3B

UDC 681.51

R. Bucki
The College of Computer Science and Management, Bielsko-Biała, Poland
rbucki@wsi.edu.pl

Modelling Flexible Production System

The article highlights the problem of modelling the flexible production system which is used to manufacture orders in accordance with the proposed control algorithms. The tools replacement is carried out under the control of the replacement heuristic. The equations of state of the production system and the stand are given as well as the order vector resulting from general assumptions. Furthermore, the changeable structure of the whole system is emphasized.

Introduction

In today's highly competitive world, there is an increasing pressure for companies to concentrate on continuous improvements. In the manufacturing environment this means that companies will often review their factory layouts or the way in which the factory is controlled and managed. Today's market system requires manufacturing flexibility to ensure low production costs and frequent assortment changes. On the other hand, it is also important to develop technological requirements of the products. Production should also include the need for either tight product tolerances or short lead times [1].

A flexible production system is in fact a foundation for a computer program aimed at providing a form of artificial intelligence. There is a set of rules which control the production process and show how the system behaves. These rules enable the system operator to plan production, obtain expert knowledge and select the appropriate action [2]. A flexible production system provides the mechanism necessary to execute production steps in order to achieve optimization of functionality [3]. Satisfying the production requirements remains a very complex issue while designing a system for manufacturing certain types of products. The most effective solution to production challenges are sought for taking into account production management and performance evaluation. If the system is dedicated, it is much more difficult to adapt it to the new order environment [4]. However, if the system is more elastic, its flexibility helps manufactures change the course of production within a short period of time. The use of dedicated machines has its impact on the architecture of the system and enables the designer of such a system to meet the needs of potential clients only then when the system is designed explicitly [5].

The proposed design approach represents a general production context and the author has concentrated on the main aspects which are to show the reader the methodology of modeling a production system of this kind. Particular attention has been paid to mathematical modelling with the aim of building a simulator which would let us evaluate various production strategies for the operation of the technological system.

General assumptions

The production system presented in this article consists of production stands placed in M rows and N columns. Any stand is characterized by its coordinates m, $m=1,...,M$ and n, $n=1,...,N$ (fig. 1). Each existing production stand $\omega_{m,n}$ can perform a defined production operation which requires a specific time to be completed and only then the manufactured product is passed to the subsequent stand. Every product manufactured by the system needs its specific route to be defined. The system consists of stands which are used for production, were used or will be used and those which are non-existent for the reasons given further. It is assumed that the charge is universal which means any type of product can be manufactured from it. The charge is passed through the determined route in the production system. The products must satisfy the order vector.

$$\text{Charge} \quad \Rightarrow \left\{ \begin{matrix} 1,1 & ..... & 1,n & ..... & 1,N \\ ..... & ..... & ..... & ..... & ..... \\ m,1 & ..... & m,n & ..... & m,N \\ ..... & ..... & ..... & ..... & ..... \\ M,1 & ..... & M,n & ..... & M,N \end{matrix} \right\} \Rightarrow \quad \text{Products}$$

Figure 1 – The production system

Let us assume the order vector is given as $Z=[z_c]$, $c=1,...,C$, where z_c is the c-th order. Let us also introduce the structure matrix for producing the product z_c: $E^c = \lfloor e^c_{m,n} \rfloor$, where $e^c_{m,n}$ represents the stand $\omega_{m,n}$ in the system used for manufacturing the product z_c. The elements of the matrix E^c take the following values:

$$e^c_{m,n} = \begin{cases} m, & \text{if the stand in the m-th row of the n-th column exists} \\ & \text{and is used to produce the order } z_c, \\ 0, & \text{if the stand in the m-th row of the n-th column exists} \\ & \text{and was used or will be used to produce the order from the vector Z,} \\ -m, & \text{if the stand in the m-th row of the n-th column does not exist.} \end{cases}$$

As seen above, there can be C matrixes of structure. To produce the order z_c the structure matrix must be adjusted. After finishing realizing the order z_c the production process is brought to a halt because the structure is transformed for the next product or, if all elements of the vector Z have been manufactured, the production is over. Only one product can be manufactured in the given production system at one time.

Let us introduce the route matrix of products for manufacturing elements of vector Z: $D^Z = \lfloor d^c_{m,n} \rfloor$, where $d^c_{m,n}$ is the number of the stand in the m-th row of the n-th column which shapes the z-th product. Moreover, the elements of the matrix are defined below as $d^c_{m,n} = m$, $m=1,...,M$, $n=1,...,N$. Let $g_{m,n}$ be the life of the tool in the stand in the m-th row of the n-th column. Then the life matrix of stands can be presented as $G = \lfloor g_{m,n} \rfloor$.

To produce a product there are K states needed. Let $s^k_{m,n}$ be the state of the tool of the stand in the m-th row of the n-th column in the k-th state. Then the state matrix of stands in the k-th state can be shown as follows: $S^k = \lfloor s^k_{m,n} \rfloor$. The state must meet the following condition: $s^k_{m,n} < g_{m,n}$. If $s^k_{m,n} = g_{m,n}$, then the tool in the stand in the m-th row of the n-th column must be replaced.

