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# IMPACT OF RFID TECHNOLOGY ON PETRI NET MODELISATION: APPLICATION TO AN ASSEMBLY PLATFORM

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Abstract: Petri net models are useful tools for the modelling of discrete event systems and hybrid systems. It may be used in order to analyse, to simulate and analyse its performances so as to control it (command or diagnose). This paper is about the modelling, with the Petri net tool, of an assembly platform integrating Auto-Id systems in the objective is the simulation of the functioning of the platform. The objective is the simulation of the functioning of the system for two cases: two scenarios bring into play various industrial functions like assembly-desassembly, sorting, processing time. The first results highlight usefulness of the Petri Net tool in such a specific context where the impact of the RFID technology on the system performances has to be evaluated.

Keywords: Petri nets, Auto-Id, RFID, Modelling, Assembly platform.

## 1 INTRODUCTION

Petri nets (PN) are useful for modelling of discrete event systems (DES) and hybrid systems (HS) (Cassandras, 1993; Zaytoon *et al.*, 1998) because they combine, in a comprehensive way, intuitive graphical representations and powerful analytic expressions (Brams, 1983; Brauer *et al.*, 1986; Murata, 1989). A lot of results have been established for the analysis (Askin *et al.*, 1993; Zerhouni *et al.*, 1995) and the control design (Hirasawa *et al.*, 1998; Lefebvre, 1999) of systems. PN are usually considered as knowledge – based models. Places have a physical meaning and the firing conditions of the transitions (incidence applications, firing duration or frequency, predicate) are assumed to result from an a priori knowledge.

This paper is about the design of models of an assembly platform with Petri nets. The results highlight usefulness of Petri nets in order to model systems including specific automatic identification technology like RFID. It becomes then one way to evaluate the impact of this technology on the performance of the system.

The paper is divided in 6 sections. The section 2 is about Petri nets. The Timed Petri nets and the coloured Petri nets are also highlighted. The assembly platform is described in section 3, with the focus on the RFID technology and the presentation of the scenarios which are the object of the modelisation. The Petri nets models are presented and commented in section 4. Last, some conclusions and future works are presented.

## 2 PETRI NETS

A Petri net (PN) with  $n$  places and  $p$  transitions is defined as  $\langle P, T, \text{Pre}, \text{Post}, M_I \rangle$  where  $P = \{P_i\}_{i=1, \dots, n}$  is a not empty finite set of places,  $T = \{T_j\}_{j=1, \dots, p}$  is a not empty finite set of transitions, such that  $P \cap T = \emptyset$  (Brams, 1983; Murata, 1989).  $IN$  is defined as the set of integer numbers and  $IR^+$  as the set of non - negative real numbers.  $\text{Pre}: P \times T \rightarrow IN$  is the pre-incidence application:  $\text{Pre}(P_i, T_j)$  is the weight of the arc from place  $P_i$  to transition  $T_j$  and  $W_{PR} = (w_{PR}^{ij})_{i=1, \dots, n, j=1, \dots, p} \in IN^{n \times p}$  with  $w_{PR}^{ij} = \text{Pre}(P_i, T_j)$  is the pre-incidence matrix.  $\text{Post}: P \times T \rightarrow IN$  is the post-incidence application:  $\text{Post}(P_i, T_j)$  is the weight of the arc from transition  $T_j$  to place  $P_i$  and  $W_{PO} = (w_{PO}^{ij})_{i=1, \dots, n, j=1, \dots, p} \in IN^{n \times p}$  with  $w_{PO}^{ij} = \text{Post}(P_i, T_j)$  is the post-incidence matrix. The PN incidence matrix  $W$  is defined as  $W = W_{PO} - W_{PR} \in IN^{n \times p}$ . Let us also define  $M(t) = (m_i(t))_{i=1, \dots, n} \in IN^n$  as the marking vector at time  $t$  and  $M_I \in IN^n$  as the initial marking vector.  ${}^oT_j$  (resp  $T_j^o$ ) stands for the pre-set (resp. post-set) places of  $T_j$ . A firing sequence is defined as an ordered series of transitions that are successively fired from marking  $M$  to marking  $M'$ . Such a sequence is represented by its characteristic vector  $X = (x_j)_{j=1, \dots, p} \in IN^p$  where  $x_j$  stands for the number of  $T_j$  firing. The marking  $M'$  is related to the marking  $M$  and to the firing sequence  $X$  according to the relation (1):

$$M' = M + W.X. \quad (1)$$

When two transitions  $T_j$  and  $T_{j'}$  have a common place in the pre-set, the PN presents a structural conflict. The conflict becomes an effective one if there are not enough tokens in the common place to fire both transitions. PN theory does not solve the conflicts. Conflicts are solved according to a decision maker that completes the PN models. In autonomous PN

without conflict, the firing sequence  $X$  related to the marking  $M$  is given by equation (2):

$$x_j = \min_{P_i \in {}^\circ T_j} \left( \text{fix} \left( \frac{m_i}{w_{ij}^{PR}} \right) \right), \quad (2)$$

where  $\text{fix}(\cdot)$  stands for the integer part of  $(\cdot)$ .

