units and informs about the number of the elements needed to the realisation of the consecutive steps of the assembly process. That matrix specifies which additional processes and/or assembly units enter the given assembly resource and which assembly units exit from that resource [15].

The M_U^A alternative routes matrix is $r \times s$, where r is the number of assembly resources existing in the system; s is the number of assembly units realised in the considered assembly system. The elements of the M_U^A alternative routes matrix are signed as z_{ab}^A and admit value *1*, if the assembly unit can be at the R_a assembly resource realised or *0* in the opposite case. The M_U^A alternative routes matrix informs at which assembly resources the given assembly units can be optionally realised.

4. Methodology

The A assembly system described by the set of matrices is given. The Z_u customer order should be realised in the A system as soon as possible. The realisation of the Z_u customer order is equivalent to the completion of the N_u assembly process. The completion of that assembly process can be executed in different ways. Those ways can be mathematically represented by the M_U^A alternative routes matrix.

The following question arises: *Which production route from the set of the alternative production routes enables the fastest customer order realisation?* In order to answer that question it is necessary to act according to the methodology. There are three following steps of the proposed methodology:

- The identification of the alternative production routes and the M_U^A alternative routes matrix construction;
- The calculation of the ET_{ab} expected times for each non-zero element of the M_U^A alternative routes matrix;
- The selection of the fastest production route from the set of the alternative production routes.

It has been assumed that the N_u assembly process includes the set of the S_b assembly units, $S_b \in \{S_1, S_2, ..., S_s\}$. Each S_b assembly unit can be realised at least at one from the set of the available assembly resources. The beginning data needed for the iterations realisation are as follows: the set of the M^{N_u} assembly process matrices, the M_U^L processes links matrix and the information about idle times at resources. According to a presented way it is necessary to know whether the considered S_b assembly unit can be realised at the R_a assembly resource. Next, it is checked whether the idle time at the R_a selected assembly resource is enough for the S_b assembly unit realisation at least once. The z_{ab}^A element of the M_U^A alternative routes matrix can admit values *one* or *zero*. It depends on the fact whether the R_a actually considered assembly resource belongs to the set of the assembly resources at which the S_b assembly unit can be realised. All assembly resources existing in the system should be checked for the given S_b assembly unit. Next, the same procedure should be repeated for each S_b assembly unit belonging to the N_u assembly process corresponding with the completion of the finished product ordered by the customer. The result of first step of the outworked methodology is the alternative routes matrix informing about every possible ways of the completion of the assembly units.

The M_U^A alternative routes matrix includes the z_{ab}^A matrix elements. The S_b assembly units belong to the N_u assembly process; thereby the completion of the N_u assembly process is equal to the creation of the finished product ordered by the customer. The expected time of the occupation of the R_a assembly resource during the given S_b assembly unit realisation can be defined as (2):

$$ET_{ab} = \frac{ST_{ab}^O + 4z_{3\Psi_b}^{N_u} + ST_{ab}^P}{6} + \frac{PT_{ab}^O + 4z_{2\Psi_b}^{N_u} + PT_{ab}^P}{6} \qquad (2)$$

where ST_{ab}^O is optimistic set-up time of the S_b assembly unit realised at the R_a assembly resource, $a = 1,2,...,r$, $b = 1,2,...,s$; $z_{3\Psi_b}^{N_u}$ is most likely set-up time of the S_b assembly unit realised at the R_a assembly resource described by the M^{N_u} assembly process matrix, $N_u \in \{N_1, N_2, ..., N_U\}$, $\Psi_b \in \{\Psi_1, \Psi_2, ..., \Psi_{S_u}\}$, $s_u \in \{s_1, s_2, ..., s_U\}$; ST_{ab}^P is pessimistic set-up time of the S_b assembly unit realised at the R_a assembly resource; PT_{ab}^O is optimistic processing time of the S_b assembly unit realised at the R_a assembly resource; $z_{2\Psi_b}^{N_u}$ is most likely processing time of the S_b assembly unit realised at the R_a assembly resource described by the M^{N_u} assembly process matrix; PT_{ab}^P is pessimistic processing time of the S_b assembly unit realised at the R_a assembly resource.

The last step of the proposed three-step methodology concerns the selection of the fastest production route from the set of the possible production routes. The subject of the carried out analysis are non-zero elements of the M_U^A alternative routes matrix. The analysis concerns the bth consecutive matrix column corresponding with the S_b consecutive assembly unit. Among all expected times calculated for the z_{ab}^A non-zero elements of the bth matrix column should be selected one which has the minimum value. The R_a assembly resource corresponding with the z_{ab}^A matrix element is the found element of the FP_u production route. The described procedure should be repeated with reference to each column of the M_U^A alternative routes matrix. The final result of the application of third step of the methodology has been the production route which enables the customer order realisation in the shortest possible time. The FP_u fastest production route determines at which R_a consecutive assembly resources should be realised S_b assembly units forming the N_u assembly process in order to minimise the time of the finished product manufacturing. The FP_u the fastest production route enabling the completion of the N_u assembly process is given by (3):

$$FP_u = \{\rho_{u1}, \rho_{u2}, ..., \rho_{us_u}\} \quad (3)$$

where $\rho_{u1}, \rho_{u2}, ..., \rho_{us_u}$ are the figures of the assembly resources; the production realised at those resources enables the fastest completion of the N_u assembly process; $u \in \{1,2,...,U\}$, U is the number of the assembly processes realised in the A assembly system; $s_u \in \{s_1, s_2, ..., s_U\}$, s_u is the number of the assembly units forming the N_u assembly process.

5. Conclusions

In that paper the logical function "OR" in relation to the production routes has been considered. According to those production routes the completion of the given assembly process in the analysed system can take place. That system belongs to the set of the assembly systems and is described by the set of the assembly process matrices, the processes links matrix and the alternative routes matrix. The proposed methodology enables fast determination of the production routes with the shortest occupation time of the assembly resources. That methodology includes three steps. First, the identification of the production routes and description that knowledge in the M_U^A alternative routes matrix is necessary. Next, the expected time of the occupation of the given assembly resources during the given assembly units realisation is calculated. The expected time of the occupation of the R_a assembly resource during the S_b assembly unit realisation is the sum of the expected set-up time and the expected processing time. The last step is connected with the selection of the fastest production route from the set of the alternative production routes. The proposed three-step methodology enables production planning in the way which guarantees the fastest customer order realisation, thereby satisfying the customer needs as soon as possible.

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