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# MASTER THESIS

## Maintenance of Flexible Manufacturing Systems using Petri Nets Modeling

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# ANL-MED

ANL-MEd assembles for 36 months a consortium with 14 partners with unique combination of skills and expertise. The consortium, coordinated by USTHB, has a hierarchical structure that ensures an efficient communication and cooperation. Four European universities with solid competence in maintenance engineering and management will contribute to development of teaching material and training students, teacher, trainers and industry staff. This will contribute to strengthening the active cooperation between university and industry, as well between Algeria and EU. The project activities are distributed in 7 work packages according to a detailed work plan that adequately structures the efforts into manageable work packages with clear responsibilities and objectives. For improved effectiveness in the project for organization of implementation, the partners are grouped in three clusters: ANL-EDUC – cluster for education, ANL-VET – cluster for vocational education and training and ANL-ORG for organization of the ANL, coordinating the resources for integration, communication and exploitation. The goal of the ANL-MEd is to provide Algerian industry with a new generation of skilled personnel, especially at mid- and higher levels, along with ensuring flexible and continuing education and training of industry personnel at all levels. Flexibility is necessary to adapt and update the knowledge according to the day-to-day progress of science and technology. The partners in the project have been selected above all to suit to the genuine structure of Algerian academia and industry and to align it to a modern and dynamic European standard. The reference line is represented by the two main characteristics of the Algerian industry

- Relative low productivity determined especially by the lacking knowledge in modern manufacturing technology, maintenance and asset integrity.
- Few large companies and many SMEs with very small resources for internal development.

## ACKNOWLEDGEMENTS

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# ABSTRACT

This paper presents a production manufacturing system model based on Petri Nets. In this work we are interested to studying the performance evaluation of the flexible manufacturing system (FMS) using Petri nets which are a powerful tool in modeling production systems. The studied model is a real production system from (Berlad URB groupe-Romania). The FMS type where we have considered various ratios to job to increase the complexity, like shared machines. The performance analysis of this FMS is based on these parameters scheduling routings, machines availability and insufficiency. The Petri net reacts to detected errors by changing the control flow of tokens in the Petri net during the operation of the system. The modeling and simulation allow to determine the FMS productivity, these parameters are important for the political choice strategy of reparation (maintenance) by switching defective machines with similar machines in the same system. We show the flexibility and simplicity of our modeling approach.

A case study of a manufacturing system is presented, the obtained results of simulation allows us to identify the best scheduling in the considered case, this scheduling will provide an optimal objective between production and maintenance of the manufacturing system.

Keywords:

**Flexible manufacturing systems – Petri nets – Modeling – Maintenance**

# RESUME

Ce document présente un modèle de système de fabrication basé sur les réseaux de Petri. Dans ce travail, nous intéressons à l'évaluation de la performance du système flexible de production (FMS) à l'aide des réseaux de Petri, qui constituent un puissant outil de modélisation des systèmes de production. Le modèle étudié est un véritable système de production de (Berlad URB groupe-Romania). Le type FMS où nous avons envisagé divers ratios d'emploi pour augmenter la complexité, comme des machines partagées. L'analyse des performances de ce FMS est basée sur ces paramètres : ordonnancement des routages, disponibilité et insuffisance des machines. Le réseau de Petri réagit aux erreurs détectées en modifiant le flux de contrôle des jetons dans le réseau de Petri pendant le fonctionnement du système. La modélisation et la simulation permettent de déterminer la productivité de système, ces paramètres sont importants pour le choix politique de la stratégie de réparation (maintenance) en commutant des machines défectueuses avec des machines similaires dans le même système. Nous montrons la flexibilité et la simplicité de notre approche de modélisation.

Une étude de cas d'un système de fabrication est présentée, les résultats obtenus de la simulation nous permettent d'identifier le meilleur ordonnancement dans le cas considéré. Cet ordonnancement fournira un objectif optimal entre la production et la maintenance du système de fabrication.

Les mots clés :

**Systèmes de fabrication flexibles - Réseaux de Petri - Modélisation - Maintenance**

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# INTRODUCTION

The master degree project mechatronics, carried out at the University of Galati, is part of the mobility of students of the project of the European Union "Algerian National Laboratory for Maintenance Education Project No. 586035-EPP- 1-2017-1-DZ-EPPKA2-CBHE-JP ". DUNAREA DE JOS University of Galati (Romania) and M'HAMED BOUGARA University of Boumerdes (Algeria) are partners in this international project.

The final project is entitled: Maintenance of flexible manufacturing systems using petri nets modeling. In this subject, three fundamental notions are predominant and deserve detailed explanations in the following chapters: maintenance, flexible manufacturing systems and Petri nets modeling.

Flexibility, responsiveness and agility are essential qualities for production systems that are faced with a varied and fluctuating demand with increasingly high quality and time constraints. The challenge for companies is therefore to install modular and flexible production tools with control systems capable of managing them. These must, on the one hand, adapt to the heterogeneity of available equipment (computers, robots, machines, etc.), equipment that can be replaced, removed or reconfigured as needed, and on the other hand, be robust face to the various malfunctions and hazards. Often there is a dilemma of modeling flexible production systems, between the development of an overly simplistic model that allows an analysis of the easy behavior of the manufacturing system that is flexible but far from its actual behavior, and a model that is closer to the real system, but whose the study is too complex. The ever-increasing complexity of production systems requires more and more representation methods and analysis techniques to efficiently account for the various features associated with the system as well as its temporal characteristics. This imperative inevitably leads to the need to have formal methods to verify a certain number of properties of interest of the modeled system. In recent years we have seen many methods and tools for the modeling, simulation and analysis of complex systems. To this end our choice fell on the Petri nets.

The using of Petri nets in the modelling has been emerged during 1960, from the contributions of Petri which won him the Degree of Ph.D. during 1962. The momentum of using of Petri nets and analysis based on transitions from firing of the nets has gained in the earlier 1980s. Petri net models, therefore, the resulting controlled model of the system is not maximally permissive. That is, the solutions obtained in such case are suboptimal. To overcome such situation in FMSs, a flexible manufacturing system (FMS) model is developed using Petri nets for analyzing the important qualitative aspects of FMS behavior such as existence / absence of deadlocks and butter overflows. It has also been observed that the classical invariant analysis of Petri net related to qualitative properties of the FMS such as existence of deadlocks, buffer overflow, invariance of number of jobs and recoverability from failures is determined. Later-on the FMS has undergone more than four generations by the year 1986 with the emergence Tool Management issues. To start with, issues are dealt with the analysis of Scheduling, Tool Management, Deadlocks and Overflows, Liveness and Siphons, and Monitoring and Control.

Using of supervisory control theory on the real systems in many modeling tools such as Petri Net (PN) becomes challenging in recent years due to the significant states in the automata models or uncontrollable events. The uncontrollable events initiate the forbidden states which might be removed by employing some linear constraints. Although there are many methods which have been proposed to reduce these constraints, enforcing them to a large-scale system is very difficult and complicated. This paper proposes a new method for controller synthesis based on PN modeling. In this approach, the original PN model is broken down into some smaller models in which the computational cost reduces significantly. Using this method, it is easy to reduce and enforce the constraints to a Petri net model. The appropriate results of our proposed method on the PN models denote worthy controller synthesis for the large-scale systems.

To present the work done in this project we have presented the following chapters:

- Chapter I: PRESENTATION OF THE WORKING ENVIRONMENT
- Chapter II: GENERALITY ON PETRI NETS
- Chapter III: FLEXIBLE MANUFACURING SYSTEMS
- Chapter IV: ANALYSIS AND SIMULATION OF A REAL PRODUCTION SYSTEM
- Chapter V: GENERAL CONCLUSION

# CHAPTER I

## Presentation of the working environment

# CHAPTER I: PRESENTATION OF THE WORKING ENVIRONMENT

## I.1. INTRODUCTION

My internship took place in Romania, in a laboratory of the Department of Manufacturing Engineering, Faculty of Engineering, Dunarea de Jos University of Galati. During my internship I visited the society URB Group - Rulmenti S.A. from Barlad. In my project I have used a data base obtained from this manufacturing company in order to modeling the process of work using Petri net.

## I.2. GENERAL PRESENTATION OF THE UNIVERSITY “DUNAREA DE JOS” OF GALATI

Galati city, which is known to be the fifth most important town of the country, is set at the east of the land, close to the border with Moldova and Ukraine, and on the banks of the end of Danube. This region owns a deeply rooted industrial base, as the most major Romanian steelworks (Arcelor Mittal Galaţi) or the dockyard can bear witness.


*Figure I. 1 Map of Romania*

The main asset of Galaţi, in terms of education and scientific research, lies in the Dunărea de Jos University. It is made up of fifteen faculties with more than thirty departments. It has diverse unique fields of education in the country, such as naval engineering or fishery. It also organizes programs for doctoral and master degrees in various technical fields, such as chemistry, physics, mathematics, economy, food technology and fishing, automatic control and computation techniques, artificial intelligence, or even social and humanistic sciences. During the years, specialists covering a wide range of education fields have been trained in this University, like engineers, teachers and programmers.

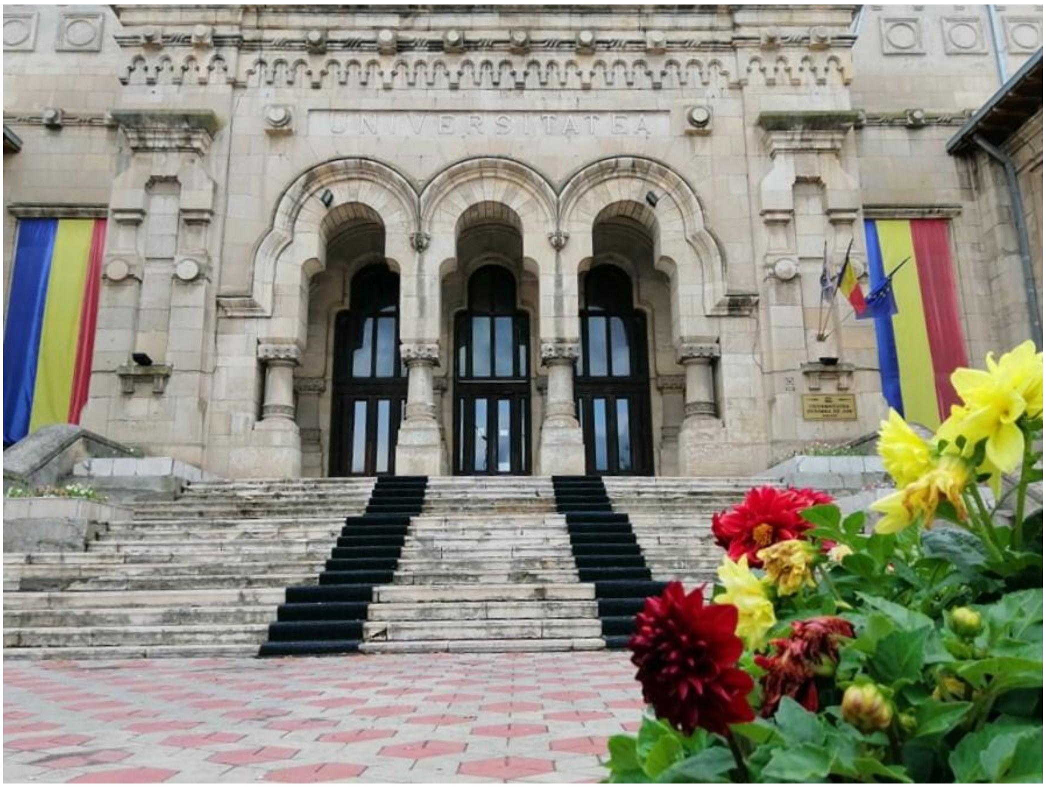



***Figure I. 2*** *Dunarea de Jos University of Galati*

**Dunarea de Jos University of Galati** is the most important institution of higher education in the South-East of Romania.

Dunarea de Jos University of Galati functions according to the university Charter, whose provisions are in agreement with the national legislation and with the principles of the European Space and Higher Education, being recognized by all members of the university community.

**The history of higher education in Galati covers the following stages:**

**1948:** establishment of the Land Improvement Institute;

**1951:** establishment of the Naval-Mechanical Institute;

**1953:** merging the Naval-Mechanical Institute with the Agronomic Institute, and with the Fish Farming and Fishing Institute (transferred from other University centres), and the establishment of the Technical Institute in Galati;

**1955:** merging of the Technical Institute with the Food Industry Institute in Bucharest;

**1957:** transforming the Technical Institute into the Polytechnic Institute;

**1959:** establishment of the Pedagogic Institute and relocation of the Land Improvement Institute to Iaşi;

**1974:** establishment of the University of Galati by merging the Polytechnic Institute with the Pedagogic Institute (State Council Decree of 20 March 1974);

**1991:** the University of Galati becomes Dunarea de Jos University of Galati (Government Decision of 4 January 1991).

In the structure of the above mentioned institutes, there were a series of study programmes that were **unique** in the country: **Naval Constructions, Harbours and Ship Exploitation, Food Industry, Fish Farming Technology, Cooling Devices** – which meant that an important creation process on elaborating educational curricula and syllabi, lectures, laboratory equipment etc., presently being used in other university centres around the country, was fully the work of the academics in Galati higher education.

The internship took place more accurately in a division of the University, which is the Faculty of Engineering. This entity is an historic one of the University, because it directly results from the former Technical Institute of Galaţi.

Initially reputable for its competence in two domains, namely naval construction and technology of ships and ports, this division has regularly grown through the years, by extending its specializations such as:

¬ Refrigeration and Technology of machinery building in 1960

¬Thermal machines and Welding technology in 1978

¬ Metallurgical engineering, Mechatronics and Robotics and Economical Engineering in 1990.

Become in the late nineties one of the largest faculty of mechanics in the country, a breaking up took place, which resulted in a transfer of competences to the Faculty of Engineering of Brăila and the Technical College. Nowadays, the mission assumed by the faculty of mechanics is to form specialists through training (normal and post university studies) in areas such as mechanical engineering, industrial engineering, or environmental engineering.

This mission includes the development of scientific research centers in strong fields, promoting the national and international cooperation of inter-university and economic environment, and contributing to the universal heritage of knowledge. Over the years, the faculty of mechanics has forged strong ties with the field of industry, even with multinational companies such as Dacia, Fiat, or Mittal Steel. In terms of figures, this entity represented in 2008:

¬ More than 70% of research projects accepted for the whole university

¬ More than 1400,000 € allocated for research, a tenfold growth over the last 3 years

¬ More than 50 papers published in professional journals

¬ More than 30 scientific papers published in conferences

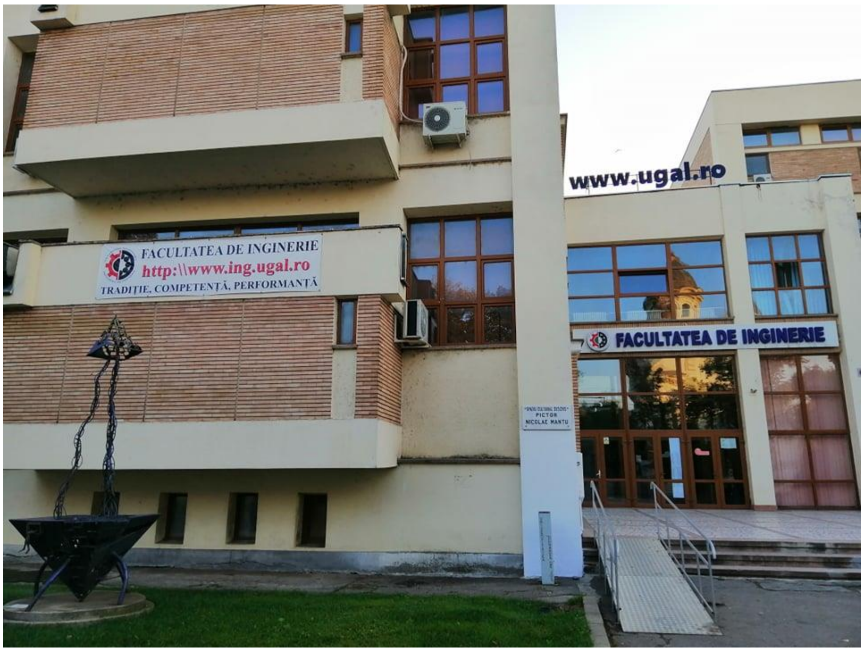



***Figure I. 3*** *Entrance of the Faculty of Engineering*

## I.3. General presentation of URB Group – Rulmenti S.A Barlad

The manufacturing company, Rulmenti S.A. from Barlad, Romania, is a part of the large URB Group.


***Figure I. 4*** *URB Group*

The short history of this company is:

1953 – Barlad Factory started production;

1973 – The Forging technology from Haterbur and Wagner Germany was applied successfully;

1975-1982 - Modernization of turning and grinding workshops;

1992-1996 - Continuous modernization of various machinery and equipment;

2000 - Finalization of privatization process;

2001-2005 - A period of big investments in machine technologies;

2006 - Founding Anadolu Rulman factory (ART) in Turkey;

2007 - Acquisition of MGM factory in Hungary;

2011 - Starting the building of India factory;

2018 - Continued investment.


*Figure I. 5 URB Group – Rulmenti S.A.*

The Group URB produce different kinds of bearings (cylindrical, spherical, radial, axial), turning components and other components. The sales regions of their products are presented in the (**figure I.5**).

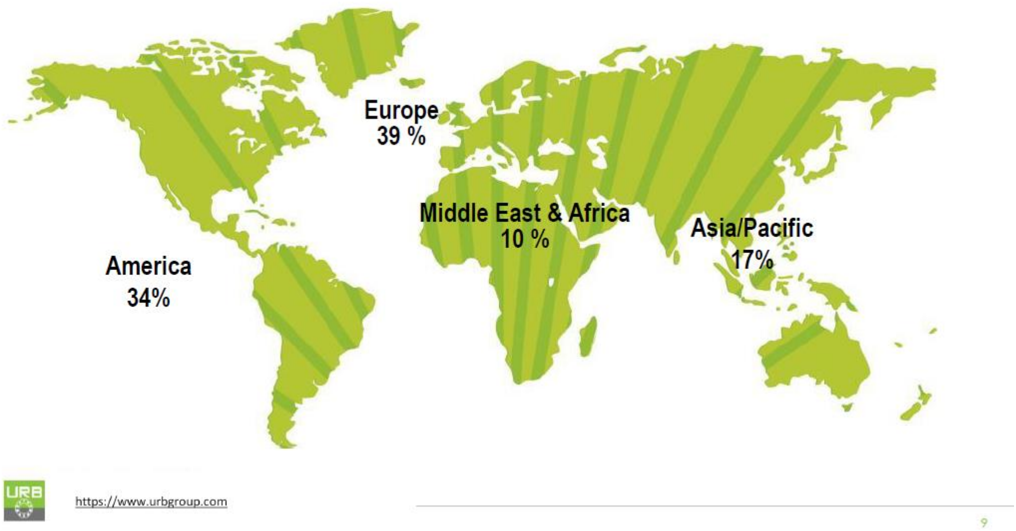



*Figure I. 6 Sales regions of URB*

The conception activity in URB Group use computer aided design software Pro/ENGINEER, a 3D CAD/CAM/CAE parametric software, and the computer aided analysis software – ANSIS in order to assure the good quality of their products.


***Figure I. 7*** *URB Group Softwares*

The total area of tooling workshop (figure I.8) is 10,900 $m^2$. There are 357 direct machines & 114 auxiliary machines, capable of:

- Turning;
- Milling;
- Grinding;
- Metallic structuring (bending, shocking, rolling, welding);
- Heat treatment;
- Titanium covering;
- Electrical discharging.

The turning process for the bearing rings has been modernized with CNC turning lathes (PUMA, DOOSAN (Korea), OKUMA (Japan), Fuji, MURATA).

***Figure I. 8*** *DOOSAN bought from south Korea*


***Figure I. 9*** *Tooling workshop*

One of the main parts of tooling workshop is Grinding Section consisting in following grinding equipment:

- CNC - grinding machines;
- Centerless grinding machines;
- Classic grinding machines,

and quality control equipment for:

- Dimensional (ID/OD/H, angles, raceways, recess, radius)
- Form deviations (ovality, profile deviation, parallelism, conicity, raceway deviations)
- Surface checking (surface defects, roughness).

**Assembly workshop:**

All bearings components are inspected before assembly activities by qualified quality inspectors.


**Figure I. 10** *Marking and wrapping machines*

# CHAPTER II

## GENERALITY ON PETRI NETS

# CHAPTER II GENERALITY ON PETRI NETS

## II.1. INTRODUCTION

Petri net [1] is a modelling formalism proposed by Carl Adam Petri in 1962 for modelling distributed systems. It was rapidly recognized as a promising formalism, due to its adequacy to represent a number of features of discrete event dynamic system behavior. PN are used for modeling complex systems in order to analyze and verify their properties. Petri nets are particularly suited to the modeling of distributed systems operating in parallel and with synchronization constraints. The analysis of the models in Petri nets highlights the absence of blockage during the evolution of the modeled system or the existence of a steady state, this makes it possible to detect the errors of design, to reduce the risks as well as the time and cost of design.