### 2.1 T-Timed Petri nets

Timed Petri nets are a particular class of PN whose behaviour depends explicitly on time. For this reason, timed Petri nets are interesting to describe dynamical systems. Among the existing timed Petri nets, let us mention T - timed Petri nets (TPN) (Ramchandani, 1973), P - timed Petri nets (Sifakis, 1977) and time Petri nets (Merlin, 1974). In what follows, let us focus on TPN without conflict. A TPN with  $n$  places and  $p$  transitions is defined as  $\langle \text{PN}, D_{\min} \rangle$  where PN is a Petri net and  $D_{\min} = (d_{\min j})_{j=1, \dots, p} \in \mathbb{R}^+{}^p$  the vector of the minimal firing duration of the transitions. Before firing transition  $T_j$ , tokens are reserved in the  $T_j$  pre-set places during a time  $d_{\min j}$ , and the firing of the transitions is no more instantaneous.

Considering a time increment  $\Delta t$ ,  $X(k) = (x_j(k))_{j=1, \dots, p} \in \mathbb{N}^p$  is defined as the characteristic vector of the firing sequence that ends during the time interval  $[(k-1) \cdot \Delta t, k \cdot \Delta t[$ . In the same way,  $E(k) = (e_j(k))_{j=1, \dots, p} \in \mathbb{N}^p$  is defined as the characteristic vector of the firing sequence that starts during  $[(k-1) \cdot \Delta t, k \cdot \Delta t[$  (also known as the enabling sequence). Let us also define  $R(k) = (r_i(k))_{i=1, \dots, n} \in \mathbb{N}^n$  as the reserved marking vector at time  $t = k \cdot \Delta t$ , and  $L(k) = (l_i(k))_{i=1, \dots, n} \in \mathbb{N}^n$  as the non - reserved marking vector at the same instant. The TPN marking is given by:

$$\begin{aligned} R(k+1) &= R(k) + W_{PR} \cdot (E(k) - X(k)) & k \geq 0 \\ L(k+1) &= L(k) - W_{PR} \cdot E(k) + W_{PO} \cdot X(k) & k \geq 0 \\ M(k+1) &= R(k+1) + L(k+1) & k \geq 0 \\ &= M(k) + W \cdot X(k) \end{aligned} \quad (3)$$

Only non - reserved markings are considered to enable the transitions according to equation (4):

$$e_j(k) = \min_{P_i \in {}^\circ T_j} \left( \text{fix} \left( \frac{l_i(k)}{w_{ij}^{PR}} \right) \right), \quad k \geq 0 \quad (4)$$

and the firing sequence is given by (5):

$$x_j(k) = e_j \left( k - \text{fix} \left( \frac{d_{\min j}}{\Delta t} \right) \right), \quad k \geq \frac{d_{\min j}}{\Delta t} \quad (5)$$

### 2.2 Coloured Petri nets

Non-hierarchical coloured Petri net (CPN) (Jensen, 1997; Kristensen *et al.*, 1998) is a graphical modelling language that models both the states of a system and the events that change the system from one state to another. Coloured Petri nets combine the strength of Petri nets and programming language. Programming languages can be used to define data

types and manipulation of data. A CPN is defined (Jensen, 1997) as  $\langle \text{PN}, \Sigma, C, G, E, I \rangle$  where PN is a Petri net,  $\Sigma$  is a finite set of non - empty types called colour sets,  $C$  is a colour function,  $G$  is a guard function,  $E$  is an arc expression function and  $I$  is an initialisation function. The set of colour set  $\Sigma$  determines the types, operations and function that can be used in the net inscriptions (arc expressions, guards, initialisation expression, ...). The colour function  $C$  maps each place  $p$  to a colour set  $C(p)$ . The guard function  $G$  maps each transition  $t$  to an expression of type Boolean. The arc expression  $E$  maps each arc  $a$  into an expression which must yield a multi-set over the colour set that is attached to the corresponding place. The initialisation function  $I$  maps each place,  $p$ , into a multi-set over  $C$ .

