

# Performance analysis of the production line

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**Abstract** — This article deals with the performance analysis of the production line, which is modeled using Petri nets. The aim of this paper is to present a methodology that allows the performance analysis of real production lines or even the lines in their design phase. A current trend in the design of production lines is their modeling and analysis. This approach ensures the required properties and the possibility of preparing a production planning. Possibility to plan their production in the required quantity and quality on a fixed time or on periodic intervals is a goal of many manufacturing plants today.

**Keywords** — Petri nets, manufacturing line, performance, analysis

## I. INTRODUCTION

Production systems in present are different from the older mainly in their complexity and the technology used. Many production plants are using fully or semi-automated production systems with high requirements on reliability, quality, productivity and efficiency. One of the reasons for the fully automated production is to reduce the production time and thereby increasing the production. Increasing the production is connected with the increasing of requirements on storage space if the production logistics is missing. In such cases the JIT (just in time) systems come to the fore, which are designed to produce just right quantity at the time required and there is no need for storing. Analysis of the individual parts and mainly of the connections among them is the important part of the design when using JIT systems. An analysis of the project in its design phase often provides suggestions for improvement that are easily incorporated into the project. Analysis of the real systems can sometimes bring better results, but the improvements are difficult. In the analysis with respect to the JIT system is necessary to consider the real production capacity, which often differs from the ideal one of 20 to 30%. In modeling and later in the analysis of production systems in the design phase is often overlooked the fact that the results are often overstated and in practice unattainable. For modeling and analysis of the production line the Petri nets (PN) were chosen, which are suitable for discrete system modeling. Modeling allows us to know the characteristics of the production system before implementing or before modification. The simulation results are helpful in verifying the required performance of the production system.

First part of the article is devoted to the description of the production line model, which is modeled by timed PN.

The second part is devoted to the analysis of this model. The results of the model analysis are compared with the experimental results obtained on the real production line.

## II. PRODUCTION LINE DESCRIPTION

### A. Description of the production line model

Production line can be also considered as the model of fully automated production line (Fig. 1), which was named Flexible Manufacturing System (FMS) and is used for educational and research purposes.



Fig. 1. Flexible Manufacturing System

The model is located at the Department of Cybernetics and Artificial Intelligence (DCAI) of the Technical University (TU) in Košice. The model is located at the laboratory V147, on Vysokoškolska Street number 4. FMS is used in the learning process and in the process of bachelor, master and

doctoral theses creation. This model is divided into 5 posts that represent different parts of the production process. The manufacturing process starts with the templates selection from the stock, which is formed by the input and output storage. The selected template is placed on a conveyor belt by the manipulator, and moves to the end of the belt. It is then transferred to second conveyor belt, after which it moves to the fifth post. If the template is full it is emptying on this post. Empty template is moved to the post 1, where it is stored in with the colored cubes. This work presents an accurate assembly of parts or materials for a specified location on the product. After storing, the template moves on the end of the second conveyor, where the video camera control is made. It is in charge of verifying the correctness of the pattern stored. Finally, the template is moved back to the first conveyor,

moved to the post 3 and stored into the output storage. This entire production cycle is performed automatically and there can be simultaneously up to four templates in the production process. Each post is managed independently and its activity begins with the template arrival. This allows parallel handling up to four templates. Moreover, the sharing of resources is present on the post 3, where can the requirements for entry and exit of the template occur at one moment. A more detailed description can be found in [1] and [3].

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

FMS model described in the previous section is modeled by a generalized PN, which is shown in Fig.2. This model describes the activities of FMS.