This chapter introduces the basic concepts of basic Petri nets as well as the high-level Petri nets that allow to analyze and verify certain qualitative and quantitative properties of the systems. Petri nets can be used to specify, validate and implement any discrete system including simultaneous evolutions, they are recommended when these systems communicate with the outside world.

There are several application domains, implementation of dynamics in information systems, production management, the design of resource allocation mechanisms and task synchronization procedures in centralized or distributed systems or good for the development of specifications of industrial process control system.

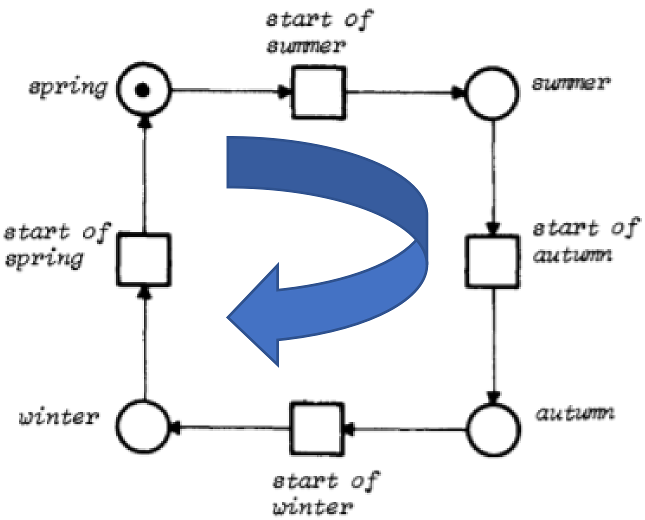



*Figure II. 1 The four seasons and their changes*

## II.2. DEFINITION

A Petri net may be identified as a particular kind of bipartite directed graphs populated by three types of objects. These objects are places, transitions, and directed arcs (**Figure II.2**). A place is represented by a circle and a transition by a bar (certain authors represent a transition by a box). Places and transitions are connected by arcs. The number of places is finite and not zero. The number of transitions is also finite and not Zero. The arcs of the graph are directed and run from places to transitions or transition to a place. The state of a Petri net is the distribution of tokens (Black dots) on its places, called a marking of the net. A transition is enabled if each of its input places holds at least one token. Firing a transition means removing one token from each input place and adding one token to each output place. A Petri Net is a graph model for the control behavior of systems exhibiting concurrency in their operation. [2]

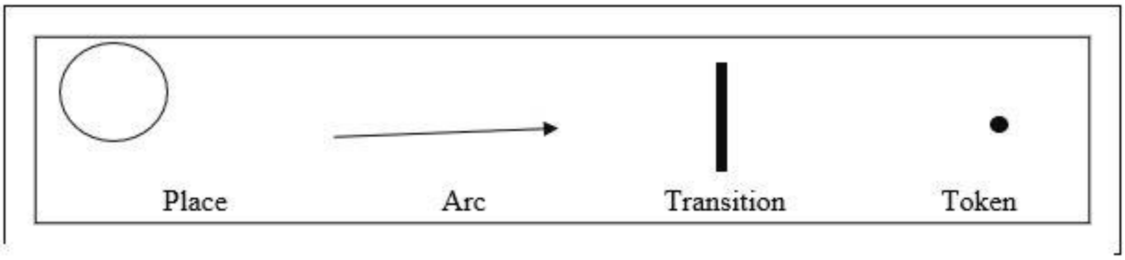



***Figure II. 2*** *Graphical representation of the elements of petri net*

Input places may represent preconditions, output places may represent postconditions and the transition an event. Input places may represent the availability of resources, the transition their utilization, output places the release of the resources.

| **Input places** | **Transitions** | **Output places** |
|---|---|---|
| Preconditions<br>Input data<br>Input signals<br>Resources needed<br>Conditions<br>Buffers | Event<br>Computation step<br>Signal processor<br>Task for job<br>Clause in logic<br>Processor | Postconditions<br>Output data<br>Output signals<br>Resources released<br>Conclusions<br>Buffers |

***Table II. 1*** *Petri Nets elements representation*

An example of a Petri net is shown in **Fig. II.3**.

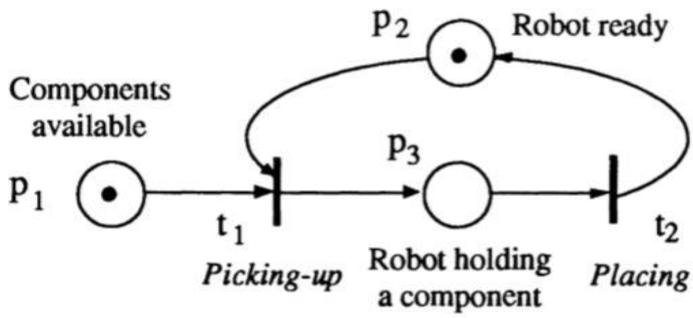



***Figure II. 3*** *Simple Example*

This net consists of three places, represented by circles, two transitions, depicted by bars, and directed arcs connecting places to transitions and transitions to places. In this net, places P1 and P2 are two input places of transition t1. Place P3 is an output place of transition t1 and it is an input of transition t2. Each place may potentially hold either none or a positive number of tokens, pictured by small solid dots, as shown in **Fig II.3**. The presence or absence of a token in a place can indicate whether a condition associated with this place is true or false, for instance. For a place representing the availability of resources, the number of tokens in this place indicates the number of available resources [3]. For example, a token in P1 and P2 means a component and a robot available, respectively. At any given time instance, the distribution of tokens on places, called Petri net marking, defines the current state of the modeled system. A marking of a Petri net with n places is represented by an (n x 1) vector m, elements of which, denoted as m(p), are nonnegative integers representing the number of tokens in the corresponding places, A Petri net containing tokens is called marked Petri net. For example, in the Petri net model shown in **Fig.II.3**,

## II.2.1. Formal definition

Mathematically, a Petri Net (PN) is defined as a 5-tuple:

$PN = \langle P, T, I, O, M_0 \rangle$ where: (1)

- P: a finite set of places, {p1, p2, ..., pn}
- T: a finite set of transitions, {t1, t2, ..., ts}
- I: an input function, (T x P) —> {0, 1}
- O: an output function, (T x P) —> {0, 1}
- $M_0$: an initial marking, P —> N

## II.3. BASIC DESIGN AND DEFINITIONS

### II.3.1. Concept of marking

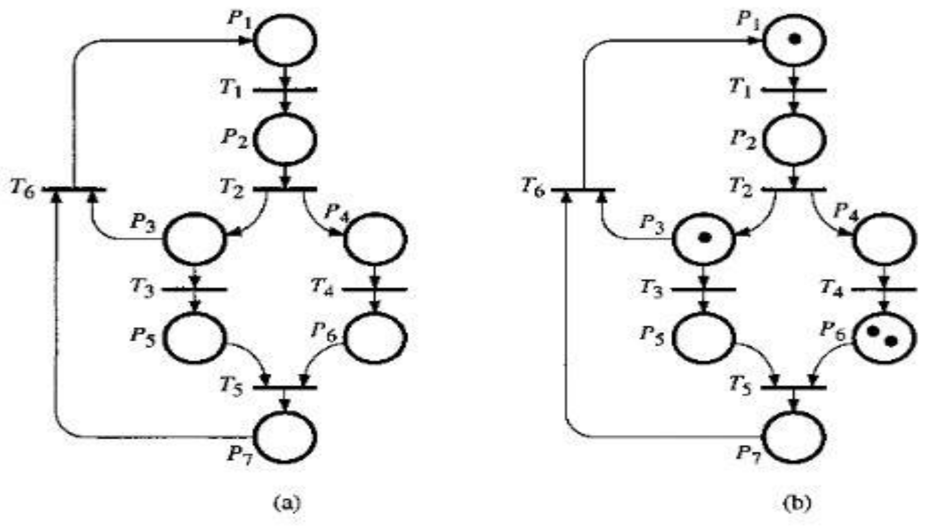



*Figure II. 4 Petri net, not marked and marked models*

Figure II.4 (b) represents a marked Petri net. And Figure II.4 (a) represents a not marked Petri net. [1]

the number of tokens contained in a place $P_i$, will be called $m(P_i)$ or $m_i$

The net marking **m** is defined by the vector m= ($m_1$, $m_2$, $m_3$, $m_4$, $m_5$, $m_6$, $m_7$)

For example, in Figure II.4(b) we have $m_1 = m_3 = 1$, $m_6 = 2$ and $m_2 = m_4 = m_5 = m_7 = 0$

So, the marking of PN is m= (1, 0, 1, 0, 0, 2, 0). Always marking defines the state of the system described by PN

### II.3.2. Incidence matrix

The input incidence matrix is called the matrix:

$$W^{-}_{ij} = I\ (P_i, T_j) \quad (2)$$

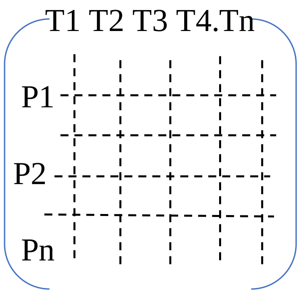
The output matrix is called the matrix:

$$W^{+}_{ij} = O\ (P_i, T_j) \quad (3)$$

The incidence matrix (W) of a Petri net whose lines identify places and columns transitions; is defined by:

$$\mathbf{W=W^{+}_{ij}-W^{-}_{ij} \Longrightarrow W[i][j] = O\ (P_{i}, T_{j}) - I\ (P_{i}, T_{j})} \quad (4)$$

W[i][j]=




## II.3.3. Awareness Rule

A transition t is sensitized (validated, passable or pullable) if each of the places of entry p contains a number of tokens greater than or equal to the weight of the arc connecting p to t.

$$\forall\ p \in P,\ M(p) \geq I\ (p, t) \quad (5)$$

## II.3.4. Firing of a Transition

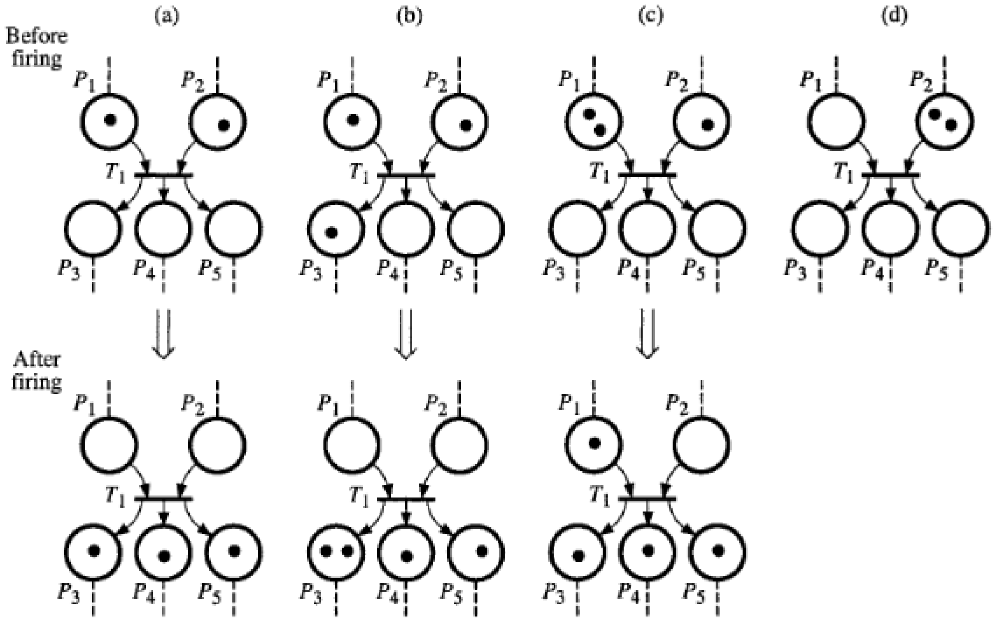



*Figure II. 5 Firing of a transition*

- The firing of a transition t with draws from each of its places of entry p a number of tokens equal to the weight of the arc connecting p to t (I (p, t)) and deposits on each of its places of exit p a number of tokens equal to the weight of the arc connecting t to P (O (p, t)).

- Note:
- When a transition is validated, it does not imply that it will be immediately fired; this represents only a possibility of firing. In a PN, even if several transitions are validated by the same marking one and only a transition can be fired.
- Firing is an instant operation.

A transition t = < I, O > can be fired from m if for any place p:

$$\mathbf{M(p) \geq I(p)} \quad (6)$$

Figure II.6 illustrates the chemical reaction ($2H_2 + O_2 \rightarrow 2H_2O$) and the change in labeling after crossing the transition t.

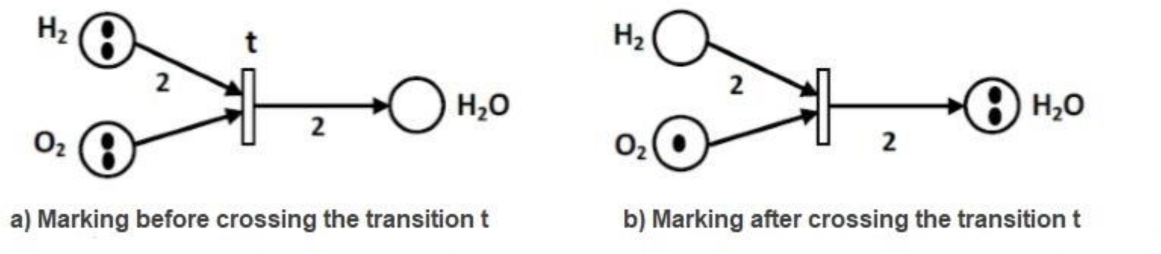



***Figure II. 6*** *The composition of water modeled with PN (2H2+O2 = 2H2O)*

Before firing $M_0 = \{2, 2, 0\}$, after firing $M_1 = \{0, 1, 2\}$. Places are ordered in this vector as follows: $\{H_2, O_2, H_2O\}$.

## II.4. PETRI NETS PROPERTIES

Among these properties we will mention the following ones [2] [1]:

### II.4.1. Vivacity

A Petri network is said to be alive for an initial marking Mo if, whatever the attainable marking M∈R (Mo), it is possible to find a firing sequences which makes it possible to fire any transition. A blocking corresponds to a marking or no transition is negotiable. The vivacity property therefore ensures non-blocking. Vivacity Verifies that a system state can be reached regardless of the state in which it is located

### II.4.2. Consistency and reversibility

A PN is said to be consistent if there is an initial mark Mo and a firing sequence containing at least once each transition.

A PN is reversible for an initial marking Mo if, whatever the attainable firing, In other words, in a reversible PN, it is always possible to return to the initial marking. Most industrial processes have a repetitive operation. It is therefore important to check if the PNs that represent them are reset.

### II.4.3. Persistence

A PN is persistent for an initial marking Mo if whatever the transition torque that can be firing for this marking, the firing of one of the two transitions does not prevent the firing of the other. Persistent PN does not require decision making for conflict resolution, as the firing order will not result in the cancellation of a crossing opportunity. For this reason, a persistent PN and also called a Petri Net without a decision.

A Petri Net without conflict is always persistent.

## II.4.4. Structural and effective conflict

### II.4.4.1. Structural conflict

A structural conflict is a set of transitions that have at least one entry point in common.

### II.4.4.2. Effective conflict

An effective conflict corresponds to the existence of a structural conflict and a firing M such that the number of marks in the place of the conflict is lower than the number of marks necessary to ignite any exit transitions of this place which are validated by M.

## II.4.5. Mutual exclusion

Two places are in mutual exclusion if for a given initial marking Mo, they cannot be simultaneously marked regardless of the marking M reached from Mo.

Mutual exclusion is encountered in any system that includes resource sharing.

## II.4.6. Blocking

A blocking is a marking such that no transition is validated.

## II.4.7. Modeling competition

Competition: Checks whether the transition to a state involves the collaboration of two or more parts of the system.

It is the convergence of arcs on a place [4]: figure II.7

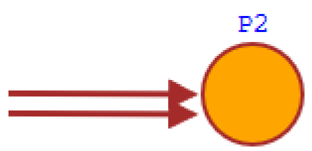



***Figure II. 7*** *Convergence of arcs*

It is the divergence of arcs from a place figure II.8: this "structural conflict" must be arbitrated (when it actually occurs both must be activated) by a rule of any priority; if not the behavior of the system is not fully specified [4]

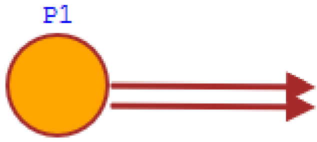



***Figure II. 8*** *Divergence of arcs*

## II.4.8. Confusion

Situations in which competition and conflict are present are called confusing situations.

Suppose that in the network of Figure II.9 tokens in P1 and P4 arrive simultaneously in these places. In this case the transitions T1 and T3 are in conflict and it is necessary to make the choice of the transition which must be fired [5]

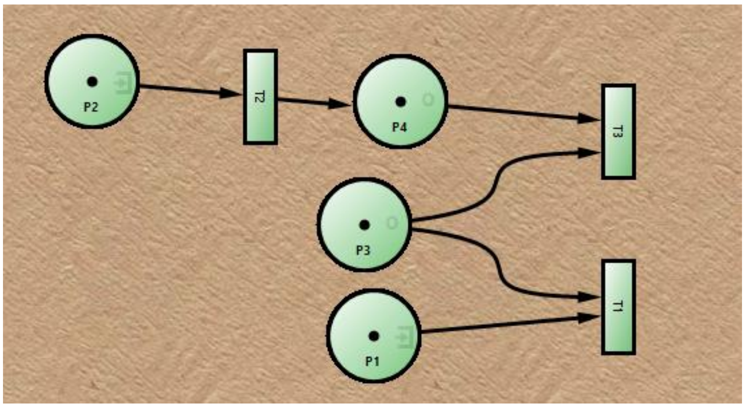



***Figure II. 9*** *Confusion situations*

Suppose now that the token of place P4 arrives in this place at a time after the arrival time of the token in P1. At this moment, the transitions T1 and T3 are not in conflict, T1 is passable T1 immediately does not guarantee in any way that the speed of the operation is maximum.

### II.4.9. Producer and consumer

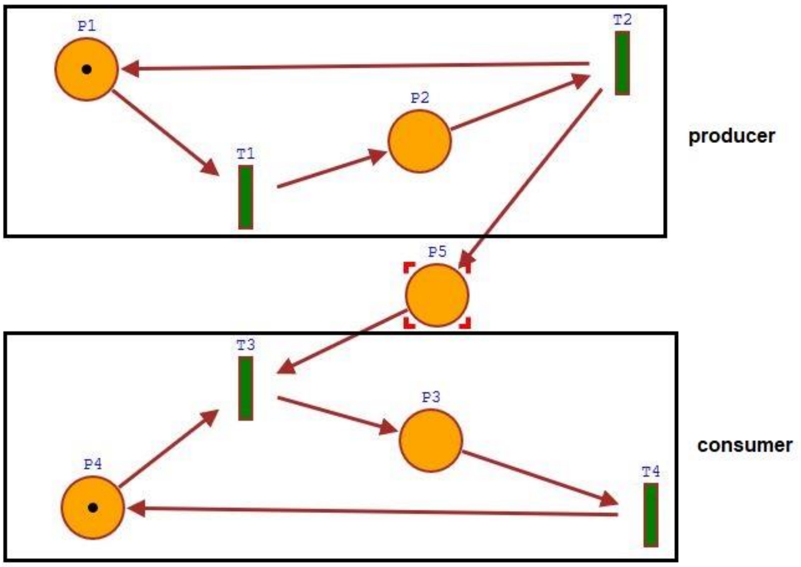



*Figure II. 10* *Producer and consumer*

## II.5. PETRI NET'S MODELING

### II.5.1. Synchronization

The figure II.11 shows two synchronized operations

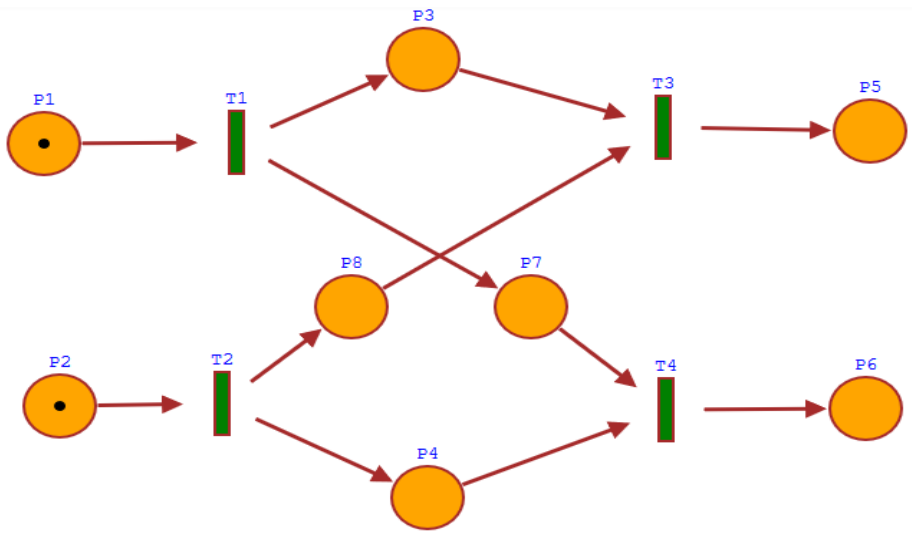



*Figure II. 11* *Synchronized operations*

### II.5.2. Parallelism

In Figure II.12 the transitions t1 and t2 are drawn in parallel

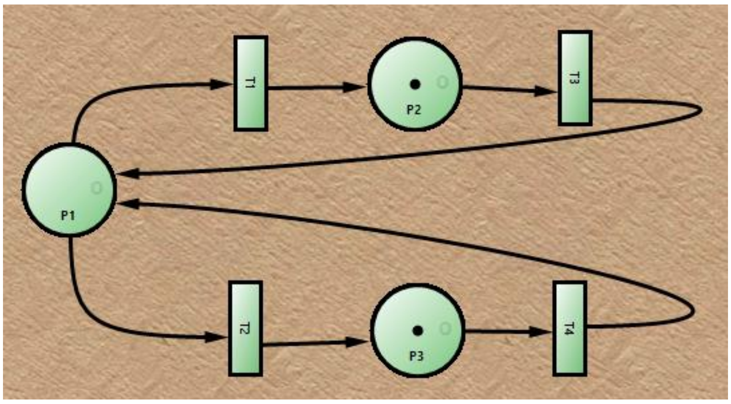



***Figure II. 12*** *Parallel petri net*

## II.6. PARTICULAR PETRI NETS

### II.6.1. Stat graph

An unmarked or marked petri net is a state graph (SG) if and only if any transition has exactly one entry place and one exit place [2] [6].