Let us consider the production process which leads to the change of the state:

$$S^0 \rightarrow S^1 \rightarrow ..... \rightarrow S^k \rightarrow ..... \rightarrow S^{K-1} \rightarrow S^K.$$

Let $p^k_{m,n}$ be the capacity of the stand in the m-th row of the n-th column in the k-th state. Then the capacity matrix of stands in the k-th state can be shown as follows: $P^k = \lfloor p^k_{m,n} \rfloor$. For each existing stand the following expression is valid: $p^k_{m,n} = g_{m,n} - s^k_{m,n}$.

Let R be the route capacity vector for producing products z_c, $c = 1,...,C$ as the elements of the vector Z. This can be defined as follows: $R = [r_c]$, where r_c is the capacity of the route for producing the product z_c.

The total production time of products given in the vector Z is as follows:

$$\tau = \tau_{ef} + \tau_{repl} + \tau_{del},$$

where τ_{ef} is the effective production time, τ_{repl} is the replacement time of tools, and τ_{del} is the time of awaiting the necessary delivery when the system cannot be operated (these times are stochastic).

The production of the c-th product is stopped when the stand in the m-th row of the n-th column in the k-th state is brought to a standstill because of its total usage. Then the tool in it is to be replaced. The times of replacement of tools are shown by means of the replacement times matrix: $T^r = \lfloor \tau^r_{m,n} \rfloor$, where $\tau^r_{m,n}$ is the replacement time of the tool in the stand $\omega_{m,n}$.

Let us introduce the production times matrix: $T_{ef} = \lfloor \tau_{m,n} \rfloor$, where $\tau_{m,n}$ is the production time in the stand $\omega_{m,n}$. The production times of stands may differ as they carry out different operations. If a preceding stand's time of carrying out an operation is higher than the considered stand's time, then the stand awaits the product. In the opposite case, the stand blocks the previous stand as there are no buffer stores in the system. An ideal situation appears when the stand's operating time and the preceding stand's operating time are the same.

To simplify the whole case, it is assumed that a production operation carried out at each stand of the system takes the same period of time so the production process is treated as the continues one. If the stand $\omega_{m,n}$ in the route for manufacturing the c-th product cannot produce any more products, then an alternative route for another product is determined and, in the meantime, the used up tool in the stand $\omega_{m,n}$ is exchanged.

Equations of state of the production system

The initial state S^0 is given. The equation of state of the production system takes the general form:

$$S^k = f(S^{k-1}, x^k_c, \omega_{\mu,\eta}),$$

where x_c^k is the amount of the product z_c realized in the k-th step; $\omega_{\mu,\eta}$ is the stand with the tool assigned to replacement, $1 \le \mu \le M$, $1 \le \eta \le N$.

In a production case the decision x_c^k is made on the basis of a determined algorithm.

As the orders are not realized as a whole, therefore K>Z. Decision numeration allows for tools' replacement.

Let us make the following assumptions:

– the production rate vector is $V = [v_c]$, $c = 1,...,C$, where v_c is the number of the product z_c units manufactured in the given time;

– the order vector of products at the moment $k = 0$: $Z^0 = [z_c^0]$, $c = 1,...,C$, where z_c^0 is the c-th product units number at the moment of ordering.

In the course of production orders decrease: Z^0, Z^1,..., Z^k,..., Z^K, which means that after each decision k the vector Z is modified. Simultaneously, we assume that $Z^0 = [z_c^0]$ is bigger than the flow capacity, so the orders are realized partially. Orders are realized to the end when all vector Z^k elements are equal 0.

If an order z_c^0, where $c = 1,...,C$, is completely realized and at the same time no other route passes through the given stand, then we assume that $g_{m,n} = -m$. In such a case, after the given order realization, the number of products left to be manufactured decreases by one.

Let us determine the following:

$$Z = [z_c^{k-1}], \ k = 1,\dots, K,$$

where z_c^{k-1} is the order c number in state $k-1$.

The order vector changes after each decision about production (x_c^k) is:

$$z_n^k = \begin{cases} z_c^{k-1} - x_{z_c}^k, & \text{if } c = \alpha; \\ z_c^{k-1}, & \text{if } c \ne \alpha, \end{cases}$$

where x_c^k is the number of units of the product z_c to be manufactured in the k-th step.

The equation of state can be presented as follows:

$$s_{m,n}^k = \begin{cases} s_{m,n}^{k-1}, & \text{if the charge is not passed through the stand in the m-th row of the n-th column,} \\ s_{m,n}^{k-1} + \min\left(r_\alpha^{k-1}, z_\alpha^{k-1}\right), & \text{otherwise.} \end{cases}$$

In case of the tool replacement in the stand $\omega_{m,n}$ the equation of state takes the form:

$$s_{m,n}^k = \begin{cases} s_{m,n}^{k-1}, & \text{if the tool in the stand } \omega_{m,n} \text{ is not replaced,} \\ 0, & \text{otherwise.} \end{cases}$$

As it can be seen above, replacement brings about the opportunity for starting further production.

