

# Analysis of manufacturing systems using Petri nets

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**Abstract** — This article deals with the analysis of manufacturing systems that are modeled using Petri nets. The purpose of this article is present the tool for analysis of manufacturing systems in the design phase and helps to create real manufacturing systems. Article present an application that allows calculation of the reachability of wished state, the time transformation PN to the wished state and production costs on the basis of calculation for firing sequence. The existences of a firing sequence the feasibility of the selected state. With firing sequence is possible to calculate the time for transformation PN, performance of the manufacturing system, as well as production costs.

**Keywords** — Petri net, manufacturing system, incidence matrix, firing sequence

## I. INTRODUCTION

A new manufacturing system is differing from the older and especially the complexity of the technology used. Today is trend to fully automate production to increase reliability, quality, productivity and efficiency. One of the main reasons for the automation of manufacturing systems is to reduce time to production and thereby increase production. When designing manufacturing systems, it is difficult to analyze the proposed project. Analysis of the project design phase often brings suggestions for improvement that is easily incorporated into the project. The analysis of the real systems brings better results, but improvement project is challenging. One of the aspects that can be analyzed is the time of the production cycle. If this is insufficient time already in the design phase, it is clear that the project not met demands for production. In this situation it is necessary to prevent early analysis and optimization of production systems.

In the first part of the article deals with the description of the model Flexible Manufacturing System (FMS) using Petri nets (PN).

The second part is devoted to the description of the application that analyzes the production system is modeled by PN. Application to the calculation of firing sequence analyzes production system.

## II. DESCRIPTION OF THE MANUFACTURING PROCESS

### A. Description of the model FMS

The production system can be considered a model of a fully automated production line, which was called FMS and serves as a learning model. The FMP is located at the Department of Cybernetics and Artificial Intelligence (KKUI), Technical University (TU) of Košice. This model is placed in the laboratory V147, which is at a Vysokoškolska street number 4. FMS is used in teaching and in the creation of bachelors, masters and doctoral theses. FMS is shown in Fig. 1 and a detailed description can be found in [1], [2] and [3].



Fig. 1. Flexible manufacturing system

**B. Description of the model FMS using PN**

The real model FMS is modeled using a generalized PN, which is shown on figure Fig.2. This model describes the activities of FMS. To monitor the time required to manufacture the product is necessary to extend this model for times of operation. The extension of the generalized PN with times we create T - timing PN. On model FMS is shown the basic calculations to be carried out to analyze the PN, which models the real manufacturing system.

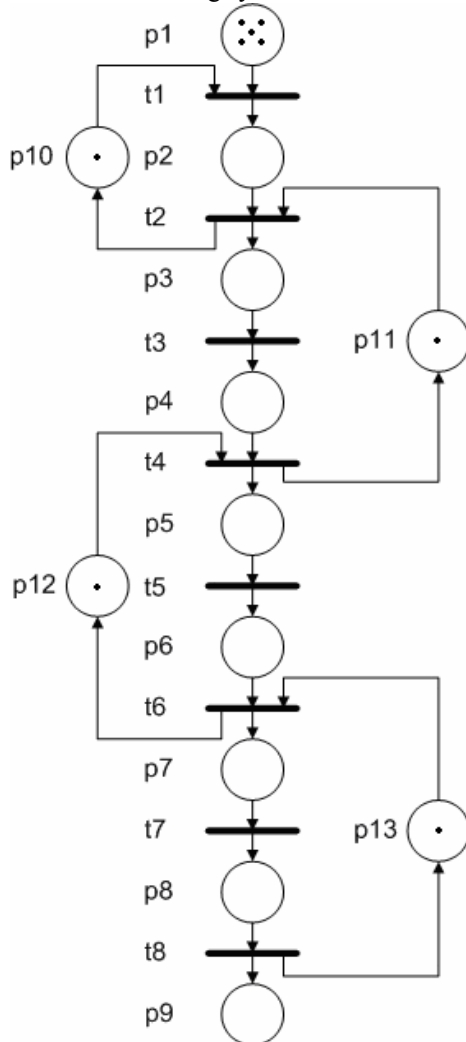


Fig. 2. PN modeling FMS

**The places and transitions in the PN, these states and activities of FMS:**

- p1 – a pallet is on input storage of post 3 and waiting for the release of the post 4,
- t1 - the movement of pallet on the post 4,
- p2 - a pallet of post 4 is ready to move to second conveyor and waiting for the release of the post 5,
- t2 - move pallet from first conveyor to second conveyor and then on post 5, release of post 4,
- p3 - a full pallet of post 5 is ready for emptying,
- t3 - emptying pallet on the post 5,
- p4 - empty pallet on the post 5 is ready to move and waiting for the release of the post 1,
- t4 - move pallet of post 1, release post 5,
- p5 – a pallet is on the post 1 and waiting for a folding shape,
- t5 - folding pictures in a pallet of post 1,