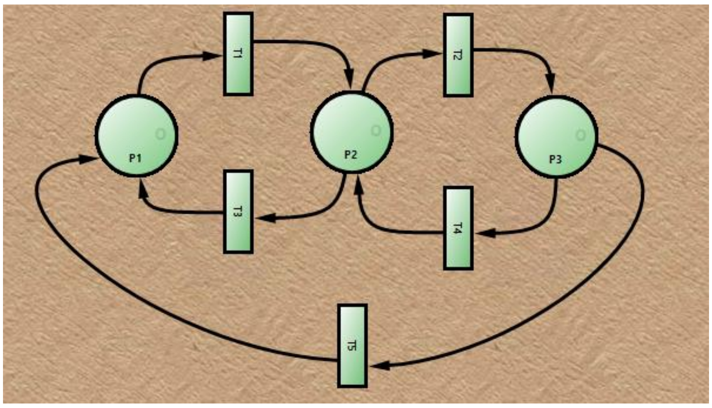



***Figure II. 13*** *Stat graph*

### II.6.2. Event graph

An Event Graph (EG) is a Petri Network in which each place has exactly one input transition and one output transition. It is characterized by the absence of structural conflicts. [2]

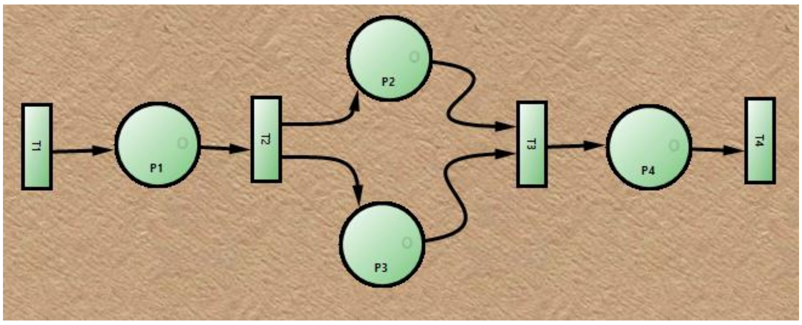



*Figure II. 14 Event graph*

## II.6.3. Free choice

Two definitions exist, which are distinguished by the appellations free choice and extended free choice. [7]

- A free choice PN is a PN in which for every conflict none of the transitions possesses another input place.
- An extended free choice PN is such that for every conflict all the transitions have the same set of input places.

In such a PN (free choice or extended free choice), if a transition involved in a conflict is enabled, all the transitions involved in the same conflict are also enabled.

## II.6.4. Pure PN

A transition is said to be pure if it has no place that is both an entry place and an exit place (**Figure II.15.a**). If all PN transitions are pure the PN is pure. [8] [9]

A transition is said to be impure if it has a place that is both a place of entry and a place of exit (**Figure II.15.b)**. If the PN transitions are impure the PN is impure. [8] [9]

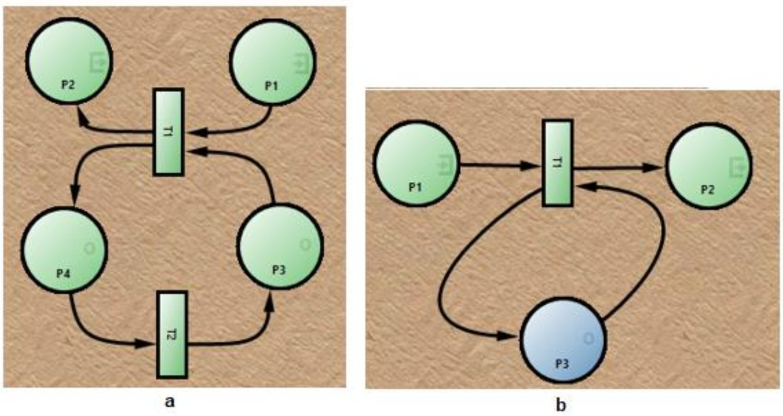



*Figure II. 15 Pure and impure PN [8], [9]*

### II.6.5. Simple PN

Simple Petri nets are ordinary PN such that each transition has at most one entry place that can be related to other transitions, (Any transition belongs to one conflict at most).

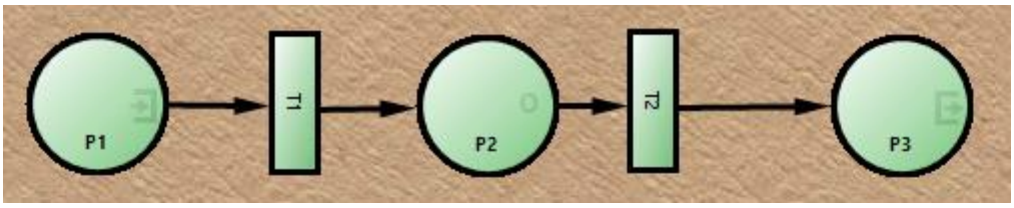



***Figure II. 16*** *Simple PN*

## II.7. MODELING A SYSTEM

Example:

We have one starter and two cars. When the starter receives ready signs from the two cars (a, b), he gives the starting signal and the cars begin the race. [10]

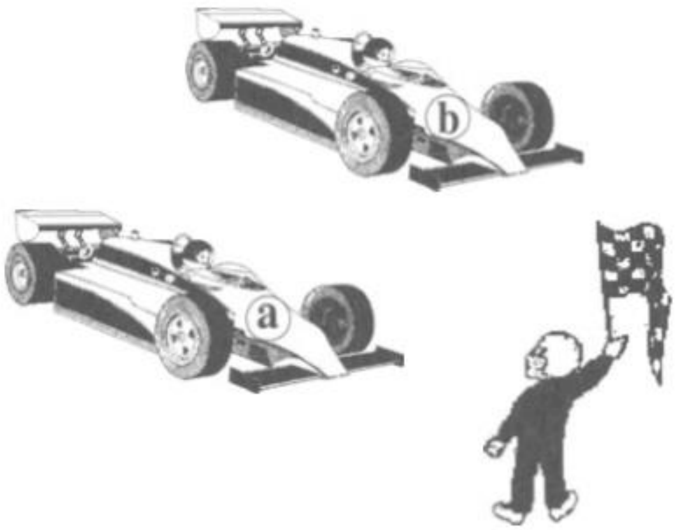



***Figure II. 17*** *Starting two racing cars example [10]*

So, the cars send ready sign after preparing for start and then still waiting for start

(figure II.18 a). The starter gives start sign to the cars (figure II.18 b). Both of cars a and b running after the sign given by the starter (figure II.18 c). Essential conditions and actions have been identified on the following table:

| List of conditions | List of actions |
|---|---|
| $P_1$: car a; preparing for start | $t_1$: car a; send ready sign |
| $P_2$: car a; waiting for start | |
| $P_3$: car a; running | $t_2$: car a; start race |
| $P_4$: ready sign of car a | |
| $P_5$: start sign for car a | $t_3$: starter; give start sign |
| $P_6$: starter; waiting for ready signs | |
| $P_7$: starter; start sign given | $t_4$: car b; send ready sign |
| $P_8$: ready sign of car b | |
| $P_9$: start sign for car b | $t_5$: car b; start race |
| $P_{10}$: car b; preparing for start | |
| $P_{11}$: car b; waiting for start | |
| $P_{12}$: car b; running | |

***Table II. 2*** *List of conditions and actions*

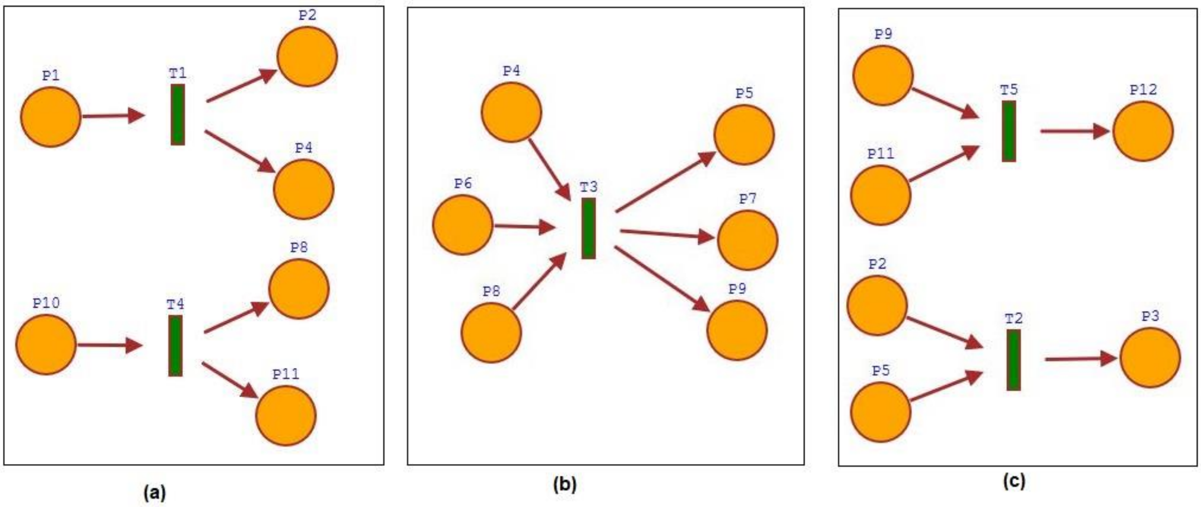



***Figure II. 18*** *Graphical representation of phases*

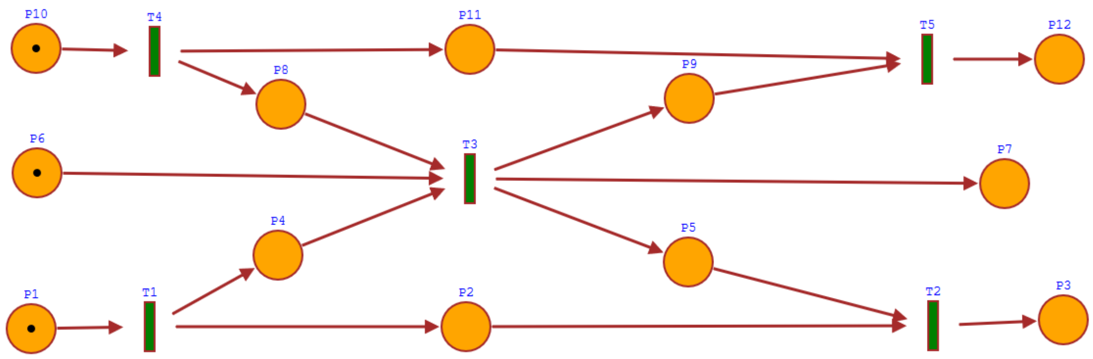



*Figure II. 19 Net of the full system*

## II.8. HIGH LEVEL PETRI NETS

There are several types of petri nets and in our case, we will only study the timed petri nets which belongs to the category of non-autonomous PN like synchronized petri nets and other types.

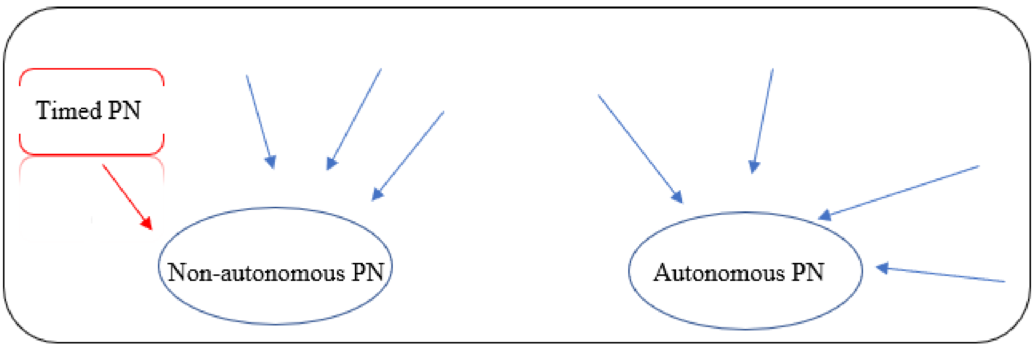



*Figure II. 20 Illustrative schema*

 **:** means that there are other PN's types that belong to this category

## II.7.1. Timed Petri nets

The Petri nets discussed so far model systems whose evolution does not depend on time. Indeed, in the classical model, transitions are activated without taking into account time constraints such as timers for example. There are also time petri nets which allow to study more specific problems with real time systems, such as dynamic scheduling. These networks have shown their interest in particular in evaluating the performance of a system.

Among the proposed techniques for specifying and verifying systems in which time appears as a parameter, two are widely used: Timed Automata and Time Petri Nets, introduced in [11].

#### II.7.1.1. Definition

A timed Petri net is used to describe a system whose operation depends on time. For example, there may be some time between the start of an operation and the end of this operation. If a mark in a certain place indicates that this operation is in progress, a timed PN will account for this duration. Timed Petri nets are useful for evaluating the performance of a system. There are mainly two ways to model the delay: either the delays are associated with the places we say that we have a P-timed PN, or the delays are associated with the transitions we say we have a T-timed PN.

#### II.7.1.2. Formal definition

A timed Petri net (**TPN)** with n places and p transitions is a doublet RT= <R, D> (7)

R is a PN < P, T, I, O> with initial marking $M_0$

D is a function called static interval:

**D : T ⟶ Q+**

Q+: is the set of real non-empty intervals with non-negative rational bounds.

The application D associates a time interval D(t) with each transition of the network.

#### II.7.1.3. State of TPN

A state of a temporal network is a couple s= (m, D) in which m is a marking and D a function that associates a time interval with every transition sensitized by m.

The initial state is $e_0$ =($m_0$, $D_0$) where $D_0$ is the restriction of D to transitions sensitized by the initial mark $m_0$. [12].

## II.8. Augmentation Methods of Petri Nets

We desire to incorporate the results of error recovery planning to augment the model Z to form Z'. Four basic methods for augmentation to Z' from Z are proposed. They are input conditioning, alternate path, backward error recovery, and forward error recovery. The last subsection will deal with the maintainability of behavioral properties.

### II.8.1. Input Conditioning Method

The idea of the input conditioning method is that an abnormal state in a place that represents a process or a state of a manufacturing system can become a normal state after other actions are finished or some conditions are satisfied. An example of this is the arrival of a part that requires additional finishing prior to processing at a workstation.

### II.8.2. Alternate Path Method

The philosophy of the alternate path method (also called error avoidance) states that there exists another sub-Petri net which can transform an abnormal state in place p directly into a normal state in a system. Depicts this type of construction of Z' from Z. It is assumed that the state in the place w will be achieved after the state in the place p. S' and Z satisfy the same conditions described as in the last subsection.

### II.8.3. Backward Error Recovery Method

Backward error recovery suggests that under the assumption that the state is normal, i.e. e(p) = 1, Q in Z is executed and a new faulty state in place w results. But this state can become a normal state in place p after the operation of a sub-Petri net.

### II.8.4. Forward Error Recovery Method

The forward error recovery method is similar to the backward error recovery method; suppose that a faulty state results after the operation of Q in Z. However, this state can be directly transformed into a normal state in Z after a Petri net controller S' operates. Again, the same conditions about Z and S' are assumed. This strategy is particularly useful when a fault at p is difficult to detect while it can be relatively easier to detect at w.

### II.8.5. Maintainability of behavioral Properties

The property analysis of a Petri net includes boundedness, safeness, liveness (absence of system deadlock), and reversibility (re-initializability or properness). The following will focus on the maintainability of these properties of a Petri net when Z' is constructed from Z using the four basic construction methods discussed above. The four basic construction methods are input conditioning, alternate path, backward error recovery, and forward error recovery. For each method, there are t' , r' ,S' that do not belong to the controller Z. Let S' be a Petri net block which represents the error recovery procedure with its initial marking mo· An associated Petri net S* is defined as a Petri net which consists of a place p, t', r', and S' where p is called an idle place. Its initial marking is mo*= (1, mo) where mo is the initial marking of S' and 1 implies that the idle place is initially marked.

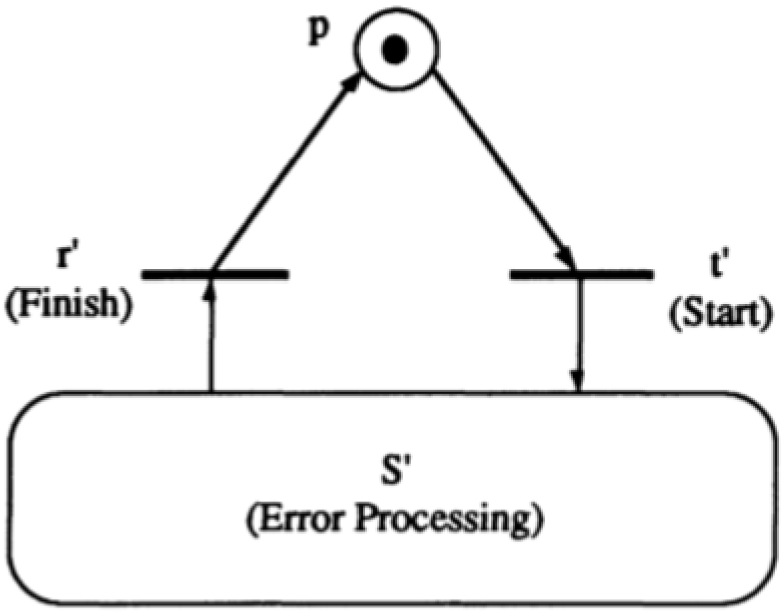



***Figure II. 21*** *Associated Petri net S**

## II.9. CONCLUSION

This chapter was the subject of the presentation of the basics of the Petri nets. Petri nets are particularly well suited to describe some aspect of control of systems with parallel evolution, such as conflicts. Sequencing as well as basic communication mechanisms. Their interest in the representation of discontinuous or discrete processes is well established. The Petri nets is a powerful tool both for its diversity of modeling and the technical tool associated with it, that’s why Petri net tool attracts more and more researchers. On our part, we have found it useful for modeling and analysis our application which concerns the study of a production system. it allows us to analyze the behavior of the system represented and to determine many properties.

# CHAPTER III

## FLEXIBLE MANUFACURING SYSTEMS

# CHAPTER III: FLEXIBLE MANUFACURING SYSTEMS

## III.1. INTRODUCTION

To produce quality products in large quantities and at a lower cost, which entrepreneur was not haunted by this objective!  Indeed, considering the separation of production or processing (one sector for turning, another for milling, a third for sharpening, a sector for the assembly… The parts follow a complex circuit in workshop, the consequence immediate is naturally a waste of time due to transfers and waiting as well as a multiplication of the adjustment times, the question is posed: how to overcome these disadvantages?  [13]

So engineering product development has moved away from the traditional linear steps to a more integrated product life cycle development process, Manufacturing requires materials, manpower, machines, methods, and measures, to achieve the challenge posed by variable demand, manufacturing companies have two basic alternatives: build manufacturing plants with excess capacity and stock excess goods in inventory to smooth fluctuations in demand, or increase the flexibility of their manufacturing plants so that production volume and variety can be varied more easily to match changes in demand. Numerous manufacturers have pursued this second option of increased flexibility. [14]

In order to bring a good understanding to the modeling of the flexible workshop, we will first give the general notions associated with flexible production systems.

## III.2. DEFINITION

The development of CNC and DNC led to the first U.S. implementation of a Flexible Manufacturing System (FMS) at Caterpillar Tractor in the mid-1970's. The typical configuration of an FMS is an integrated group of processing CNC machines and material-handling equipment under computer control for the automatic processing of palletized parts. Many of these systems use robots or automated guided vehicles for loading and unloading parts. The operation of the FMS is integrated by supervisory computer control. The major advantage of a FMS is ability to produce in random order a variety of products as well as new products on the same machine and accommodate design changes. FMS is called flexible because it is capable of processing a variety of different part types and quantities of production.