Algorithms

Production algorithms

Heuristic algorithms are the core of the production system as their proper implementing may minimize the total manufacturing time, lower production costs by replacing fully or nearly used tools $\left(p_{m,n}^{k} \to 0\right)$ or fulfill special requirements of the clients.

We can put forward the following heuristics which are responsible for choosing the route to produce the order z_c.

– *The maximal order heuristic:*

$$\left(q^k = \varepsilon\right) \Leftrightarrow \left(z_\varepsilon^{k-1} = \max_{1 \le c < C} z_c\right).$$

This algorithm finds and determines the biggest remaining order and is justified by avoiding excessively bringing the production line to a standstill. The route is changed only when it is blocked by a used up stand in it.

– *The minimal order heuristic:*

$$\left(q^k = \varepsilon\right) \Leftrightarrow \left(z_\varepsilon^{k-1} = \min_{1 \le c < C} z_c\right).$$

This algorithm finds and determines the smallest remaining order and is justified by letting the system complete manufacturing one group of products z_c, $c = 1,...,C$ earlier and dispatch these products immediately to the client.

– *The maximal flow capacity heuristic:*

$$r_\varepsilon^{k-1} = \max_{1 \le c < C} r_c^{k-1}.$$

This algorithm leads to blocking the route by using up at least one stand in its course.

– *The minimal flow capacity heuristic:*

$$r_\varepsilon^{k-1} = \min_{1 \le c < C} r_c^{k-1}.$$

This algorithm enables liquidating the remaining pass capacity of the stand with the lowest flow capacity.

Replacement algorithm

If the currently used route becomes blocked, another one is chosen so that another product z_c could be realized until the newly chosen route either becomes blocked or the product z_c realization has come to the end. Then the realization of the subsequent product begins. Control by means of a stand replacement heuristic may be the only way of minimizing the production time and cutting the costs. To simplify the whole case no tolerance for replacement is used, and only the completely used tool can be replaced. Should there be two or more completely used tools in the stands, the stand with the lowest number n is subjected to replacement. If, after the replacement of a tool in the stand, another route appears for manufacturing any remaining product z_c, it is produced according to control choice by the set production algorithm.

Conclusions

The presented approach represents a highly complex flexible production system. The structure of the system is modified each time when a new product is to be manufactured. The equations of state show the change of state of the system, the stand itself and the order. The four control algorithms show that experimenting with production tasks is possible with the use of any of them. The tools replacement is carried out under the supervision of the replacement heuristic. Knowing that there is an order to be realized, we can easily find out in advance what kind of charge will be necessary, and what amount of it will be needed. However, any of the methods used in industry to create goods and services from various resources should be simulated in advance to find the best and fastest way to realize the order (it should be later verified). There is a direct need to simulate as the system is characterized by uncertainty and its complexity. Real life experiments seem to be impossible as there is too much risk, and the costs are too high. Direct experimentation is the cheapest alternative allowing compressing or expanding time. Simulations are precisely repeatable offering risk-free environment. Interactive simulation lets a model build in small steps (model building interaction), and change the model during the run (model user interaction).

Literature

1. Tolio T. Design of Flexible Production Systems: Methodologies and Tools / Tolio T. – Berlin-Heidelberg : Springer-Verlag, 2009. – 300 p.
2. Буцкі Р. Комп’ютерне моделювання процесів управління виробничими лініями / Р. Буцкі, Ф. Марецький. – Львів : Держкомзв’язку України, НАН України, Державний науково-дослідний інститут інформаційної інфраструктури, 2006. – 112 с.
3. Bucki R. Thorough analysis of the technological case control / R. Bucki // Management & Informatics. – Network Integrators Associates. – 2007. – Vol. 1, № 1. – P. 68-112.
4. Marecki F., Bucki R. Robots group control in the production line / F. Marecki, R. Bucki // Artificial Intelligence. – 2005. – № 3. – P. 322-327.
5. Bucki R., Marecki F. Computer-based simulators of logistic systems / Selected Problems of IT Application / Ed. Grabara J.K. – Warszawa : WNT, 2004. – P. 29-38.

Р. Буцки
Моделирование гибких производственных систем
Статья посвящена проблеме моделирования гибкой производственной системы, которая используется для изготовления изделий в соответствии с предлагаемыми алгоритмами управления. Перемещение средств производства в такой системе осуществляется в соответствии с определенной стратегией. Сформированы уравнения состояния производственной системы и рабочего места, а также вектор заказов с учетом базовых допущений. Основное внимание обращено на изменяемость структуры всей системы.

Р. Буцкі
Моделювання гнучких виробничих систем
Стаття присвячена проблемі моделювання гнучкої виробничої системи, яка використовується для виготовлення виробів у відповідності з пропонованими алгоритмами управління. Переміщення виробничих засобів в такій системі здійснюється у відповідності з певною стратегією. Сформовано рівняння стану виробничої системи та окремо взятого робочого місця, а також вектор замовлень з врахуванням базових допущень. Основну увагу звернуто на змінність структури всієї системи.

Статья поступила в редакцию 20.05.2009.