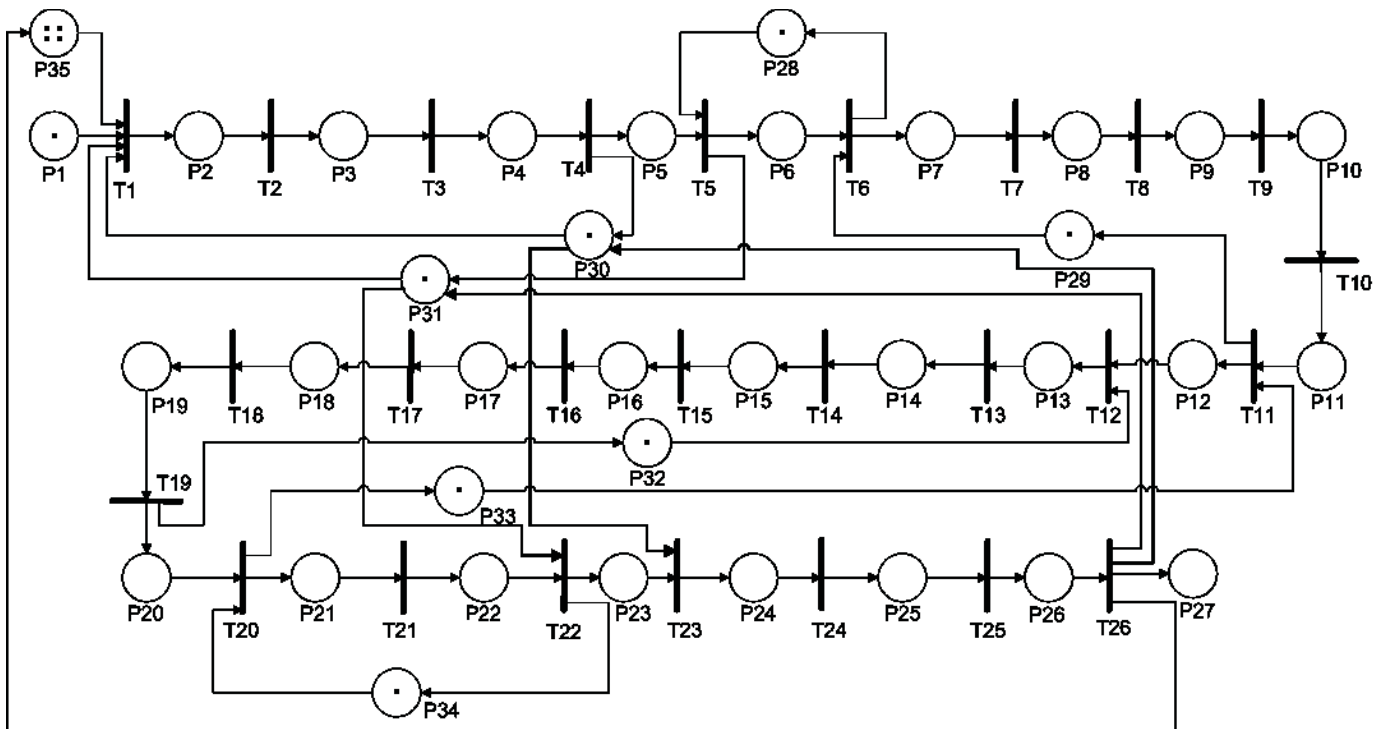


Fig. 2. PN model of the FMS.

Places P1 to P27 and transitions T1 to T26, is a major production of the production line where each operation is performed as described in Chapter II. Places P28, P29, P31, P33 and P34, determine whether the post is free, or the operation is held. Places P30 and P34 determine readiness of the manipulators. Place P35 determines the number of templates that can be produced at one time. The number of templates is limited to a maximum of four templates in the production. The initial marking of the model is derived from the state of the production line. All positions are free and manipulators are ready for the production. On the input stock P1 is one token representing a requirement to one template production. In the place P35 are located four tokens, providing an opportunity to produce four pieces at a time.

For the performance analysis of this model it is necessary to extend the model for times of the operations. These times can be obtained in the design phase from the specifications of the equipment intended to be used for the production line implementation. In this case, the individual times were obtained experimentally from the real model in ideal conditions. In order to obtain the time data there were

performed 100 measurements each time and the average value was considered for the reference one. Expanding the generalized PN with the times of individual transitions we obtain the T - timed PN. The model of timed PN will be used to analyze the performance of the manufacturing line, which is compared to a real production line under standard conditions. Ideal conditions compared to the standard ones always provide full cube stores, constant pressure, and failure-free state.

The proposed model of the production line must satisfy certain properties of PN such as reachability, liveness, conflictless, and can not include own cycles.

PN in Fig. 2 can be described using matrices to describe T - timed PN.

$$N = (P, T, pre, post, M_0, Tempo) \quad (1)$$

where  $P = \{p_1, p_2, \dots, p_m\}$  is a finite set of places,  
 $T = \{t_1, t_2, \dots, t_n\}$  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<sub>0</sub>* – is initial marking  $M_0 : P \rightarrow N$ ,  
*Tempo* ( $t_i$ ) =  $d_i$  – specifies the time interval of the implementation of transitions, where  $d_i \geq 0$ .

For the analysis it is necessary to know the matrixes *post* and *pre* from which it is possible to calculate the incidence matrix *C* [4] according to equation (2).

$$C = \text{post} - \text{pre} \quad (2)$$

Incidence matrix for the PN in Fig. 2 is not presented according to its dimensions of 54 x 26. Using the matrix *C*, *M<sub>0</sub>* and *M<sub>x</sub>*, which represents the desired state of the system, it is possible to work with the PN model not only graphically, but also analytically.