So simply FMS can be defined as a group of processing work stations interconnected by means of an automated material handling and storage system and controlled by integrated computer control system. [15]

### III.2.1. Manufacturing systems

A production system consists of all the necessary resources, both human and material, that make it possible to transform the raw material or the components into finished products. Production systems are organized and managed according to the demands and resources available.

## III.3. PRODUCTION MODES

### III.3.1. Continuous production

Homogeneous products (manufacture of steel, chemical products), is carried out continuously, by a continuous flow of materials and products, and is concentrated in one place. Automation is important (little manpower and a lot of machines).

The most characteristic examples of continuous production are products such as sugar, oil, cement, steel in continuous casting. [16] This type of workflow typically has the following characteristics:

- ✓ Single or quasi product
- ✓ Machine layout linearly
- ✓ Little flexibility
- ✓ Balancing machine capacity very good
- ✓ Significant investment and strong automation

### III.3.2. Discrete production

production on demand or fractionated in time or space, concerns the production of relatively small quantities of very varied products which require different assembly processes. This production system results in the creation of large stocks of intermediate products. [16] Mechanical industries are examples of this type of production (workshop).

This type of workflow typically has the following characteristics:

- ✓ implementation of machines by function,
- ✓ great flexibility because the machines are not specific,
- ✓ Balancing the capacity of the machines difficult hence the appearance of current.

### III.3.3. Comparison between continuous production and discrete production

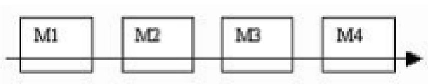
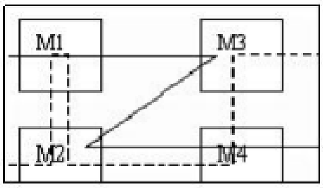
| | **continued** | **discontinued** |
|---|---|---|
| **implantation** |   linear flow |   complex flows |
| **flexibility** | specialized production line<br>little flexibility | generalist production line<br>good flexibility |
| **efficiency** | good | low |
| **In progress** | low | important |
| **stocks** | low | long |

***Table III. 1*** *The difference between continuous and discrete production*

## III.4. FLEXIBILITY

A flexible system must be capable of changing in order to deal with a changing environment. According to Kickert (1985) [17], flexibility increase control capacity by means of an increase in variety, speed and amount of responses as a reaction to uncertain future environmental developments.

Flexibility in manufacturing means being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality.

## III.5. FLEXIBILITY IN A PRODUCTION SYSTEM

### III.5.1. Basic flexibility

#### III.5.1.1. Flexibility of machines

The flexibility of a machine refers to the variety of operations that can be performed by it. [18] The advantages of the flexibility of the machines in a system are: the decrease of the size of the transport batches, the increase of the utilization rate of the machines, the production of complex parts, the reduction of the time of introduction of new products in the production system

#### III.5.1.2. Flexibility of handling tools

It is the ability of a handling system to move the different parts efficiently through the production system during a production phase. [18] The purpose of the flexibility of handling means is to increase the availability of machines, to increase the rate of use of machines, to reduce production times and consequently to increase the efficiency of the manufacturing production system.

#### III.5.1.3. Flexibility of operations

It is the ability to replace operations that allow the manufacture of a part. In this case, this means that there are no precedence constraints between all the manufacturing operations of a part. The objectives of the flexibility of the operations are the improvement of the availability of the machines, and of their rate of use, the possibility to continue the production even if a machine is defective.

## III.5.2. System flexibilities

### III.5.2.1. Flexibility of manufacturing processes

It is the set of parts that a system can produce without making major changes. The goal of such flexibility is to reduce the size of production batches and inventories, increase resources and minimize duplication of machines.

It should be noted that the presence of personnel with transversal skills makes it possible to improve the flexibility of the manufacturing processes.

### III.5.2.2. Product flexibility

It's the ability to integrate a new part into a production system while minimizing changeover times and minimizing costs. This flexibility can be achieved through machine flexibility but also through an efficient planning and control system. [18]

### III.5.2.3. Flexibility of product routing

It is the ability of a production system to take into account machine failures that occur during production and still continue to produce. Product flexibility is an asset for innovative companies or those in a growth phase because the introduction of a new product usually follows a technological innovation or a strategy of growth of the offer. [19]

### III.5.2.4. Flexibility of product volumes

It is the ability of a system to adapt to the variation of orders. This adaptation can result in an addition / deletion of a machine (s) in case of increase / decrease of the production volume or by a modification of the configuration of the workshop according to the manufacturing processes of the parts. [20]

### III.5.2.5. Expansion flexibility

It is the capacity of expansion of a production system according to the will of the designer. To achieve this level of flexibility, it is essential to have flexibility in machinery and flexibility in the means of handling. The expansion flexibility of a production system concerns companies that are growing in activity. According to [21] expansion flexibility helps to reduce the costs of implementation times and costs of new products. In addition, to achieve this level of flexibility it is necessary to avoid design processes based on the implementation of production systems (eg. dedicated production lines), it is preferable to have modular flexible production cells. [22]

## III.5.3. Aggregate flexibilities

### III.5.3.1. Flexibility of control programs

In the factories where several teams work but at odd hours, there is a time when the change of team has to take place. This period causes a slowdown in production. One of the solutions to stabilize the production during the change of team is the increase of the flexibility of the control programs of the production system. Thus, the flexibility of control programs is the ability of a production system to run idle for a relatively long period of time. The aim of such flexibility is to: enable team changes, reduce production start-up times and consequently increase production system yields. [18]

### III.5.3.2. Flexibility of production

It is the set of parts that can produce a production system without it adding another major equipment. This characteristic defines the production potential. The flexibility of production allows companies that position themselves in new product areas to continually remain competitive. It reduces production costs and introduces new products and also replaces them with a production system, allowing a company to diversify its products. activities and therefore to reduce its risks. [22]

### III.5.3.3. Market flexibility

It is the ability of a production system to adapt to the changing market environment. This type of flexibility is very important for business survival in a constantly changing environment. This shift could be due to technological innovations, changes in consumer tastes and behaviors, short product life or uncertainty of supply sources. Market flexibility allows firms to cope with these changes, and this flexibility is also a real asset to a company in the face of its competitors. [22]

## III.6. FLEXIBLE MANUFACTURING SYSTEMS

A flexible production system represents several flexible cells linked together by wire-guided vehicles that make up the various production areas. The flexible system is a system able to adapt to any new constraint imposed by the environment of which the production is managed by a computer system (change of product, modification of production flow) [23]

A flexible workshop allows the automatic production of parts of various types and in variable quantities. Operators do not intervene directly in the manufacturing process and essentially limit their interventions to maintenance; the scheduling of production is managed by a computer system [24]

## III.7. DIFFERENT TYPES OF FMS

According to [25] the FMS can be divided into five categories:

### III.7.1. Flexible module: (FM)

The flexible module: is an NC machine with a storage area, a parts loader and an atomic tool magazine

### III.7.2. Flexible cell: (FC)

Represents several modules connected by a guided vehicle allowing the power of machines in pieces

### III.7.3. Flexible group: (FG)

The flexible group (FG) is a set of cells and modules forming the same production area (manufacture, machining or assembly) joined by wire-guided vehicles; everything is managed by a central computer.

### III.7.4. Flexible system: (FS)

The FS represents several flexible cells interconnected by wire-guided vehicles making up the various production zones

### III.7.5. Flexible line : (FL)

The FL is a set of instruments allocated to various machines such as a line of wire-guided vehicles, robots, conveyors, shuttles, ... [26]

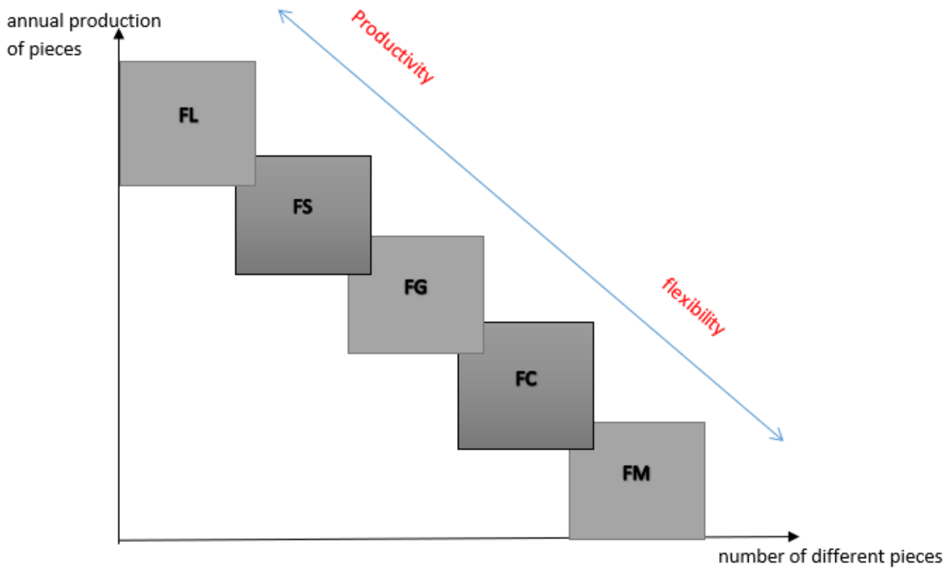



***Figure III. 1** Different types of FMS between flexibility and productivity*

## III.8. AREA OF APPLICATION OF FMS IN INDUSTRY

The following chart in the Fig. III.2 shows the various applications in an industry

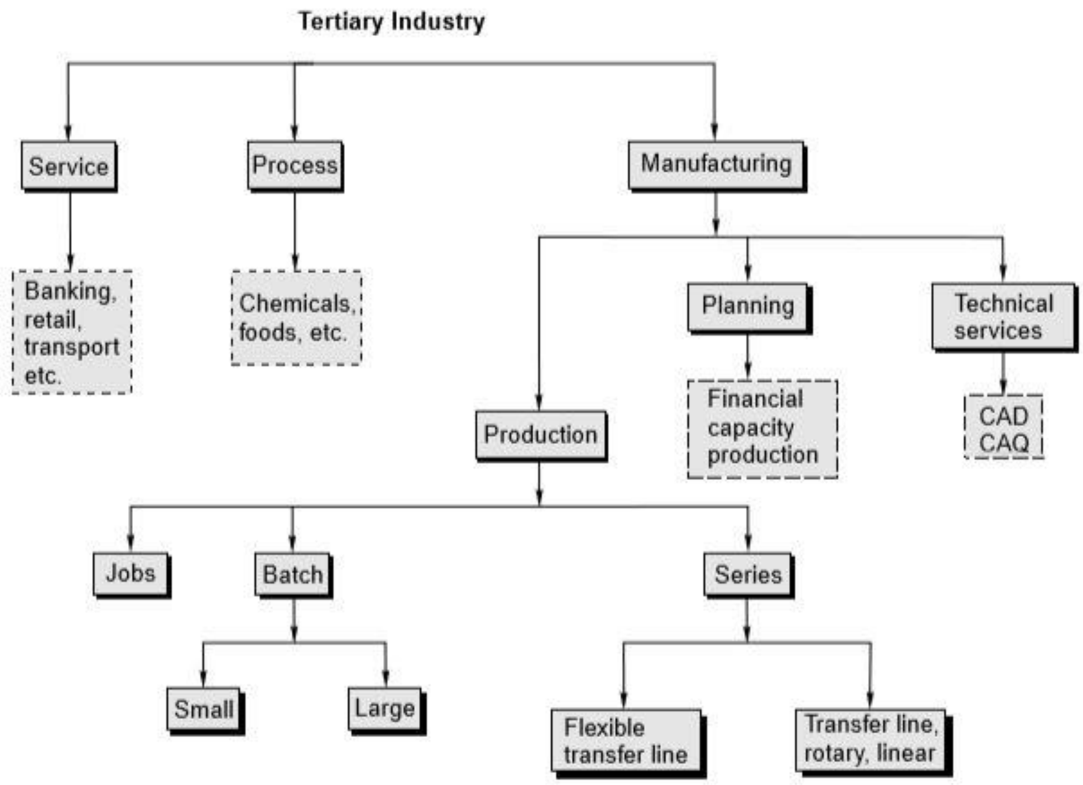



***Figure III. 2** Area of applications of FMS in an industry*

CAD: Computer Aided Design  CAQ: Computer Aided Quality Control

## III.9. COMPONENT OF A FMS

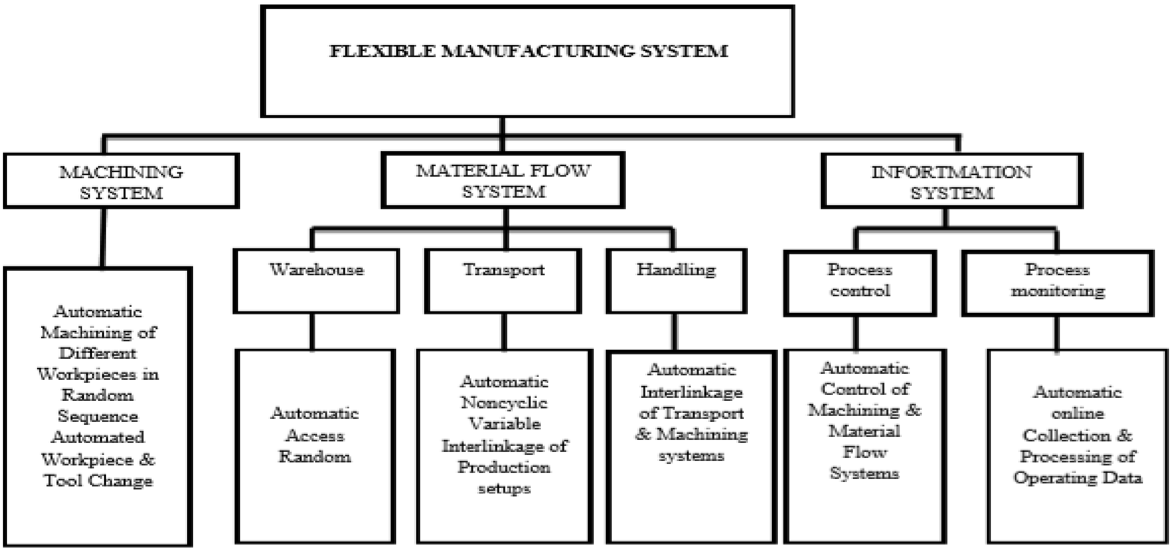



*Figure III. 3 Components and structure of Flexible Manufacturing System*

### III.9.1. Workshops

A workshop is characterized by the number of machines it contains and by its type. [27]. There are three types of workshops: flow-shop, job-shop and open-shop, with possible extensions for each of them. [28]

#### III.9.1.1. Flow-shop

These are workshops where a production line consists of several machines in series; all the operations of all the tasks go through the machines in the same order, so a flow-shop is a single path workshop, for example, if the product needs two drilling operations, you will have two drilling machines.

- **Easy to automate:** It is simple to apply robotics to a flow shop because the steps are consistent and repetitive.
- **Easy to measure:** Many manufacturing KPIs (Key Performance Indicators) are designed for flow shops.
- **Easy to optimize:** As a result of being easy to measure, it is also easy to tell which stages in the process need to be optimized and there are clear solutions for dealing with unoptimized steps.

#### III.9.1.2. Job-shop

These are workshops where operations are carried out according to a well-defined order, varying according to the task to be performed; the flexible job-shop is an extension of the classic job-shop model; its particularity lies in the fact that several machines are potentially capable of performing a subset of operations. Also called multi-path workshops

**Easy to set up:** Small businesses often implement jobs shops because they are simple to set up and the initial investment is minimal. You can begin with one or two machines and add them as needed.

**High flexibility:** It is easy to add, change or remove stages in the process. If a part needs to be re-machined, it is simply sent to the corresponding machine.

**Easy to increase capacity:** Because it is easy to add a new machine to a job shop, you can increase capacity incrementally by adding a new machine.

#### III.9.1.3. Open-shop

Compared to other workshop models, open-shop is not commonly used in companies. This type of workshop is less constrained than that of flow-shop type or job-shop type. Thus, the order of operations is not fixed, it have no scheduling at all, operations can take place in any order, which means they are very flexible but hard to optimize in practice, the problem of scheduling consists, on the one hand, in determining the path of each product and, on the other hand, in scheduling the products taking into account the ranges found.

## III.10. PROBLEMS IN A FLEXIBLE MANUFACTURING SYSTEM

There are four problems with flexible production systems [29]:

### III.10.1. FMS design problems

In developing an FMS design, there is a partial ordering to some of the decisions that have to be made. Some decisions must precede others in time. We partition these into initial specification decisions and subsequent implementation decisions.

### III.10.2. FMS planning problems

We define FMS planning problems to be those decisions that have to be made before the FMS can begin to produce parts. Once the FMS is 'set-up', production can start.

When the FMS planning problems have been solved, and all of the cutting tools have been loaded into the appropriate tool magazines, production can begin. These FMS planning problems can be solved sequentially, or iteratively, or several simultaneously. They can be re-solved as often as every couple of days or weeks. They may re- quire re-solving if one of the machine tools is down for a long time.

### III.10.3. FMS scheduling problems

MS scheduling problems are concerned with running the FMS during real time once it has been set up during the planning stage which is in advance of actual production. There are many possible approaches that can be taken to schedule the manufacture of parts through the system. Different approaches might be applicable in different situations [28].

### III.10.4. FMS control problems

We define FMS control problems to be those associated with the continuous monitoring of the system, the keeping track of production to be certain that production requirements and due dates are being met as scheduled.

## III.11. SOLUTION OF FMS PROBLEMS:

There are many models available that can be applied to help answer some of the preceding problems. Each model can structure the problems differently. Each model ignores or aggregates some features of the system to focus on particular aspects. The models have provided either operational or qualitative insights into some of the FMS decision problems. A list of several of the models that can and have been applied include: simulation, group technology, computer aided process planning, queueing networks, mathematical programming (linear, nonlinear, integer), perturbation analysis, Petri nets, and artificial intelligence.

## III.12. MODELING OF PRODUCTION SYSTEMS

We are engaged in the proposal of a simulation model of production systems, so it is important to remember what are the objectives of modeling for production systems, what are the main models used, and also what are the approaches and approaches used in this modeling. In this way we will be able to choose the model that we will use as part of our work. Before that, let us recall the objectives of the modeling of production systems.

### III.12.1. Objectives of modeling a production system

- **Analysis:** description or simulation: the analysis and description tools make it possible to define the models of the subsystems of a production system as defined in [30], namely the physical subsystems, d. information and decision-making.
- **Evaluation**: evaluation models make it possible to determine the performance of a production system through indicators defined by the manager of the production system. The models that allow the evaluation of a production system are most often so-called simulation models. These simulation models are based on mathematical equations or graph theory. Simulation is obviously only possible with the help of appropriate calculation or simulation software.
- **Optimization**: it is done by the exact methods or approximate methods, using mathematical models or graphs.

There are two main types of models, mathematical models, and discrete event models. Among mathematical models we have linear models, integer models, quadratic models. And among the models with discrete events we distinguish disjunctive-connective graphs, precedence graphs, automatons, and Petri nets.

## III.13. PETRI NETS MODELING AND PRODUCTION SYSTEMS:

Petri nets have been used for more than 30 years for modeling and verifying different aspects of flexible production systems.

| Date and reference | Type of Petri nets | Description |
|---|---|---|
| 1989 [31] | Timed Petri nets | Modeling flexible production systems using timed PN. |
| 2002 [32] | Colored Petri nets | Multi-objective optimization for minimizing production costs under multiple production plans and minimizing reconfiguration costs. The PN are coupled to the genetic algorithms as well as to the priority rule SIO (Shortest Imminent Operation time) |
| 2003 [33] | Timed Petri nets | Optimized scheduling using the A* algorithm (the smallest path search) and marking graphs in order to |

| Date and reference | Type of Petri nets | Description |
|---|---|---|
| | | minimize productivity (Makespan) flexible production workshops |
| 2007 [34] | Timed Petri net | Modeling and analysis of a flexible workshop using Petri nets |
| 2008 [35] | High level Petri nets | The purpose of this work is the use of PNs for the modeling and evaluation of Flexible Production Systems. The author also proposes an object vision of Petri nets, where tokens are now considered as objects. |
| 2009 [36] | Colored Petri nets | Modeling and maximization of the performance of the transport system consisting of automatically guided vehicles. The activity of a machine is represented by a transition. |
| 2011 [37] | Colored Petri nets | Using timed state graphs to model the processing of a two-machine Job Shop. |
| 2011 [38] | Stochastic Petri nets | In this work, the authors present a methodology for the analysis of flexible production systems. This methodology is based on stochastic and modular Petri nets. The authors present in their work the models of the basic elements of a flexible production system, namely: machines, transport resources, products. The authors also develop a stochastic model to model the dependability. |
| 2013 [39] | Timed Petri nets | Modeling and simulation of the scheduling of the Job-Shop using timed Petri nets. The models of the machines which are presented take into account the availability of the machine but do not seem to take into account the various tools. |
| 2014 [40] | deterministic and stochastic Petri nets | The models are used to evaluate the performance of the Manufacturing Production Systems. The machine models used take into account the availability problem |

| Date and reference | Type of Petri nets | Description |
|---|---|---|
| | | by the tool change. This work presents a methodology for the design of modular production systems taking into account transport times, machine breakdowns, and maintenance tasks. |
| 2014 [41] | Fuzzy Petri nets | Planning of maintenance of time-constrained production manufacturing systems based on Fuzzy PN |
| 2016 [42] | Place& transition Petri nets | Development of a methodology for increasing the flexibility of planning in service-oriented production systems. |
| 2017 [43] | Nested Petri nets | Authors use the synthesis-based modeling approach to synthesize a Petri net from specified behavior. they have a model of simple executions of a process by means of a very intuitive modeling language. And use a synthesis algorithm to produce a relative Petri net model. |
| 2017 [44] | Place& transition Petri nets | This paper illustrates the Petri net modeling of a conceptual model of flexible manufacturing system (FMS) and addresses the problem of deadlock by deadlock prevention policy. |
| 2018 [45] | Place& transition Petri nets | The authors focused on solving deadlock problems in flexible manufacturing systems modeled with Petri nets by adding a set of recovery transitions. |

***Table III. 2** Components and structure of Flexible Manufacturing System*

## III.14. CONCLUSION

It must be recognized that flexible systems are a wonderful tool that technology makes available to us to achieve significant progress, regardless of the technological and human levels of the companies. The real novelty does not lie in the technology implemented, except at the level of control and management software. The evolution is in the mode of conception, in the approach that must be applied and in the operations that must be solved. As such an analogy is possible with the simulation, it is necessary before the actual processing to make model.