Each CPN can be translated into an equivalent PN and vice versa. The translation from CPN to PN is unique. The existence of an equivalent PN permits to generalize the basic concepts and the analysis methods of PN to CPN (Jensen, 1997).

### 2.3 CPN tools

Coloured Petri nets can be used in practice only because there are mature and well-tested tools supporting them. CPN/tools is a complete redesign of Design/CPN (Kristensen *et al.*, 1998), a graphical editor and simulator of coloured Petri Nets developed at Meta Software (USA) and the university of Aarhus (Denmark) over the past 10 years.

## 3 THE ASSEMBLY PLATFORM

### 3.1 Description

The assembly platform is a research and learning resource which may perform various industrial operations such as assembling, disassembling, sorting, stocking.

The products manufactured by this platform are wood or based products. They are constituted by one board 20\*20 cm. This kind of pallet supports  $n$  pieces with  $n$  between 0 and 4. Green and blue are the two possible colours for one piece. Instead of tooling, the set of a pastille (a small cylindrical wooden piece) simulates machining time. So, each piece presents a bore able to receive a pastille positioned by an automated arm.

These choices permit to define a large number of different products. Figure 1 presents an example of one product constituted by 1 support, 3 pieces of 2 different colours and 1 pastille.

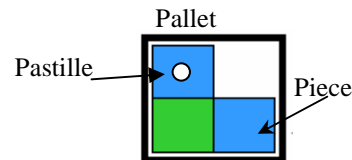


Figure 1: an example of product

The assembly platform is constituted by conveyors, storage areas, manipulator arms, work-in-process and RFID systems. It is shown on figures 2a and 2b.



Figure 2a: general view of the assembly platform

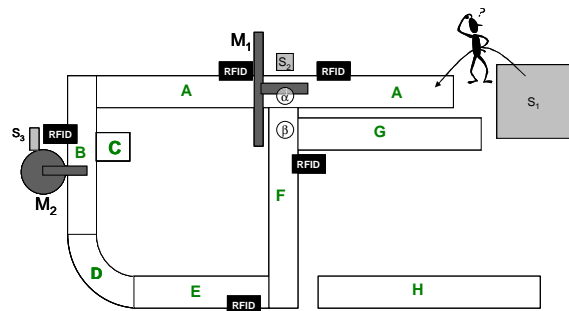


Figure 2b: plan of the assembly platform

Conveyors are in white, stocks in light grey, manipulator arms in dark grey and RFID systems in black. The stock of pallets is  $S_1$ , the pieces are stocked in  $S_2$  and the pastilles in  $S_3$ . The arm manipulator  $A_1$  permits to assemble (localisation  $\alpha$ ) and disassemble (localisation  $\beta$ ) the products. The arm manipulator referenced  $A_2$  is able to add a pastille to pieces present on the pallet. The conveyor C corresponds to a stand-by path which can contain only one piece.

### 3.2 RFID systems

An RFID network has been set up on this platform; to some extent, it constitutes the hart of it. Indeed, the role of the assembly platform is to measure the impact of the new automatic identification technologies on the supply chain management, particularly on the structure of the decision systems.

Schematically, an RFID system is composed by a tag (a micro-chip and an antenna) and a reader which by the way may also write information on the tag. Data is collected on a tag and decoded by the reader. Then it is communicated to a host computer for treatment. RFID presents the advantages first to hold data more complex than just an identifier, and second to add or modify the stored data on demand.

The communication between the reader and the tag is wireless. The range is depending on the power and the frequency used by the system.

In the present case, the range of the reading or the writing is about 5 cm; tags may be included in or on each component of the product: pallet, pieces and pastilles. That means that each product may be identified and may support not only its identifier but also information relevant to the going-on process.

The assembly platform with RFID capacity is very flexible and permits to emulate a large type of production processes. So, first of all, its functioning has to be defined that is to set the type of products, the sequences of manufacturing and the platform elements to be used. Two situations of functioning so-called scenarios are presented in this paper.

### 3.3 Scenario 1: Sorting; assembling-disassembling

In this scenario, products with one and two pieces on the pallet are considered. These products are respectively called “Type 1” and “Type 2”. The colour of the pieces in the “Type 2” products is not taken into account contrary to “Type 1” products which should be sorted according to the colour of the pieces (blue or green).