### III. PERFORMANCE ANALYSIS OF FMS

Performance analysis is created on the FMS model described in the previous chapter. Times of individual transitions have been obtained experimentally. These times can be entered into the rate matrix, which indicates the time intervals of the transitions. In the production systems are in terms of their analysis of the most interesting hour performance, it is how many pieces can produce per hour. In the case of fully automated production lines, it is interesting to see how many pieces produce for one shift, or 8 hours. For comparison, we create the analysis and the production time of one and hundred of products.

As the entry requirements for the analysis we consider:

1. number of pieces produced per 1 hour
2. number of pieces produced per 8 hour
3. production time of one piece
4. production time of 100 pieces

Analysis of the production line can be created in programs for modeling and analysis of PN such as CPNtool. But this program does not offer the time unit conversion (in this case milliseconds), into the form hh:mm:ss.fff, so the analysis is difficult. It also does not allow further processing of the results. The analysis was therefore created in the PNA tool described in [2], whose output is the time value in the form hh:mm:ss.fff and there is possibility of further work with the results.

After production line analysis, we can say that in the case of 100% performance it is able to produce:

1. 80 pieces in 1 hour
2. 643 pieces in 8 hours
3. 1 product for 45 second and 591 thousandths
4. 100 products for 1 hour 14 minutes 36 seconds and 534 thousandths

These values are valid for 100% performance of the production line.

The real production systems have certain requirements to the operation of the device. Operation of the device consists of activities during which the manufacturing process is not on. For example: insufficient supply of media, debugging,

adding of missing material to storage, maintenance of the manufacturing process, waiting for the primary component, etc. Ideal hourly performance of each production system actually decreases for the following reasons. According to [5], it is generally assumed ideal hourly decrease from 20% to 30% and even more in some of the production processes. Therefore, it is necessary to calculate the real performance per hour, which represents 80% or 70% of the ideal hourly performance of the manufacturing process. Table Tab. 1 summarizes the results of the simulation at 100%, 80% and 70% performance of production line (time is shown in the form h:mm:ss.fff).

Performance	100%	80%	70%
Number of pieces per 1 hour	80	64	56
Number of pieces per 8 hour	643	514	450
Production time of 1 piece	0:0:45.591	0:0:54.709	0:0:59.268
Production time of 100 pieces	1:14:36.534	1:29:31.841	1:36:59.494

Tab. 1.: Summary of simulation results

To verify of the simulation results, there were carried out experimental measurements on the real system, which was described in chapter II, and the simulation model was also based on it. During the measuring on the real system, there was an effort to simulate real conditions. In real measurements a few errors were simulated on the line. Like occasional waiting for the missing cube in the stack, occasional loss of pressure or simulation of line fault. All of these situations happen in real productions; therefore it was necessary to enforce the errors into the system during the control measurements on the real system. The results of experimental measurements are reported in table Tab. 2. In experiments 1 and 4 there were performed 5 measurements, and the result is the average value of these measurements. Experiment 2 was performed only once, because it is time-consuming. Experiment 3 was performed 50 times and the result is average value of these measurements.

	Average time / pc	Performance [%]
Number of pieces per 1 hour	67	83,75
Number of pieces per 8 hour	554	86,16
Time of 1 piece	0:0:56.389	80,08
Time of 100 pieces	1:28:11.965	84,59

Tab. 2.: The results from the real system

By comparing the experimental results obtained from the simulation results it can be concluded that the performance of the real production line is in ranges from 80.08 to 86.16%. These results correspond to the reality, when the error of lower air pressure was present during the measurements of one piece production, but for 8 hour measurement, this error did not occur all the time. Measurement has also showed that some of the lines actuators can be set better. The results of the additional measurements and analysis will be the subject of

other articles, since it requires more complex optimization of production line actuators.

#### IV. CONCLUSION

Progressive methods used to design and implement of production lines are more and more used in practice. Modeling and analysis is of great importance for the demanding performance requirements of the system. This work provides the use of PN as one of the ways to model and analysis of production lines. The results presented in this article suggest a potential for the analysis of the production line possible also in the design process.

Comparing simulation and experimental measurements results shows that the performance of production line in average is 82.65%. This performance compared to the performance considered in the literature (70% to 80%) can be considered as sufficient and it can be further improved by optimizing the actuators settings used in the production line. Without the use of the model and its analysis, we have might never come to the conclusion that the production line is able to work faster. Therefore it is possible to say that the analysis of the production line model helped to improve the performance of the real production line. In general we can say that the analysis of the model answers to the central question of whether the production system meets the required performance or not.

#### ACKNOWLEDGMENT

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