# CHAPTER IV

## ANALYSIS AND SIMULATION OF A REAL PRODUCTION SYSTEM

# CHAPTER IV: ANALYSIS AND SIMULATION OF A REAL PRODUCTION SYSTEM

## IV.1. INTRODUCTION

The Petri net description of a system concentrates on two concepts: events and conditions [46]. Events are actions that occur in the system and conditions describe the state of various parts of the system. The condition is either true or false. In order for events to occur certain conditions, referred to as preconditions, must exist. After an event occurs these preconditions usually change and another set of conditions, referred to as postconditions, becomes valid. The postconditions of one event may be the preconditions of another and so a sequence of events may occur.

Our study of Petri net for manufacturing systems begins with the classification of places in a Petri net model. The modeling approach in which places are used to model operation processes and the availability of resources, and in which transitions are used to model the start and/or end of operations makes such a distinction among places possible.

## IV.2. RESOURCES

A resource is a technical or human means to be used for the completion of a task and available in limited quantities [47]. Resources, whether human or material, are essential for the maintenance function. However, the costs they entail require better exploitation and allocation of resources because of conflicts that arise when a resource is solicited by more than one machine.

The resolution of this conflict takes into consideration the different types of resources. This notion of conflict is relative to a decision to be made, according to unforeseen criteria.

Each maintenance task requires the use of one or more types of resources. In terms of model we can present the resources as places containing each a number of tokens, this number means the available quantity of such a resource.

We have two types of resources which is Renewable resources and consumable resources:

- **Renewable resources**

This type of resource is reusable, for example (machine, man, etc.).

❖ **Consumable resources**

The consumption of the resource is considered a constraint in addition to its availability. Examples include raw materials and financing.

The different types of resources were represented in (**Figure IV.1).**

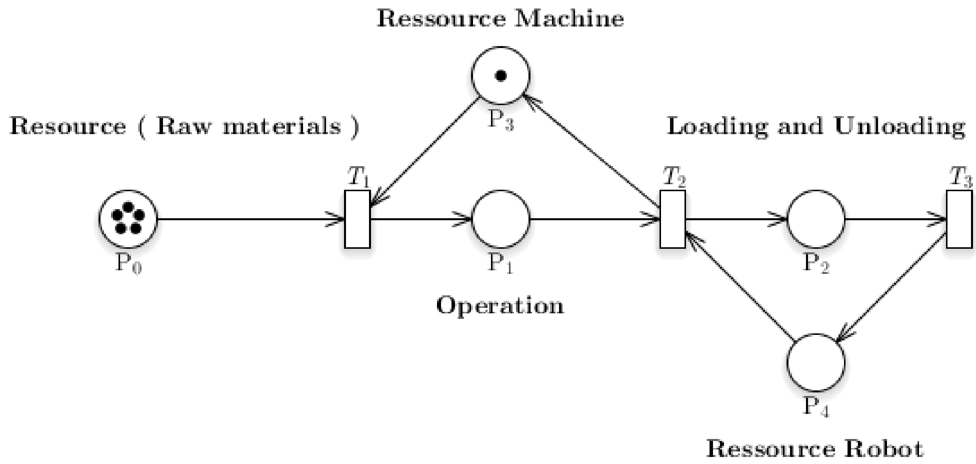



***Figure IV. 1*** *Types of resources example*

Tokens in $P_0$ represent the number of raw materials available, tokens in places P3 and P4 represent the availability of the resource, the machine is available but the robot is not.

## IV.3. SHARED AND UNSHARED RESOURCE

Each manufacturing process, whatever its type, needs resources, these resources may be shared with other operations or may be private:

- Private resource (unshared): each operation has its own resources.
- Shared resource: resources in such systems may be shared by different processes.

In manufacturing we need machines, robots and transports means as a resource, these operations can be in parallel so we can share machines, robots and transports means between different operations. A simple example below in **Figure IV.2**.

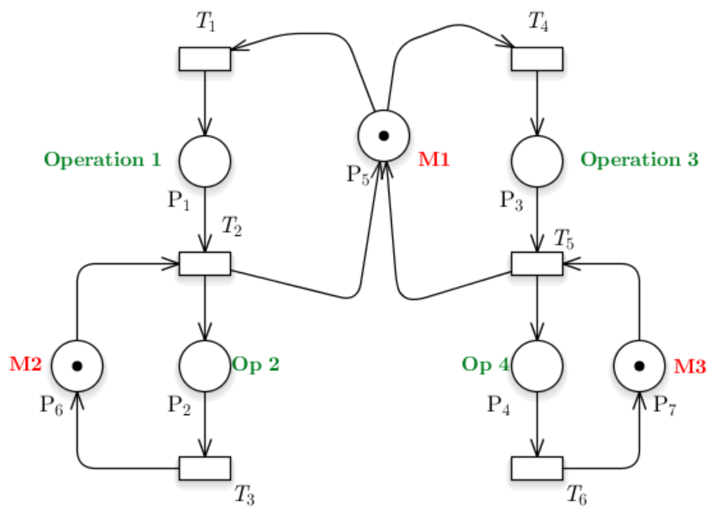



***Figure IV. 2*** *Shared and unshared resource*

The initial marking is: $M_0$= (0,0,0,0,1,1,1)

In this example we have 2 parallel process, each process with two operations and every operation uses one resource.

Operation 1 and operation 3 use M1 as a shared resource between both of it, the other operations op2 and op4 use M2 and M3 respectively.

## IV.4. Description of the system

This system uses a workstation developed at the URB Factory. The workstation uses robots to place and pull the bearing into the machines and uses Automated guided vehicles to transport the parts from block to another block. This system's layout is depicted in **Fig IV.3** and comprises the following components:

- 28 Turning Machines.
- 83 Grinding machines.
- 4 Automated guided vehicles.
- 2 Assembling stations.
- 41 Robots
- Sensors installed in the robots.
- Storage station
- 4 entries
- 2 exits

| Code of machines | The Role of the machine |
|---|---|
| G 40_OS | Drilling machine GCO-40 |
| KH300_W3 | Hydraulic lathe SHM-300 (canal W33) |
| L.KH.OSC | Lathes line KH-300 |
| MK 248 | Frontal lathe MK-248 (MA-730) |
| AJ_GA_OS | Adjustment after drilling |
| CNC_OCAR | Couple 2xCNC lathes (2XOKUMA/3XPUMA/3XLYNX) |
| 3183 | Centerless grinding machine 3183 |
| DISC_PE | Device for grinding rings |
| ICHIKAWA | Rectified plan machine ICHIKAWA |
| LZ 259 | Grinding machine LZ-259 |
| R 236 | Grinding machine GIUSTINA R-236 |
| R 242 | Grinding machine GIUSTINA R-242 |
| SASL 200 | Centerless grinding machine SASL-200 |
| SASL 5AD | Centerless grinding machine SASL-5AD |
| SL 631 | Centerless grinding machine SL-631 |
| AGL315_E | Grinding machine CDR SWaAGL-315 |
| AGL315_G | Grinding machine CDR SWaAGL-315 |
| MA464_E | Corrugated grinding machine MA-464 |
| PRI 300 | Grinding machine CDR PRI-300A |
| SAW 6 | Grinding machine SAW-6F |
| SIW4B_E | Grinding machine SIW-4/1B |
| ECOCA_R | Numerical lathe machine ECOCA |
| IGL450_E | Grinding machine -SWaIGL450 CNC-inel 10 |
| 6A-ASCE | Interior grinding machine 52ACE |
| AFCC 450 | Grinding machine CDR AFCC-450AR |
| MRG 140 | Corrugated grinding machine MRG-140 |
| SAW 4 | Exterior grinding machine SAW-4f |

***Table IV. 1** Some machines in the system and their jobs*

In this manufacturing system we have three mains operations which are turning, grinding and assembling. Two products B1 and B2 are manufactured and their process ranges are shown in **Figure IV.3** We divided the system into five blocks:

- Block 1: turning and grinding of part B1.1 (22230 CW33-10)
- Block 2: turning and grinding of part B1.2 (22230 MB-20)
- Block 3: turning and grinding of part B2.2 (22232 MB-20)
- Block 4: turning and grinding of part B2.1 (22232 MBW33-10)
- Block 5: assembling of B1 and B2

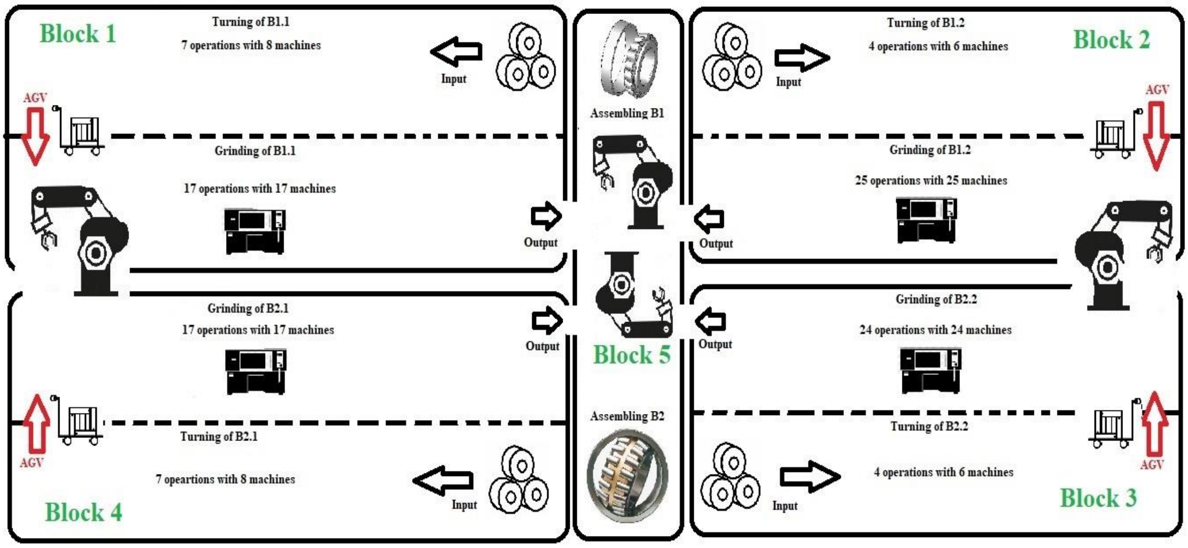



***Figure IV. 3*** *The Manufacturing System*

## IV.5. Operating cycle

An unlimited source of raw materials is assumed. Once machines, robots, or AGVs start work on any operation, they cannot be interrupted until the work is complete.

There are four entries for raw materials, which are produced into four different kinds of products. Initially, the vehicles (AGV) are empty and available for upload. Four AGVs are designed for the delivery of final parts from the turning station to the grinding station in the system. The first transfer is made from the output of Turning to the input of grinding where the product will then be grinded. From AJ_GA_OS (Manual loading), AGV1 and/or AGV4 sends final parts to the input of grinding and back to Entry. From AJ_GA_OS (Manual loading), AGV2 and or AGV3 sends final parts to the input of grinding. The transfer must wait in its state until the Robot unloading of the part. Once the vehicle is unloaded, it goes into the initial state to load new parts.

Robot R1 unloads AGV1 and AGV2 and none of these AGVs has any priority to use this robot. R1 chooses one machine if raw material is available and the AGV is ready. Robots R2, R3, R4, R5, R6, R7 and R8 used to loads and unloads machines in the grinding station in Block 1. Robots R1 and R38 is shared between block1 and block4, the robots R18 and R39 is shared between block2 and block3.

There are two exits for finished parts B1 and B2 where we have the assembling area,

Parts from Block1 will be assembled with parts from Block2 and block3 parts assembled with block4 parts.

## IV.6. Modeling general system

The criteria most used in the choice of models are:

- System data.
- Adaptation and simplicity of the model to the system.
- The implementation of the model on computers.

For the modeling we used a simulator called GreatSPN (description in Annex 1) to modeling the system and we used another simulator which is PIPEv4.3.0 to get the properties and the matrix.

The model is built in 2 steps:

- Workshops modeling.
- The modeling of operations and machines.

### IV.6.1. Workshops modeling

The Petri Net model of the workstations is shown in **Figure IV.4**

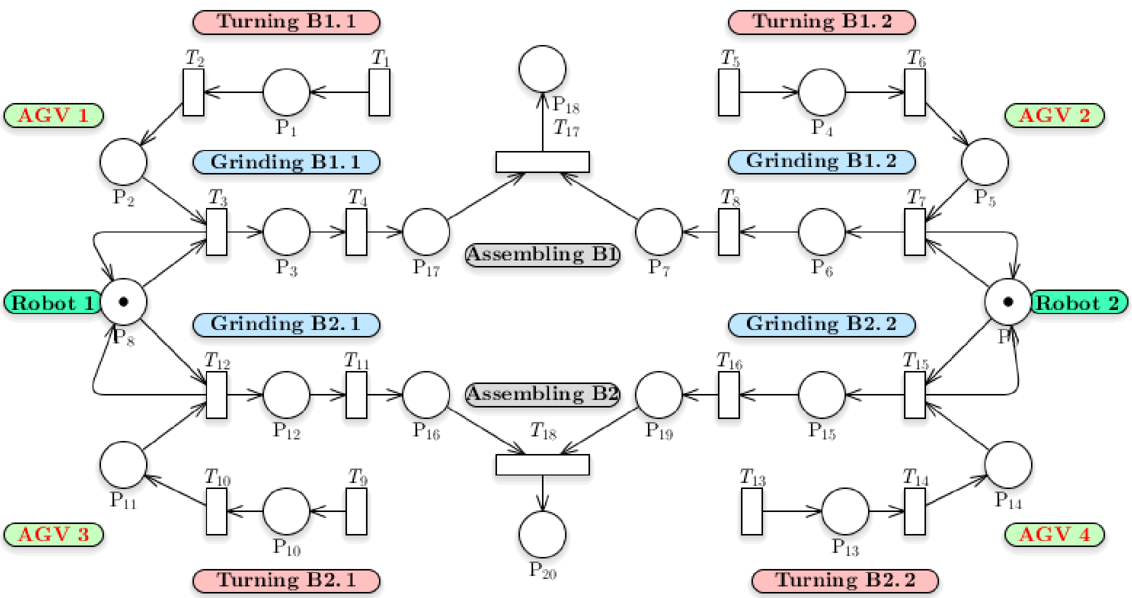



*Figure IV. 4 Modeling of general system*

In this model we see the course of the general system block by block, the incidence matrix of the system is showed in **figure IV.4, IV.5** and **IV.6**

**Forwards incidence matrix $I^+$**

| | T0 | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 | T17 | T18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| P10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| P14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| P15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| P16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P17 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| P19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| P20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

***Figure IV. 5** The output matrix*

**Backwards incidence matrix $I^-$**

| | T0 | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 | T17 | T18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| P8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| P10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| P14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| P15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| P16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| P17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| P18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| P20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***Figure IV. 6** The input matrix*

**Combined incidence matrix $I$**

| | T0 | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 | T17 | T18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P1 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P2 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P3 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P4 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 |
| P8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| P13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 |
| P14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 |
| P15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 |
| P16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| P17 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 |
| P18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| P19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 |
| P20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

***Figure IV. 7** The incidence matrix*

To make an oscillogram for the system we have the table of state of places **Table IV.1** to see how the course of simulation.

| (Time) | (P1) | (P2) | (P3) | (P4) | (P5) | (P6) | (P7) | (P8) | (P9) | (P10) | (P11) | (P12) | (P13) | (P14) | (P15) | (P16) | (P17) | (P18) | (P19) | (P20) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

***Table IV. 2*** *State of places*

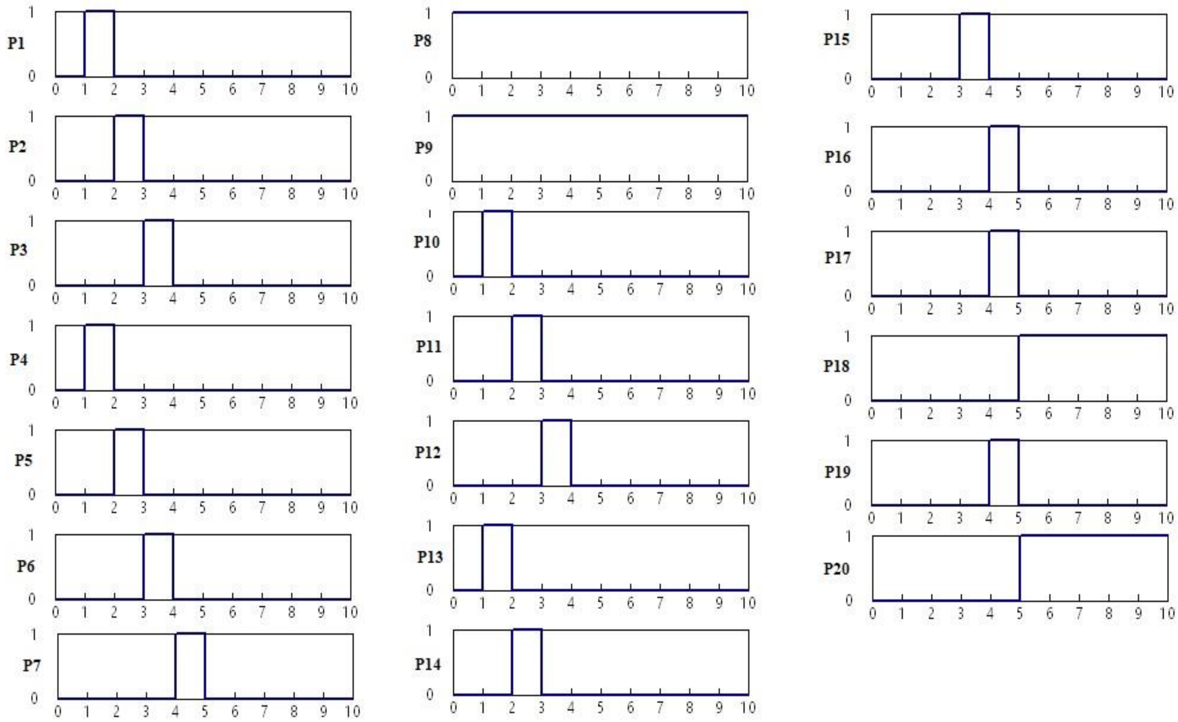



***Figure IV. 8*** *Oscillogram of evolution state of places*

The oscillogram of evolution state of places is showed in **Figure IV.7**

## IV.7. MODELING THE SYSTEM

The system may contain shared and unshared resources, renewable and consumable resources. The token (●) in the net sets (free or busy) the state of the machines or robots (resource place).

The modeling of the five blocks and the full system using GreatSPN Tool is in the next figures. This model represents the scheduling of the system.