- p6 - a full pallet of post 1 is ready to move and waiting for the release of the post 2,
- t6 - transfer a pallet to post 2, release post 1,
- p7 - a pallet of post 2 is waiting for the end of control by camera,
- t7 - control by camera for a pallet of post 2,
- p8 - a pallet after control by camera on the post 2 is ready to move to the output storage on post 3,
- t8 - move pallet to the output storage on post 3, release post 2,
- p9 – a pallet is the output storage on post 3,
- p10 - post 4 is free,
- p11 - post 5 is free,
- p12 - a post is free,
- p13 - post 2 is free.

Model of manufacturing system must satisfy certain properties of PN such as reachability, liveness, conflictless, reversibility, and can not include own cycles.

PN of figure Fig. 2 can be described using matrices to describe the T - timed PN.

$$N = (P, T, pre, post, M_0, Tempo)$$

where  $P = \{p1, p2, \dots, pm\}$  is a finite set of places,  
 $T = \{t1, t2, \dots, tn\}$  is a finite set of transitions,  
 $pre$  - is direct incidence function,  $pre: P \times T \rightarrow N$ ,  
 $post$  - is backward incidence function,  $post: P \times T \rightarrow N$ ,  
 $M_0$  - is initial marking  $M_0: P \rightarrow N$ ,  
 $Tempo (t_i) = d_i$  - specifies the time interval of the implementation of transitions, where  $d_i \geq 0$ .

The matrix  $pre$  a  $post$ , according to equation (1) calculate the incidence matrix  $C$ .

$$C = post - pre \tag{1}$$

$$C = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \end{bmatrix} \tag{2}$$

**III. ANALYSIS FMS USING PN**

**A. Insert the inputs to an application to the analysis PN**

The application is a simple tool for the analysis of PN, which is described by matrices. Description by PN matrix is a simple procedure that can be done in the PN modeling programs as well as manually. Most modeling tools provide a description of the PN with matrices  $pre$ ,  $post$  and  $M_0$  [5].

Matrix *pre* describes the multiplicity of input arcs into transitions and matrix *post* describes the multiplicity of output arcs from the transitions. Matrix  $M_0$  describes the initial marking PN. These matrixes are input to an application to the analysis of PN. Matrix *pre* a *post* are usually sparse, so the manual entry of matrix application is sufficient to specify only non-zero values. Example of insert the matrixes into the application are shown on figure Fig. 3.

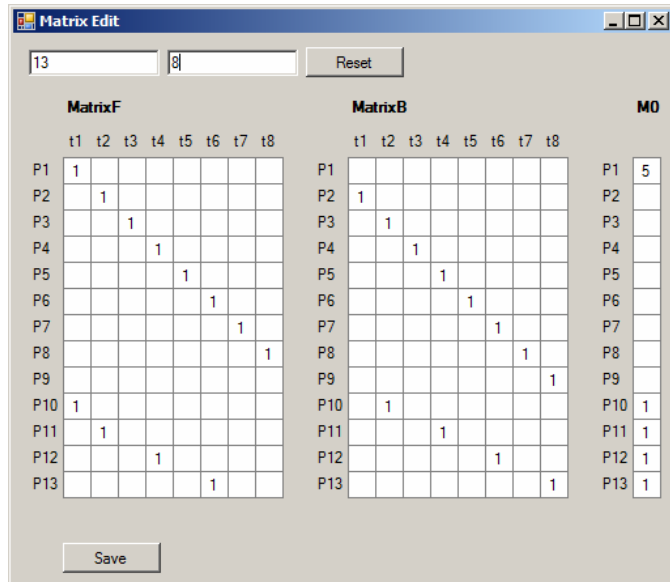


Fig. 3. Flexible manufacturing system

Matrixes after inserting into the application are stored and calculated the incidence matrix  $C$  for the PN. Reviews of matrixes are shown in a separate window that is on Fig. 4.