The pallets are manually set at the beginning of the part of the conveyor A. The RFID reader upstream the manipulator arm  $A_1$  reads the type of pallet (1 or 2) which is arriving.  $A_1$  performs the assembly, and the downstream RFID reader (but also writer) writes on the tag attached to the product the colour and the localisation of each pieces. The conveyor transfers the products to the second manipulator arm  $A_2$  by the mean of conveyors A and B.  $A_2$  adds a pastille only on the “Type 1” products which piece has a green color. The information required for this action is given by the RFID reader set upstream of  $A_2$ . Then the product is driven to the end of the conveyor E. The “Type 1 - green” products are stored on the conveyor H. The “Type 1 - blue” ones are disassembled in  $\beta$ . The pallets join the conveyor G while the pieces join  $S_2$  storage area. As for “Type 2” products, they are stored in G.

### 3.4 Scenario 2: Sorting; manual perturbation

In this case, products with 3 and 4 pieces are considered. The colour of the pieces is indifferent. The pieces are called respectively “Type 3” and “Type 4”. This scenario puts in scene external disturbances or non-desired events.

The pallets are manually set at the beginning of the part of the conveyor A. The RFID reader upstream the manipulator arm  $A_1$  reads the type of the pallets, that is, the number of pieces to add (3 or 4).  $A_1$  performs the assembling, and the next RFID reader writes on the tag of the pallet the colour and the localisation of the pieces. The conveyor drives the pieces to the manipulator arm  $A_2$ . Between  $A_1$  and  $A_2$ , a perturbation may arise. This perturbation is emulated by an operator. He may pick 1, 2, 3 or 4 pieces on the support and who can even add 1 piece, only for the “type 3” pieces.



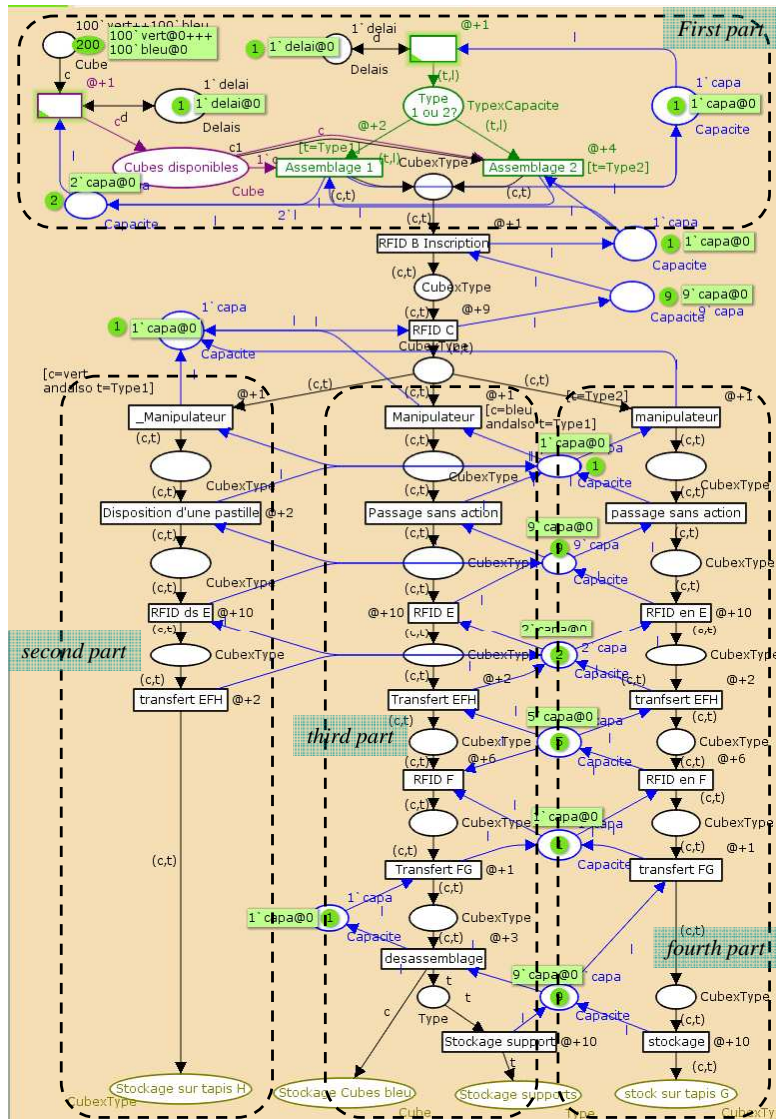


Figure 3: Petri net model of scenario 1

The RFID reader located upstream  $A_2$  checks the arriving products. If the product is correct, one pastille is added to one piece of the product then it pursues its move. Else, the product is driven in the stand-by path C. When a second incorrect product appears, the two products are launched in the conveyor together. All the products are finally driven at the end of the conveyor E. The incorrect products which have more pieces than necessary are stored on conveyor H. Correct products are stored on conveyor G. The incorrect products which have fewer pieces than necessary are driven on the conveyor A in order to be completed by the manipulator arm  $A_1$  and to start a cycle again.