### IV.7.1. Block 1

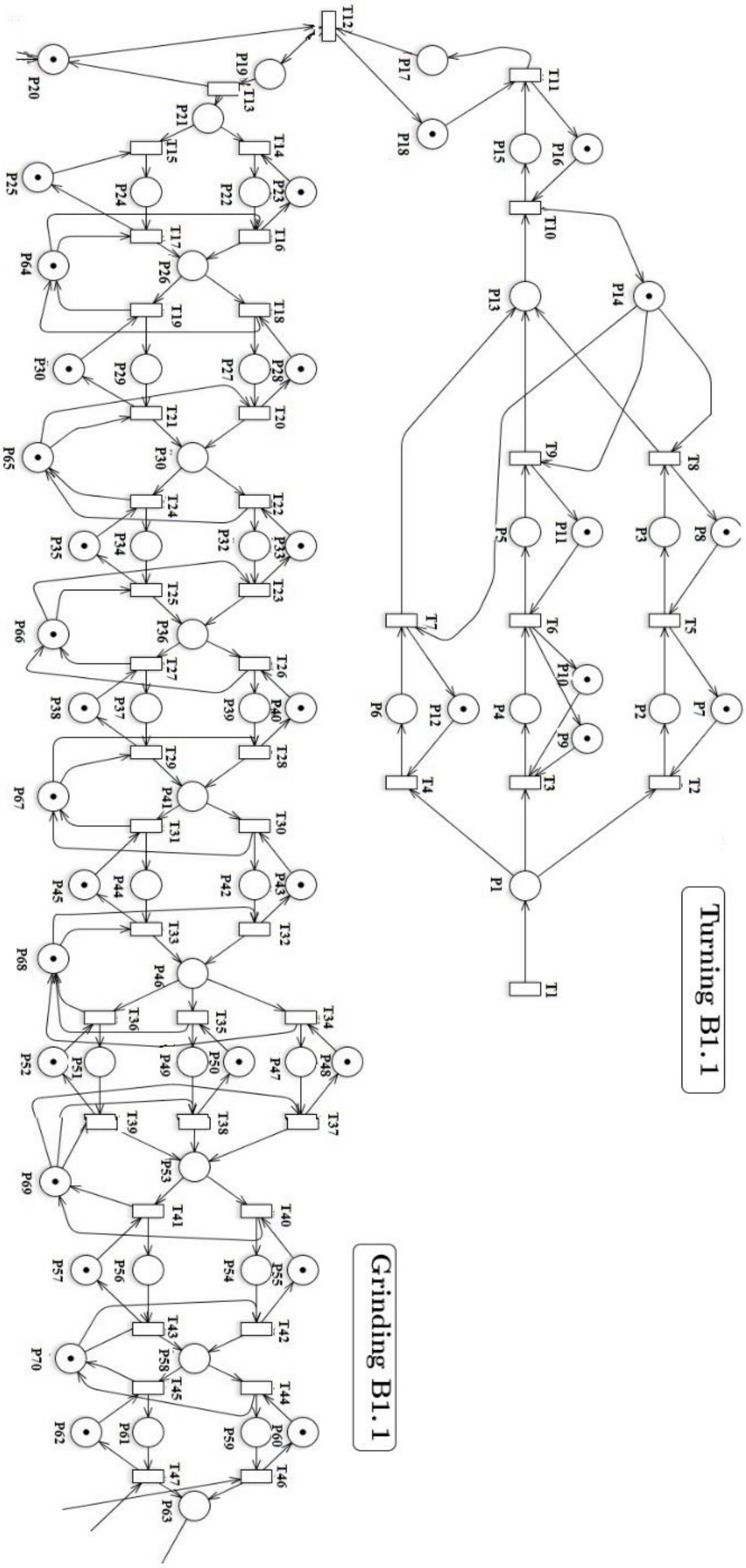



***Figure IV. 9*** *Modeling of block 1*

## IV.7.2. Block 2

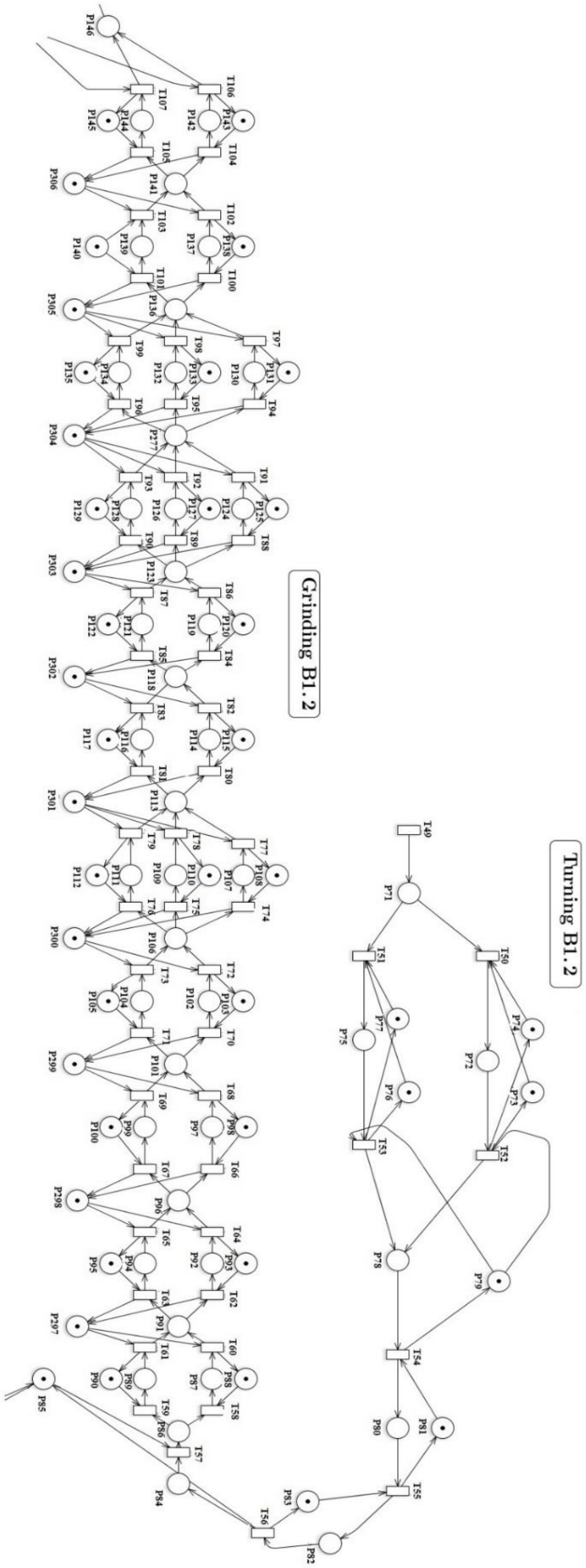



*Figure IV. 10 Modeling of block 2*

### IV.7.3. Block 3

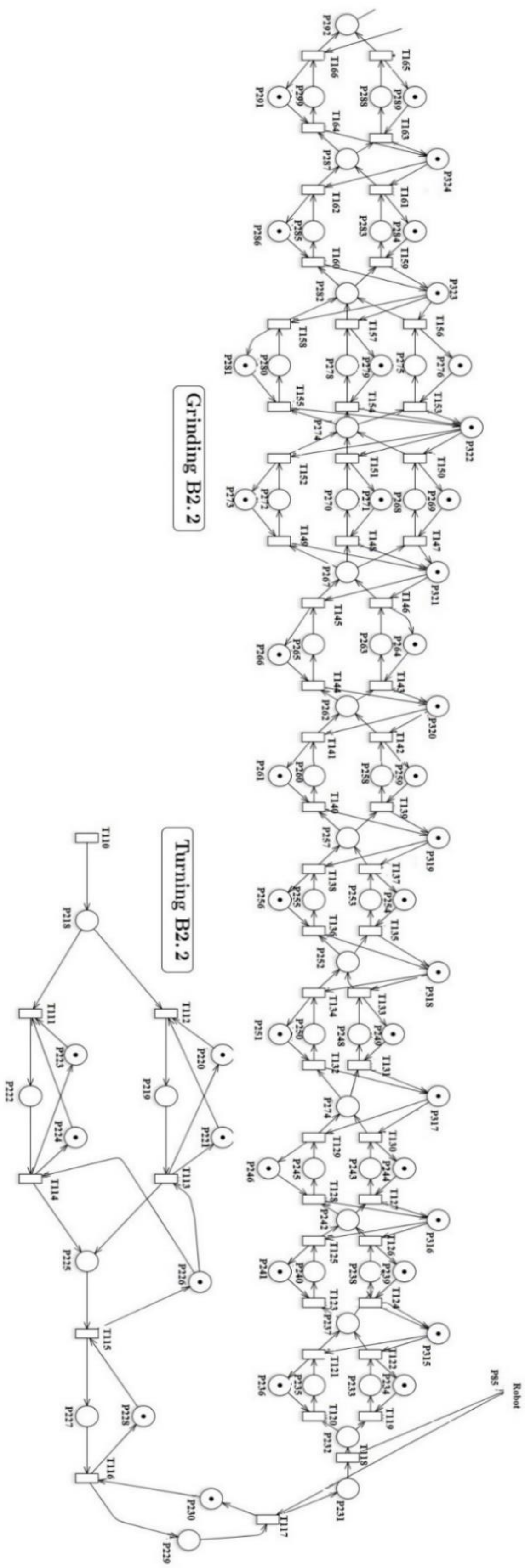



***Figure IV. 11*** *Modeling of block 3*

### IV.7.4. Block 4

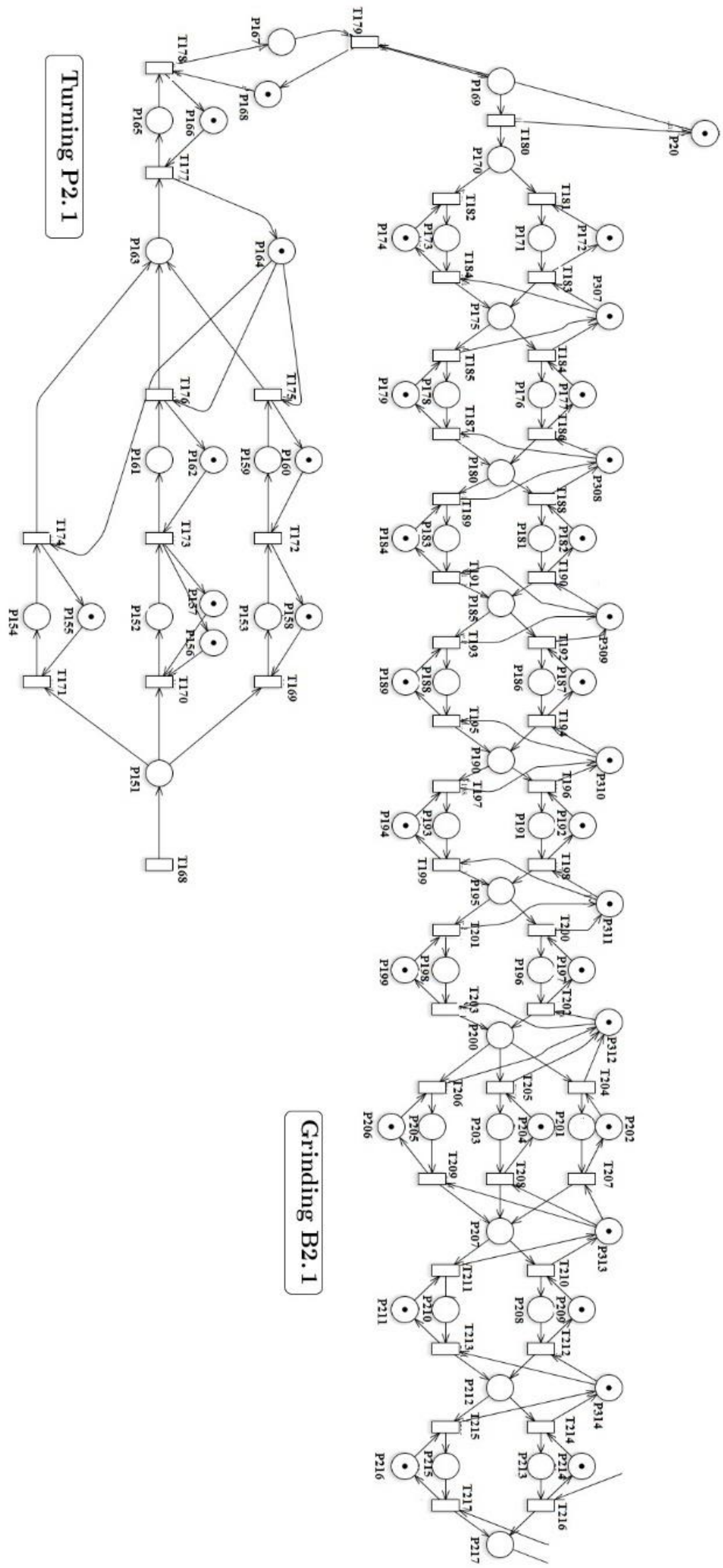



*Figure IV. 12* *Modeling of block 4*

## IV.7.5. Block 5

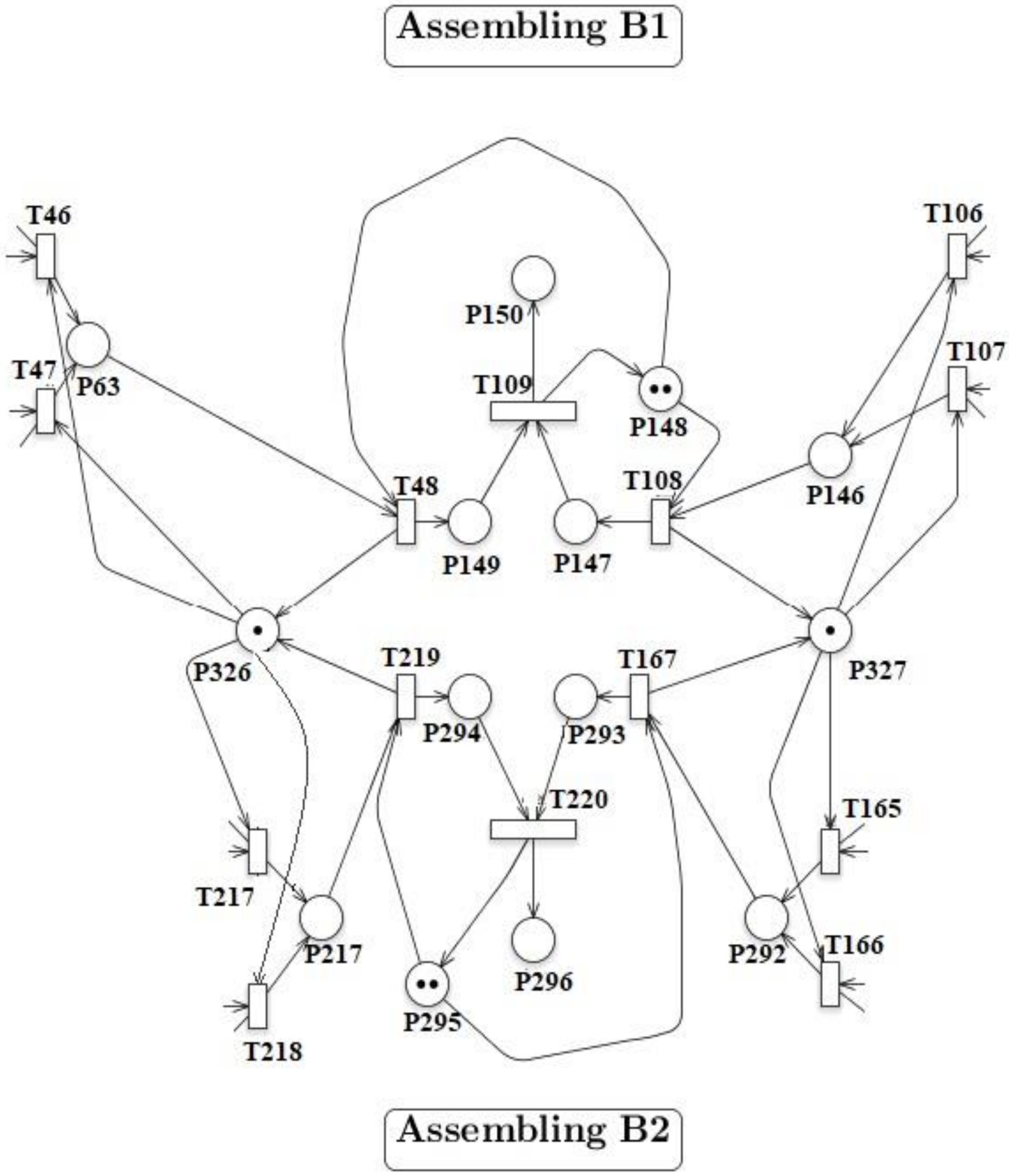



*Figure IV. 13 Modeling of block 5*

## IV.4.6. Full system

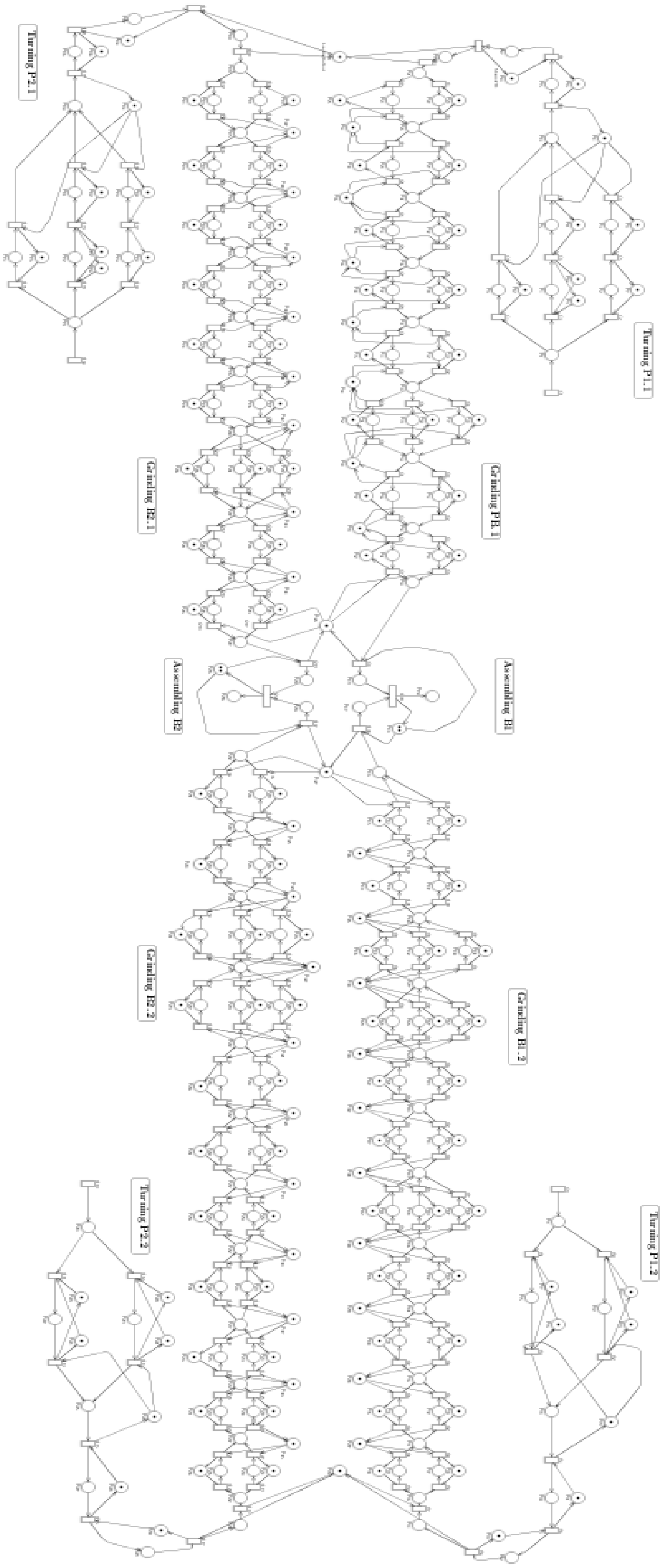


***Figure IV. 14*** *Modeling of the full system*

## IV.5. TABLES OF PLACES AND TRANSITIONS

### IV.5.1. Significance of places

| Places | Significance | Places | Significance | Places | Significance |
|---|---|---|---|---|---|
| P1 | part 1 loaded | P23 | Availability of R 236 | P45 | Availability of MRS 650 |
| P2 | Operation 1 | P24 | op 9 finishing rectification | P46 | Intermediate place |
| P3 | Operation 2 | P25 | Availability of R 242 | P47 | operation |
| P4 | Operation 3 | P26 | | P48 | Availability of LZ 259 |
| P5 | Operation 4 | P27 | op 10, exterior rectification | P49 | operation |
| P6 | operation 5 | P28 | Availability of SL 631 | P50 | Availability of 6ASCE |
| P7 | Availability of L.KH.OSC | P29 | op 11, external rectification | P51 | operation |
| P8 | Availability of KH300_W3 | P30 | Availability of 3183 | P52 | Availability of MRS 650 |
| P9 | Availability of TRC-100 | P31 | Intermediate place | P53 | Intermediate place |
| P10 | Availability of MK 248 | P32 | operation 12 | P54 | operation |
| P11 | Availability of KH300_W3 | P33 | Availability of LZ 259 | P55 | Availability of SASL 5AD |
| P12 | Availability of OK 300 | P34 | operation 13 | P56 | operation |
| P13 | Operation 6 | P35 | Availability of MRS 650 | P57 | Availability of SASL 200 |
| P14 | Availability of G 40_OS | P36 | Intermediate place | P58 | Intermediate place |
| P15 | operation 7 | P37 | operation 14 | P59 | operation |
| P16 | Availability of AJ_GA_OS | P38 | Availability of SASL 5AD | P60 | Availability of R 236 |
| P17 | transport | P39 | operation 15 | P61 | operation |
| P18 | Availability of AGV | P40 | Availability of SASL 200 | P62 | Availability of R 242 |
| P19 | loading of Part 1 | P41 | Intermediate place | P63 | B1 ready for assembling |
| P20 | Availability of Robot 1 | P42 | operation | P64 | Availability of Robot 2 |
| P21 | Intermediate place | P43 | Availability of LZ 259 | P65 | Availability of Robot 3 |

| Places | Significance | Places | Significance | Places | Significance |
|---|---|---|---|---|---|
| P22 | op 8 finishing rectification 1 | P44 | operation | P66 | Availability of Robot 4 |