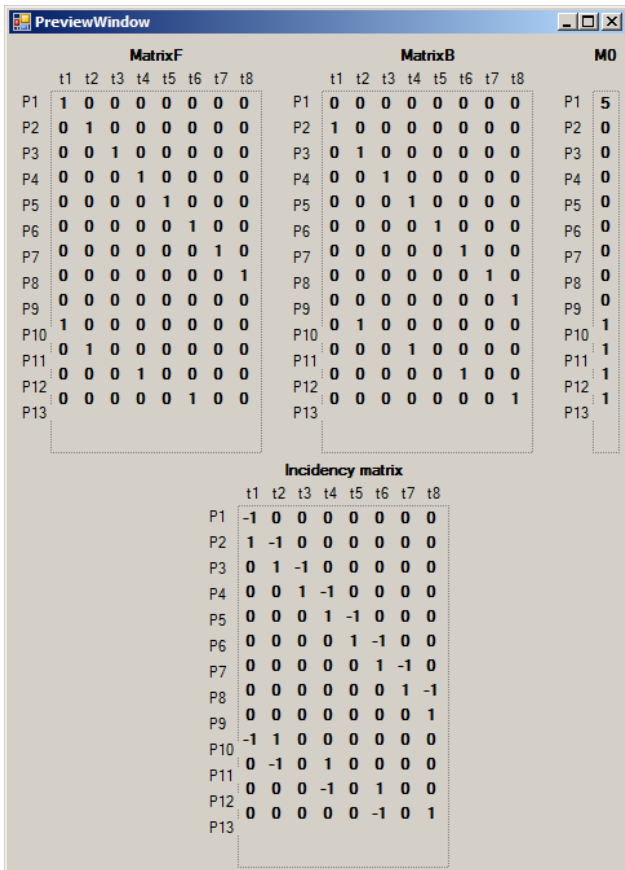


Fig. 4. Reviews of inserting matrix

The matrixes after the inserting can be edited. If the matrixes are correctly insert, can by go to the analysis of PN.

*B. Analysis PN using application*

The first step should be to verify the existence of the desired state of PN, but it is not a prerequisite.

For any state of PN is possible to calculate its reachability. Reachability state of PN can be detected from existence the firing sequence. If there existing firing sequence, which transforms the PN from the initial to the desired state then desired state is reachable. Firing sequence can take only nonnegative values of whole numbers. Firing sequence can be calculated using the modified state equation (3).

$$C^{-1} * (M_x - M_0) = \sigma \quad (3)$$

- where  $M_x$  – is desired state,
- $M_0$  – is initial marking of PN,
- $C$  – is incident matrix,
- $\sigma$  – is firing sequence.

The application after inserting the desired state is calculated the firing sequence, as is shown on Fig. 5. If the desired state is not reachable, the application displays an error message.

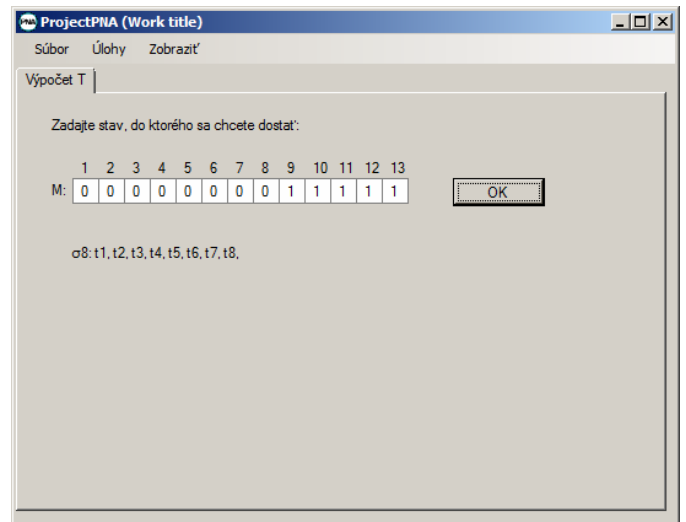


Fig. 5. Calculating firing sequence

For reachable states of the PN is possible make further analysis. The application allows to analyze the T and P timed PN. The PN model can specify time intervals for different places or transitions. According the time intervals are calculated time of transition for desire state of PN. The application calculates the costs necessary for the transformation of PN in the desired state. However, it must specify costs for each places or transitions of PN. On Fig. 6. is shown the screen, where is possible analyze the time and cost needed to transform the PN. Analysis of different states PN is impossible to compare the calculated values. Analysis of values is possible to assess whether the results obtained are sufficient or not [4].

Fig. 4. Screen for analysis production time and cost

The calculated value is the value of the real modeled manufacturing system. If reachable results are sufficient, is possible move to the implementation of the production system. However, if the results obtained are not insufficient we need to make changes in design and analysis execute again.

#### IV. CONCLUSION

The area of the design and implementation of production systems is nowadays becoming increasingly important. Major role in this respect have a new factories of the future, which seek to minimize human intervention in the production process. In the design of production systems are increasingly gaining prominence thorough analysis. One of the methods of analysis of production systems is the use of PN. Using the model of the production system can analyze some properties such as reachability state of the manufacturing process, the production time or production costs. Presented application is a simple tool for the analysis of PN, which modeled real manufacturing systems. Based on the results of the analysis of PN can decide on the implementation of the manufacturing system or its re-projection.

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