*Table IV. 3 Significance of places P1 to P66*

P1 – P16, Turning of B1,1
P21-P63 Grinding of B1,1

| Places | Significance | Places | Significance | Places | Significance |
|---|---|---|---|---|---|
| P67 | Availability of Robot 5 | P89 | operation | P111 | Availability of AFCC 450 |
| P68 | Availability of Robot 6 | P90 | Availability of R 242 | P112 | operation |
| P69 | Availability of Robot 7 | P91 | Intermediate place | P113 | Intermediate place |
| P70 | Availability of Robot 8 | P92 | operation | P114 | operation |
| P71 | Intermediate place | P93 | Availability of R 236 | P115 | Availability of AGL315_G |
| P72 | Operation | P94 | operation | P116 | operation |
| P73 | Availability of SHS28_OS | P95 | Availability of R242 | P117 | Availability of AFCC 450 |
| P74 | Availability of CNC_OCAR | P96 | Intermediate place | P118 | Intermediate place |
| P75 | operation | P97 | operation | P119 | operation |
| P76 | Availability of MK6751 | P98 | Availability of SASL 200 | P120 | Availability of SIW5B_E |
| P77 | Availability of CNC_OCAR | P99 | operation | P121 | operation |
| P78 | operation | P100 | Availability of SASL 5AD | P122 | Availability of SWaIGL 450CNC |
| P79 | Availability of FR. X53K | P101 | Intermediate place | P123 | Intermediate place |
| P80 | operation | P102 | operation | P124 | operation |
| P81 | Availability of AJ_GA_OS | P103 | Availability of SIW5B_E | P125 | Availability of MA464_E |
| P82 | transport | P104 | operation | P126 | operation |
| P83 | Availability of AGV | P105 | Availability of SWaIGL 450CNC | P127 | Availability of MRG 140 |
| P84 | loading | P106 | Intermediate place | P128 | operation |
| P85 | Availability of Robot 18 | P107 | operation | P129 | Availability of ECOCA MT312/500 |
| P86 | Intermediate place | P108 | Availability of AGL315_E | P130 | operation |

| | | | | | |
|---|---|---|---|---|---|
| P87 | operation | P109 | operation | P131 | Availability of MA464_E |
| P88 | Availability of R 236 | P110 | Availability of SAW 6 | P132 | operation |

***Table IV. 4*** *Significance of places P67 to P132*

P71 – P81 Turning B1,2
P86 – P146 Grinding B1,2

| Places | Significance | Places | Significance | Places | Significance |
|---|---|---|---|---|---|
| P133 | Availability of MRG 140 | P155 | Availability of OK 300 | P177 | Availability of SL 631 |
| P134 | operation | P156 | Availability of TRC-100 | P178 | operation |
| P135 | Availability of ECOCA MT312/500 | P157 | Availability of MK 248 | P179 | Availability of 3183 |
| P136 | Intermediate place | P158 | Availability of L.KH.OSC | P180 | Intermediate place |
| P137 | operation | P159 | operation | P181 | operation |
| P138 | Availability of AGL315_E | P160 | Availability of KH300_W3 | P182 | Availability of LZ 259 |
| P139 | operation | P161 | operation | P183 | operation |
| P140 | Availability of SAW 4 | P162 | Availability of KH300_W3 | P184 | Availability of MRS 650 |
| P141 | Intermediate place | P163 | operation | P185 | Intermediate place |
| P142 | operation | P164 | Availability of G 40_OS | P186 | operation |
| P143 | Availability of PRI 300 | P165 | operation | P187 | Availability of R 242 |
| P144 | operation | P166 | Availability of AJ_GA_OS | P188 | operation |
| P145 | Availability of DISC_PE | P167 | Transport | P189 | Availability of ICHIKAWA |
| P146 | Intermediate place | P168 | Availability of AGV | P190 | Intermediate place |
| P147 | Loading B1,2 for assembling | P169 | loading | P191 | operation |
| P148 | Availability of Robots R41 | P170 | Intermediate place | P192 | Availability of 3183 |
| P149 | Loading B1,1 for assembling | P171 | operation | P193 | operation |
| P150 | B1 Finished | P172 | Availability of R 242 | P194 | Availability of SL 631 |
| P151 | Intermediate place | P173 | operation | P195 | Intermediate place |
| P152 | operation | P174 | Availability of R 236 | P196 | operation |

| | | | | | |
|---|---|---|---|---|---|
| P153 | operation | P175 | Intermediate place | P197 | Availability of LZ 259 |
| P154 | operation | P176 | operation | P198 | operation |

***Table IV. 5** Significance of places P133 to P198*

P147 – P150 Assembling the two parts B1,1 and B1,2 to get the first piece B1
P151- P166 Turning of B2,1. P167 – P168 AGV transport B2,1 from turning workshop to the grinding workshop, P170 - P217 Grinding of part B2,1

| Places | Significance | Places | Significance | Places | Significance |
|---|---|---|---|---|---|
| P199 | Availability of MRS 650 | P221 | Availability of CNC_OCAR | P243 | operation |
| P200 | Intermediate place | P222 | operation | P244 | Availability of SASL 200 |
| P201 | operation | P223 | Availability of MK6751 | P245 | operation |
| P202 | Availability of LZ 259 | P224 | Availability of CNC_OCAR | P246 | Availability of 3183 |
| P203 | operation | P225 | operation | P247 | Intermediate place |
| P204 | Availability of 6ASCE | P226 | Availability of FR. X53K | P248 | operation |
| P205 | operation | P227 | operation | P249 | Availability of SIW5B_E |
| P206 | Availability of MRS 650 | P228 | Availability of AJ_GA_OS | P250 | operation |
| P207 | Intermediate place | P229 | Transport | P251 | Availability of SWaIGL 450CNC |
| P208 | operation | P230 | Availability of AGV | P252 | Intermediate place |
| P209 | Availability of 3183 | P231 | Loading | P253 | operation |
| P210 | operation | P232 | Intermediate place | P254 | Availability of AGL315_E |
| P211 | Availability of SL 631 | P233 | operation | P255 | operation |
| P212 | Intermediate place | P234 | Availability of R 236 | P256 | Availability of SAW 6 |
| P213 | operation | P235 | operation | P257 | Intermediate place |
| P214 | Availability of R 242 | P236 | Availability of R 242 | P258 | operation |
| P215 | operation | P237 | Intermediate place | P259 | Availability of AGL315_G |
| P216 | Availability of R 236 | P238 | operation | P260 | operation |
| P217 | Intermediate place | P239 | Availability of R 236 | P261 | Availability of AFCC 450 |
| P218 | Intermediate place | P240 | operation | P262 | Intermediate place |
| P219 | operation | P241 | Availability of R 242 | P263 | operation |

| | | | | | |
|---|---|---|---|---|---|
| P220 | Availability of SHS28_OS | P242 | Intermediate place | P264 | Availability of SIW5B_E |

***Table IV. 6*** *Significance of places P199 to P264*

P218- P228 Turning of B2,2
P229 – P230 AGV transport B2,2 from turning workshop to the grinding workshop
P232 – P292 Grinding of part B2,2
P293 – P296 Assembling the two parts B2,1 and B2,2 to get the first piece B2

| Places | Significance | Places | Significance |
|---|---|---|---|
| P265 | operation | P287 | Intermediate place |
| P266 | Availability of SWaIGL 450CNC | P288 | operation |
| P267 | Intermediate place | P289 | Availability of PRI 300 |
| P268 | operation | P290 | operation |
| P269 | Availability of MA464_E | P291 | Availability of DISC_PE |
| P270 | operation | P292 | Intermediate place |
| P271 | Availability of MRG 140 | P293 | Loading B2,1 for assembling |
| P272 | operation | P294 | loading B2,2 for assembling |
| P273 | Availability of MT 312/500 | P295 | Availability of Robot R42 |
| P274 | Intermediate place | P296 | B2 finished |
| P1, P21, P26, P31, P36, P41, P46, P53, P58, P63, P71, P86, P91, P96, P101, P106, P113, P118, P123, P277, P136, P141, P146, P151, P170, P175, P180, P185, P190, P195, P200, P207, P212, P217, P218, P232, P237, 242, P247, P252, P257, P262, P267, P274, P282, P287,P292, | Intermediate Place | P297, P298, P299, P300, P301, P302, P303, P304, P305, P306, P307, P308, P309, P310, P311, P312, P313, P314, P315, P316, P317, P318 P319, P320, P321, P322, P323, P324, P325 | Availability of Robots R9, R10, R11, R12, R13, R14, R15, R16, R17, R19, R20 R21, R22, R23, R24, R25, R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36, R37, R38, |
| P275 | operation | P281 | Availability of MT 312/500 |
| P276 | Availability of MA464_E | P283 | operation |
| P277 | Intermediate place | P284 | Availability of AGL315_E |
| P278 | operation | P285 | operation |
| P279 | Availability of MRG 140 | P286 | Availability of SAW 4 CNC |
| P280 | operation | P326, P327 | Availability of Robots R39, R40 |

***Table IV. 7*** *Significance of places P265 to P327*

## IV.5.2. Significance of transitions

| Transitions | Representation | Transitions | Representation |
|---|---|---|---|
| T1 | Start B1,1 | T10 | End of previous operation and start of next operation |
| T2 | Start operation 1 for 1,1 | T11 | End of previous operation and loading of P1,1 by the AGV |
| T3 | Start operation 2 for 1,1 | T12 | Unloading of B1,1 and loading by the robot |
| T4 | Start operation 3 for 1,1 | T13 | Unloading of B1,1 and start the next operation |
| T5 | End of previous operation and start of next operation | T14, T15, T18, T19, T22, T24, T26, T27, T30, T31, T34, T35, T36, T40, T41, T44, T45 | Unload by the robot and start the next operation |
| T6 | End of previous operation and start of next operation | T16, T17, T20, T21, T23, T25, T28, T29, T32, T33, T37, T38, T39, T42, T43, T43, T46, T47 | End of previous operation and load by robot |
| T7 | End of previous operation and start of next operation | | |
| T8 | End of previous operation and start of next operation | | |
| T9 | End of previous operation and start of next operation | | |

***Table IV. 8*** *Signification of transitions Bloc 1 (B1.1)*

| Transitions | Representation | Transitions | Representation |
|---|---|---|---|
| T49 | Start B1,2 | T55 | End of previous operation and loading of B1,2 by the AGV |
| T50 | Start operation 1 for B1,2 | T56 | Unloading of B1,2 and loading by the robot |
| T51 | Start operation 2 for B1,2 | T57 | Unloading of B1,2 and start the next operation |
| T52 | End of previous operation and start the next operation | T58, T59, T62, T63, T66, T67, T70, T71, T74, T75, T76, T80, T81, T84, T85, T88, T89, T98, T90, T94, T95, T96, T100, T101 T104, T105 | Unload by the robot and start the next operation |
| T53 | End of previous operation and start the next operation | T60, T61 T64, T65 T68, T69 T72, T73 T77, T78 T79, T82 T83, T86 T87, T91 T92, T93, T97, T98, T99, T102, T103, T106, T107 | End of previous operation and load by robot |
| T54 | End of previous operation and start the next operation | | |

***Table IV. 9*** *Signification of transitions Bloc 2 (B1.2)*

| Transition | Representation | Transition | Representation |
|---|---|---|---|
| T110 | Start B2,2 | T116 | End of previous operation and loading of B2,2 by the AGV |
| T111 | Start operation 1 for B2,2 | T117 | Unloading of B2,2 and loading by the robot |
| T112 | start operation 2 for B2,2 | T118 | Unloading of B1,2 and start the next operation |
| T113 | End of previous operation and start the next operation | T119, T120 T123, T124 T127, T128 T131, T132 T135, T136 T139, T143 T124, T147 T148, T149 T153, T154 T155, T159 T160, T164 | Unload by the robot and start the next operation |
| T114 | End of previous operation and start the next operation | T121, T122 T125, T126 T129, T130 T133, T134 T137, T138 T141, T142 T145, T146 T150, T151 T152, T157 T158, T161 T162, T165, T166 | End of previous operation and load by robot |
| T115 | End of previous operation and start the next operation | | |
| T116 | End of previous operation and loading of B2,2 by the AGV | | |

***Table IV. 10*** *Signification of transitions Bloc 3 (B2.2)*

| Transition | Representation | Transition | Representation |
|---|---|---|---|
| T168 | Start B2,1 | T177 | End of previous operation and start of next operation |
| T169 | Start operation 1 for B2,1 | T178 | End of previous operation and loading of B2,1 by the AGV |
| T170 | Start operation 2 for B2,1 | T179 | Unloading of B2,1 and loading by the robot |
| T171 | Start operation 3 for B2,1 | T180 | Unloading of B2,1 and start the next operation |
| T172 | End of previous operation and start the next operation | T181, T182 T183, T185 T186, T189 T190, T193 T194, T197 T198, T201 T202, T205 T206, T207 T211, T212 T215, T216 | Unload by the robot and start the next operation |
| T173 | End of previous operation and start the next operation | T183, T184, T187, T188, T191, T192, T195, T196, T199, T200, T203, T204, T208, T209, T210, T213, T214, T217, T218 | Unload by the robot and start the next operation |
| T174 | End of previous operation and start of next operation | | |
| T175, T176 | End of previous operation and start of next operation | | |

***Table IV. 11*** *Signification of transitions Bloc 4 (B2.1)*

| transition | Representation |
|---|---|
| T48 | B1,1 (22230 CW33-10) ready to assembly |
| T108 | B1,2 (22230 MB-20) ready to assembly |
| T109 | B1 go to stock |
| T167 | B2,2 (22232 MB-20) ready to assembly |
| T219 | B2,1 (22232 MBW33-10) ready to assembly |
| T220 | B2 go to stock |

***Table IV. 12*** *Signification of transitions Bloc 5 (assembling)*

## IV.6. MODEL VALIDATION AND RESULTS OF THE SIMULATION

In the validation of the model we will seek to define the properties of the model and the evaluation of its performances, which will be useful to us to introduce some parameters in the software which allows us to make the simulation.

Boundedness: All the places of the network are bounded so we deduce that the PN is bounded. there is no accumulation in progress in the production system.

Liveliness: All transitions are alive; there is no blockage, so the PN is alive.

State graph: The Petri net is not a state graph. If we want it to be a state graph, all transitions must have exactly one input and one output, and this is not the case in our model.

Event graph: The Petri Net is not an event graph. Because not all places have exactly one input transition and one output transition

Persistent: the firing of one of two transitions does not prevent the firing of the other. So, our model is persistent.

With the GreatSPN software, which allowed us to confirm a number of properties and especially if there is no conflict in our model. The results obtained are as follows:

After the end of each operation, the resource will be available again for the next part, the transitions T13 and T180 cannot fire simultaneously because of the shared robot, one token can fire only one transition, the shared resource is live and reversible no matter how many tokens are initially distributed in the system.

## IV.7. AUGMENTATION OF THE MODEL

No matter how fast and efficient CNC machines is, they're not infallible. They develop problems and need maintenance just like any other type of machine or tool. No matter how well you maintain your machines, how well you train your controllers or how carefully you care for your tools, problems will still pop up. Some will be easy to solve, and some will be confusing, leaving you wondering what could possibly be wrong.

To maintain the proper functioning of the system we must add maintenance models.

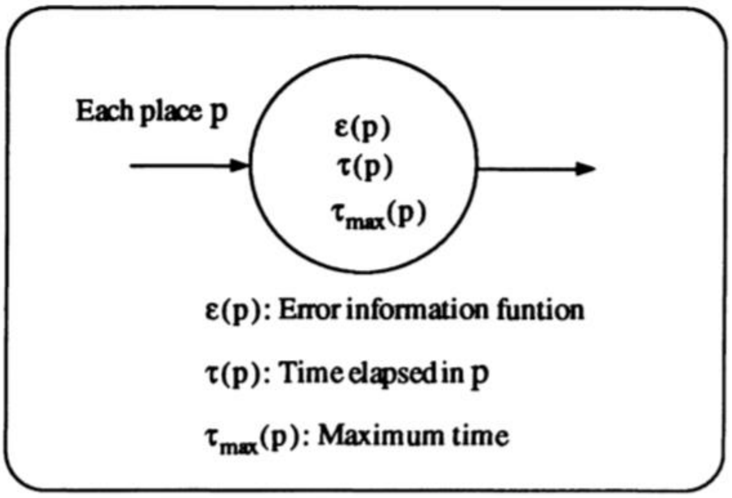



***Figure IV. 15*** *A place with Ɛ(p), T(p), and Tmax(P) in a Petri net*

Ɛ(p): the error information function, τ(p) elapsed time in a place, $\tau_{max}$(p) maximum elapsed time in a place

Ɛ (p) = 1: the normal execution of the Petri net takes place if there is at least one token in the place p. Initially, Ɛ(p)= 1, p in the Petri net controller.

Ɛ(p)= 2: emergency shut down procedure starts if there is a token in this place p.

Ɛ(p)= 3: the error is handled by executing a special part of the Petri net controller.

If no error takes place or an old error is detected through the sensor data then the net will be executed without augmentation of this Petri net.

We have the machine R242 tool is broken and the error is detected in the place P24, then a petri net block is added to the net.

The error processing procedure includes:

- P328 the machine waits for repair.
- P329 New tool available.
- P330 R242 Ready.

And three transition:

- T221 start of reparation
- T222 insert new tool
- T223 end of the reparation and the machine will be available again.

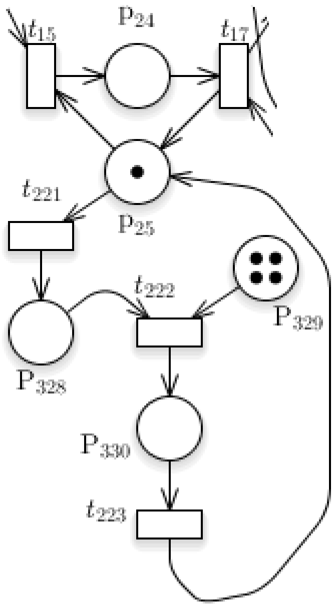



***Figure IV. 16*** *Change tool of machine R242*

The error information function Ɛ(P24) =3, when this error is first occurred in this place. The liveness, safeness and reversibility properties remain unchanged for the system. The marking after the first step of the simulation shows that P(25) = 0, P(328) = 1, P(329) = 4 and P (330)=0, this means the start of execution of the task of the Maintenance (Figure IV. 16). with the firing of the transition T222 by the resource that will consumed at the first validation and the consumed resource (New tools) in the place P(329). The marking after the second step shows the firing of the transition by a single token because the weight of the arc between P329 and T222 is equal to 1.

Machines like MRS650 and LZ259 (P35, P182) can do the same work, so it can be used to double production and it can produce another type of part according to the order without any effect to the main production. This type of machine can replace the other machine in case of something goes wrong on it. The production keeps going whatever the time to repair it. By adding a token on the new command 1 place (P331) we will switch the work from the unavailable machine to the other machine to be shared between two operation.

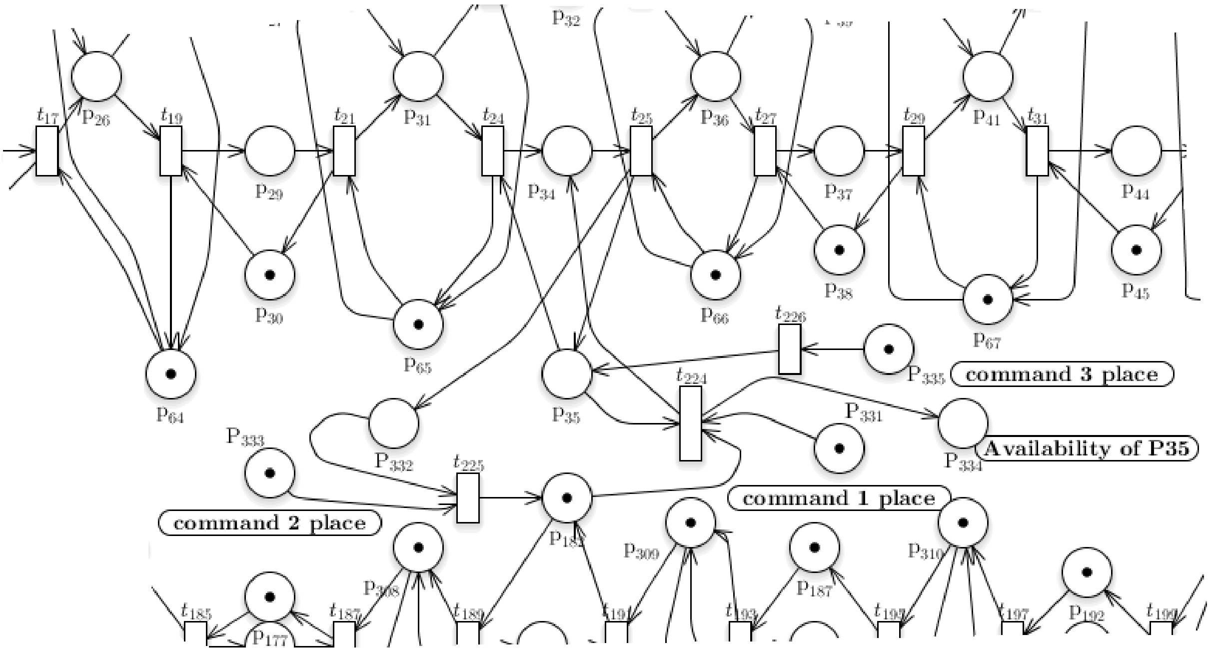



***Figure IV. 17*** *Switching the resources*

MRS650 (P35) is in repair, so it is not available for the operation, in this case we activate the three command places (P331, P333 and P335), LZ259 (P182) will be a shared machine to grinding two types of bearing B1.1 and B2.1

P331 is a command place, it will be activated after the breakdown of MRS650.

P333 is a command place, it is activated after the first command to prevent accumulation of tokens in Place P182.

P332 is an intermediate place.

P334 the number of times LZ259 replace MRS650.

P335 command place, activated in case when MRS650 is unavailable

In normal state, when MRS650 is available, P331, P333 and P335 are unmarked.

## IV.8. CONCLUSION

We can conclude from this chapter which expresses the diversity of petri nets for the modeling of production systems. The modeling of maintenance tasks is based on Petri nets, so by this diversity we can model Production Systems with great complexity and the basic principle developed is always valid. This part also expresses that the petri nets are a reliable tool that allow the modeling of the production systems, see the behavior of the system and the different situations. Petri nets offer a simple graphic support for the representation, the understanding and the synchronization of the tasks, the execution and the means necessary for the interventions. These tasks can be either those of the production or those of the Maintenance.

The complexity of production systems requires us to put into practice or use software that facilitates the manipulation of this modeling. Maintenance modeling by petri nets has the practical advantage of allowing the specification of a system's behavior in a form that can be easily used by a design engineer. In other words, it makes it possible to carry out the evaluation of the desired quantitative parameters, and to resolve conflicts related to resource sharing and to estimate the operating time of the tasks.

# GENERAL CONCLUSION

The objective of this work was to suggest a modeling of the flexible systems of production by Petri nets. To do this, our approach focused on two areas of work:

The first part of the work is composed of three chapters. It aims to provide an overview of the state of the art, delimit the research context and present some work already done in the field.

In the first chapter we presented the work environment by describing The University of Dunarea de Jos of Galati and a general presentation of URB Group – Rulmenti S.A Barlad. In the second chapter, Petri nets were presented as a set of tools for both modeling and analyzing the dynamics of complex systems. They have the dual benefit of providing both a graphical representation and the mathematical underpinnings for studying properties to evaluate the behavior of modeled systems. the third chapter presents general notions associated with the flexible system of production. In the last chapter we laid the foundations of our work by defining the production system first. We have paid particular attention to the flexible production system and the notion of flexibility which are at the heart of our concerns. Subsequently, we chose Petri nets as a modeling tool. In fact, unlike analytical models, petri nets offer the following advantages:

- Better process analysis because of its graphical representation.
- A possibility of integration in a simulator.
- The use of the properties of the Petri nets (boundedness, mutual exclusion, liveliness) ensures a representation of the problems of resource sharing, but also to ensure the non-blocking of the simulation model.

The complexity of the production systems requires us to use software that facilitates the manipulation of this modeling, that they are based on algorithms that help us to choose the type of PN adaptable to our model and to verify the validation of the models and define the properties of our PN. The use of Petri nets remains broader in the industrial field, they can be used to implement real-time control systems, which can handle the tasks of production and maintenance in case the system breaks down. We can say that PNs are modern, powerful, flexible and efficient tool for modeling and simulating FMS.

A Petri net simulator simulates execution of a Petri net, the flow of tokens in the places of the net through transitions. Simulation gives a vivid graphic description of a system's operation to aid in model design and debugging. Simulation becomes necessary when the performance cannot be predicted by the system.

This internship was not just a technical experience but also a human experience. Indeed, it enlarged my mind and gave me another vision of living abroad, particularly in Romania. I met several persons and I keep contact with them through social and professional networks.

I think this internship abroad will be an advantage for my future career because it gave me an international profile. And I want to work abroad during some years, in mechanical engineering, so this internship will be beneficial for my future career.

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# ANNEX 1

Simulation Software


***Figure A1. 1*** *Software credits*

GreatSPN (GRaphical Editor and Analyzer for Timed and Stochastic Petri Nets) is a software package for the modeling, validation, and performance evaluation of distributed systems using Generalized Stochastic Petri Nets and their colored extension, Stochastic Well-formed Nets. The tool provides a friendly framework to experiment with timed Petri net based modeling techniques. It implements efficient analysis algorithms to allow its use on rather complex applications.

The GreatSPN Framework is licensed under the GPLv2.0 license, which is available within the repository in the LICENSE. The source code owner is the University of Torino, Italy. Ajmone Marsan, Balbo, Bobbio, Chiola.

**Histoy:**

- **1982-1984 - SPN model**
  - Text interface, Pascal.
  - Introduction of GSPN models.
- **1980s**
  - Integration of qualitative analyzes: invariants: semiflots of places, transitions, syphons, traps, ...
  - Introduction of deterministic and type-phase distributions.

- Graphic interface.

➢ **1990s - high level models**
  - WN and SWN models
  - Stochastic simulation (ordinary and symbolic)

➢ **2000s extensions by complements**
  - Extended SRG (partial symmetries, LIP6).
  - Temporal logic.
  - Decomposition of SWN.

➢ **Developed by the Dpt Performance Group. of computer science from the University of Torino**
  - Partial symmetries, extensions, temporal logic: LIP6.
  - Composition: LISTIC, LAMSADE.

The interface of the software is shown in figure A1. 2.

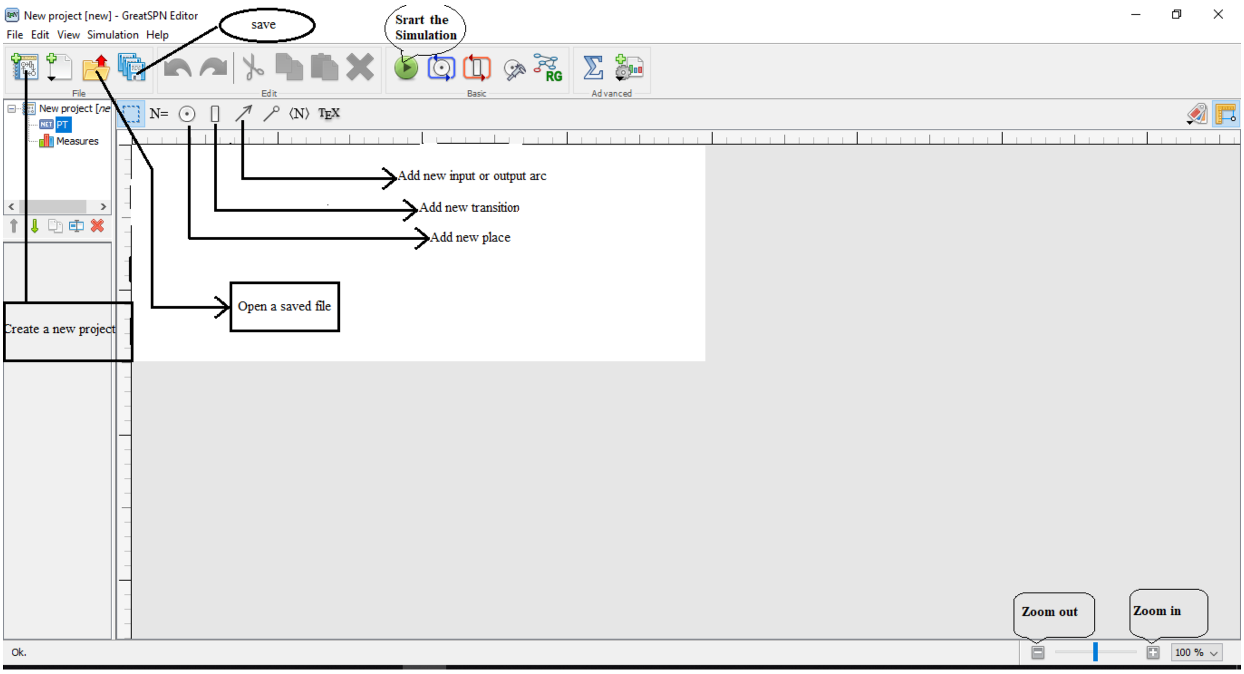


***Figure A1. 2*** *Graphical interface of the software*

# ANNEX 2

The collected data from URB GROUP – RULMENTI S.A BARLAD are used in the modeling of the system and it is in the following figures:

| | Turning B1,1 | machines |
|---|---|---|
| 1909 | Strunjire ebos plan/cdr | L.KH.OSC |
| 1909 | Strunjire finis plan/ext./raza ext. | L.KH.OSC |
| 1909 | Strunjire finis plan/cdr/raze ext./int. | L.KH.OSC |
| 1909 | Strunjire canal W33 / raza int. | KH300_W3 |
| 1909 | Gaurire (inele W33) | G 40_OS |
| 1909 | Ajustare (inele W33) | AJ_GA_OS |
| Varianta 1 | | |
| 1909 | Strunjire finis plan/int. | TRC-100 |
| 1909 | Strunjire finis plan/ext. | TRC-100 |
| 1909 | Strunjire ebos cdr+finis cdr | MK 248 |
| 1909 | Strunjire canal W33 | KH300_W3 |
| 1909 | Strunjire raze int./ext.(intoarcere) | KH300_W3 |
| 1909 | Gaurire (inele W33) | G 40_OS |
| 1909 | Ajustare (inele W33) | AJ_GA_OS |
| Varianta 2 | | |
| 1909 | Strunjire completa 1/2 | OK 300 |
| 1909 | Strunjire completa 1/2 | OK 300 |
| 1909 | Gaurire (inele W33) | G 40_OS |
| 1909 | Ajustare (inele W33) | AJ_GA_OS |
| 1909 | Control | CTC_STR |
| 1909 | Tratament termic | EBNER |
| Varianta 1 | | |
| 1909 | Tratament termic | MD318 |
| 1909 | Control final | CTC_STT |

| | Turning of B1,2 | machines |
|---|---|---|
| 1916 | Strunjire finis int.+eb. Pl+ext | SHS28_OS |
| 1916 | Strunjire cdr+deg.+raze(prin int.) | CNC_OCAR |
| 1916 | Frezare laterala | FR. X53K |
| 1916 | Ajustare | AJ_GA_OS |
| Varianta 1 | | |
| 1916 | Strunjire plan/interior | MK6751 |
| 1916 | Strunjire plan/exterior | MK6751 |
| 1916 | Strunjire cdr+deg.+raze(prin int.) | CNC_OCAR |
| 1916 | Frezare laterala | FR. X53K |
| 1916 | Ajustare | AJ_GA_OS |
| 1916 | Marcare | PAY63_OS |
| 1916 | Control strunjire | CTC_STR |
| 1916 | Tratament termic | EBNER |
| Varianta 1 | | |
| 1916 | Tratament termic | MD318 |
| 1916 | Control final | CTC_STT |

***Figure A2. 1*** *Turning B1 Data*

| | Grinding of B1,1 | machines |
|---|---|---|
| 1790 | Rectificare Finis plan | R 236 |
| Varianta 1 | Rectificare Finis plan | R 242 |
| 1790 | Rectificare Ebos exterior | SL 631 |
| Varianta 1 | Rectificare Ebos exterior | 3183 |
| 1790 | Rectificare Ebos cdr | LZ 259 |
| Varianta 1 | Rectificare Ebos cdr | MRS 650 |
| 1790 | Detensionare | AIA 350 |
| 1790 | Rectificare Semifinis exterior | SASL 5AD |
| Varianta 1 | Rectificare Semifinis exterior | SASL 200 |
| 1790 | Rectificare Finis cdr | LZ 259 |
| Varianta 1 | Rectificare Finis cdr | MRS 650 |
| 1790 | Rectificare Superfinis cdr | LZ 259 |
| Varianta 1 | Rectificare Superfinis cdr | 6ASCE |
| Varianta 2 | Rectificare Superfinis cdr | MRS 650 |
| 1790 | Rectificare Finis exterior | SASL 5AD |
| Varianta 1 | Rectificare Finis exterior | SASL 200 |
| 1790 | Rectificare Rodaj plan | R 236 |
| Varianta 1 | Rectificare Rodaj plan | R 242 |
| 1790 | Demagnetizare | DEMAG_1 |
| 1790 | Spalare | MA 654 |
| 1790 | Control final | CTC_REC |

| | Grinding of B1,2 | machines |
|---|---|---|
| 2024 | Rectificare Ebos plan | R 236 |
| Varianta 1 | Rectificare Ebos plan | R 242 |
| 2024 | Rectificare Finis plan | R 236 |
| Varianta 1 | Rectificare Finis plan | R242 |
| 2024 | Rectificare Ebos guler exterior | SASL 200 |
| Varianta 1 | Rectificare Ebos guler exterior | SASL 5AD |
| 2024 | Rectificare Ebos interior | SIW5B_E |
| Varianta 1 | Rectificare Ebos interior | SWaIGL 450CNC |
| 2024 | Rectificare Ebos cdr | AGL315_E |
| Varianta 1 | Rectificare Ebos cdr | SAW 6 |
| Varianta 2 | Rectificare Ebos cdr | AFCC 450 |
| 2024 | Detensionare | AIA 350 |
| 2024 | Rectificare Finis guler exterior | AGL315_G |
| Varianta 1 | Rectificare Finis guler exterior | AFCC 450 |
| 2024 | Rectificare Finis interior | SIW5B_E |
| Varianta 1 | Rectificare Finis interior | SWaIGL 450CNC |
| 2024 | Rectificare Finis guler mare | MA464_E |
| Varianta 1 | Rectificare Finis guler mare | MRG 140 |
| Varianta 2 | Strunjire dura | ECOCA MT312/500 |
| 2024 | Rectificare Finis guler mic | MA464_E |
| Varianta 1 | Rectificare Finis guler mic | MRG 140 |
| Varianta 2 | Strunjire dura | ECOCA MT312/500 |
| 2024 | Rectificare Finis cdr | AGL315_E |
| Varianta 1 | Rectificare Finis cdr | SAW 4 |
| 2024 | Rectificare Superfinis cdr | PRI 300 |
| 2024 | Rectificare Slefuire plana | DISC_PE |
| 2024 | Demagnetizare | DEMAG_1 |
| 2024 | Spalare | MA 654 |
| 2024 | Control final | CTC_REC |

***Figure A2. 2*** *Grinding of B1 Data*

| | Turning of B2,1 | Machines |
|---|---|---|
| 8408 | Strunjire ebos plan/cdr | L.KH.OSC |
| 8408 | Strunjire finis plan/ext./raza ext. | L.KH.OSC |
| 8408 | Strunjire finis plan/cdr/raze ext./int. | L.KH.OSC |
| 8408 | Strunjire canal W33 / raza int. | KH300_W3 |
| 8408 | Gaurire (inele W33) | G 40_OS |
| 8408 | Ajustare (inele W33) | AJ_GA_OS |
| *Varianta 1* | | |
| 8408 | Strunjire finis plan/int. | TRC-100 |
| 8408 | Strunjire finis plan/ext. | TRC-100 |
| 8408 | Strunjire ebos cdr+finis cdr | MK 248 |
| 8408 | Strunjire canal W33 | KH300_W3 |
| 8408 | Strunjire raze int./ext.(intoarcere) | KH300_W3 |
| 8408 | Gaurire (inele W33) | G 40_OS |
| 8408 | Ajustare (inele W33) | AJ_GA_OS |
| *Varianta 2* | | |
| 8408 | Strunjire completa 1/2 | OK 300 |
| 8408 | Strunjire completa 1/2 | OK 300 |
| 8408 | Gaurire (inele W33) | G 40_OS |
| 8408 | Ajustare (inele W33) | AJ_GA_OS |
| 8408 | Control | CTC_STR |
| 8408 | Tratament termic | EBNER |
| *Varianta 1* | | |
| 8408 | Tratament termic | MD318 |
| 8408 | Control final | CTC_STT |

| | Turning of B2,2 | Machines |
|---|---|---|
| 9212 | Strunjire finis int.+eb. Pl+ext | SHS28_OS |
| 9212 | Strunjire cdr+deg.+raze(prin int.) | CNC_OCAR |
| 9212 | Frezare laterala | FR. X53K |
| 9212 | Ajustare | AJ_GA_OS |
| *Varianta 1* | | |
| 9212 | Strunjire plan/interior | MK6751 |
| 9212 | Strunjire plan/exterior | MK6751 |
| 9212 | Strunjire cdr+deg.+raze(prin int.) | CNC_OCAR |
| 9212 | Frezare laterala | FR. X53K |
| 9212 | Ajustare | AJ_GA_OS |
| 9212 | Marcare | PAY63_OS |
| 9212 | Control strunjire | CTC_STR |
| 9212 | Tratament termic | EBNER |
| *Varianta 1* | | |
| 9212 | Tratament termic | MD318 |
| 9212 | Control final | CTC_STT |

***Figure A2. 3*** *Turning of B2 Data*

| | Grinding of B2,1 | Machines |
|---|---|---|
| 7202 | Rectificare Ebos plan | R 242 |
| *Varianta 1* | Rectificare Ebos plan | R 236 |
| 7202 | Rectificare Ebos exterior | SL 631 |
| *Varianta 1* | Rectificare Ebos exterior | 3183 |
| 7202 | Rectificare Ebos cdr | LZ 259 |
| *Varianta 1* | Rectificare Ebos cdr | MRS 650 |
| 7202 | Detensionare | AIA 350 |
| 7202 | Rectificare Finis plan | R 242 |
| *Varianta 1* | Rectificare Finis plan | ICHIKAWA |
| 7202 | Rectificare Semifinis exterior | 3183 |
| *Varianta 1* | Rectificare Semifinis exterior | SL 631 |
| 7202 | Rectificare Finis cdr | LZ 259 |
| *Varianta 1* | Rectificare Finis cdr | MRS 650 |
| 7202 | Rectificare Superfinis cdr | LZ 259 |
| *Varianta 1* | Rectificare Superfinis cdr | 6ASCE |
| *Varianta 2* | Rectificare Superfinis cdr | MRS 650 |
| 7202 | Rectificare Finis exterior | 3183 |
| *Varianta 1* | Rectificare Finis exterior | SL 631 |
| 7202 | Rectificare Rodaj plan | R 242 |
| *Varianta 1* | Rectificare Rodaj plan | R 236 |
| 7202 | Demagnetizare | DEMAG_1 |
| 7202 | Spalare | MA 654 |
| 7202 | Control final | CTC_REC |

| | Grinding of B2,2 | Machines |
|---|---|---|
| 7263 | Rectificare Ebos plan | R 236 |
| *Varianta 1* | Rectificare Ebos plan | R 242 |
| 7263 | Rectificare Finis plan | R 236 |
| *Varianta 1* | Rectificare Finis plan | R 242 |
| 7263 | Rectificare Ebos guler exterior | SASL 200 |
| *Varianta 1* | Rectificare Ebos guler exterior | 3183 |
| 7263 | Rectificare Ebos interior | SIW5B_E |
| *Varianta 1* | Rectificare Ebos interior | SWaIGL 450CNC |
| 7263 | Rectificare Ebos cdr | AGL315_E |
| *Varianta 1* | Rectificare Ebos cdr | SAW 6 |
| 7263 | Detensionare | AIA 350 |
| 7263 | Rectificare Finis guler exterior | AGL315_G |
| *Varianta 1* | Rectificare Finis guler exterior | AFCC 450 |
| 7263 | Rectificare Finis interior | SIW5B_E |
| *Varianta 1* | Rectificare Finis interior | SWaIGL 450CNC |
| 7263 | Rectificare Finis guler mare | MA464_E |
| *Varianta 1* | Rectificare Finis guler mare | MRG 140 |
| *Varianta 2* | Strunjire dura | MT 312/500 |
| 7263 | Rectificare Finis guler mic | MA464_E |
| *Varianta 1* | Rectificare Finis guler mic | MRG 140 |
| *Varianta 2* | Strunjire dura | MT 312/500 |
| 7263 | Rectificare Finis cdr | AGL315_E |
| *Varianta 1* | Rectificare Finis cdr | SAW 4 CNC |
| 7263 | Rectificare Superfinis cdr | PRI 300 |
| 7263 | Rectificare Slefuire plana | DISC_PE |
| 7263 | Demagnetizare | DEMAG_1 |
| 7263 | Spalare | MA 654 |
| 7263 | Control final | CTC_REC |

***Figure A2. 4*** *Grinding of B2 Data*