#### 4 THE PETRI NET MODEL

Two Petri nets have been designed, with CPN tools, in order to describe the functioning of the process considering the two scenarios.

##### 4.1 Model of scenario 1

The Petri net model for the scenario 1 is presented on figure 3. In this model, coloured and Timed Petri nets are combined.

The temporisation associated to each transition corresponds to the real transfer time.

The first part of the model (which is encircled by dashed line) concerns the assembling of the products. The two types of products are performed respectively by the transitions called “assemblage 1” and “assemblage 2”. The place “Pieces disponibles” indicates that piece(s) can be added to the pallet. The place “Type 1 ou 2” indicates that the presence of a pallet is the condition to begin the assembling. A capacity place is naturally associated to this place in order to limit the number of pallets which can be present at the assembling place  $\alpha$ . Information about assembly is written on the RFID tag by the second RFID reader which is represented by the transition “RFID B inscription”. The conveyor parts included

between the RFID readers B and C is represented by a unique place associated to a capacity place. The RFID reader C permits to make distinction between the different products which can be subject to different machining. By example, in the first scenario, only the "Type 1" products with colour "green" may receive a pastille. The transfer of these products is represented by the second part of the Petri net model. The "Type 1" products with colour "blue" are treated by the third part of the model. The fourth part of the model is dedicated to the "Type 2" products.

#### 4.2 Model of scenario 2

The Petri net model for the scenario 2 is presented on figure 4. This model has been also achieved by using CPN tools. In this model, coloured and Timed Petri nets are combined.

The temporisation associated to each transition corresponds to the real transfer time.

The first part of the Petri net models the assembling of the "type 3" and "type 4" products. Moreover, the manipulator arm  $A_1$  should add pieces to the incomplete products which were subject of a perturbation previously. As a consequence, four supplementary transitions have to be added.

The next part of the Petri net permits to emulate the perturbation. The transition "prends n pieces" corresponds to the action of the operator who may take 1, 2 or 3 pieces on the "Type 3" products and even may add one supplementary piece. The transition "prends pieces" is another name for quite the same action, but for "Type 4" products. Indeed, it refers to the operator who may take 1, 2, 3 or 4 pieces on the "Type 4" products. The transition "RFID C" represents the functioning of the RFID reader placed downstream the manipulator arm  $A_2$ . It reads the type of the product which arrives and also checks if it is correct.

If the product is correct, it follows the direct move to the transition "Depose pastille". If it is not correct, it has to be driven in the stand-by path C. If an incorrect product is already in this location C, these two products have to be launched in the conveyor together. This part of the process is described by the third part of the Petri net. Moreover, a capacity place should be added in order to avoid the collision between different products. The fourth part of the Petri net describes the transfer and the storing of the correct products on conveyor G. The incorrect products having more pieces than necessary are stored on conveyor H. The incorrect products with fewer pieces than necessary are redirected to the first part of the Petri net where four supplementary transitions have been added.

#### 4.3 Impact of RFID technology

Petri nets permits to combine a graphical representation of a system, with a mathematical formalism. This formalism is important to prove the functioning of the model.

The major evolution induced by the RFID technology for the Petri net modelisation is that each product is different of another. This fact implies that the classical Petri net can't be used alone and the coloured Petri net should be used in order to model this differentiation.

Moreover, the fact that different kind of products may be treated on the same process implies that different operations should be made. This can be performed by using different transitions which have to be mutually dismissing. The choice of the transition to be fired can be performed by using the colour of the token.

The RFID technology permits also to detect a piece which is incorrect. This fact implies that a fault detection and 'quarantine' procedure can be performed, by combining classical fault detection procedure with RFID information given by the piece itself.

## 5 CONCLUSIONS

This paper presents our first works on Petri nets modelisation of systems including RFID technology.

Even if the Petri nets preserve their ability to associate a graphical representation with a mathematical formalism, the RFID technology implies to introduce some qualitative information which requires the use of coloured Petri nets.

The RFID technology is always under processing. Especially, problems of tag reading (mis-detection, reading of a bad identifier,...) are still numerous. These problems may lead to a malfunctioning of the system. A Petri net model can be useful in order to detect this type of event and therefore to alert the control system for a reactive correction or reconfiguration.

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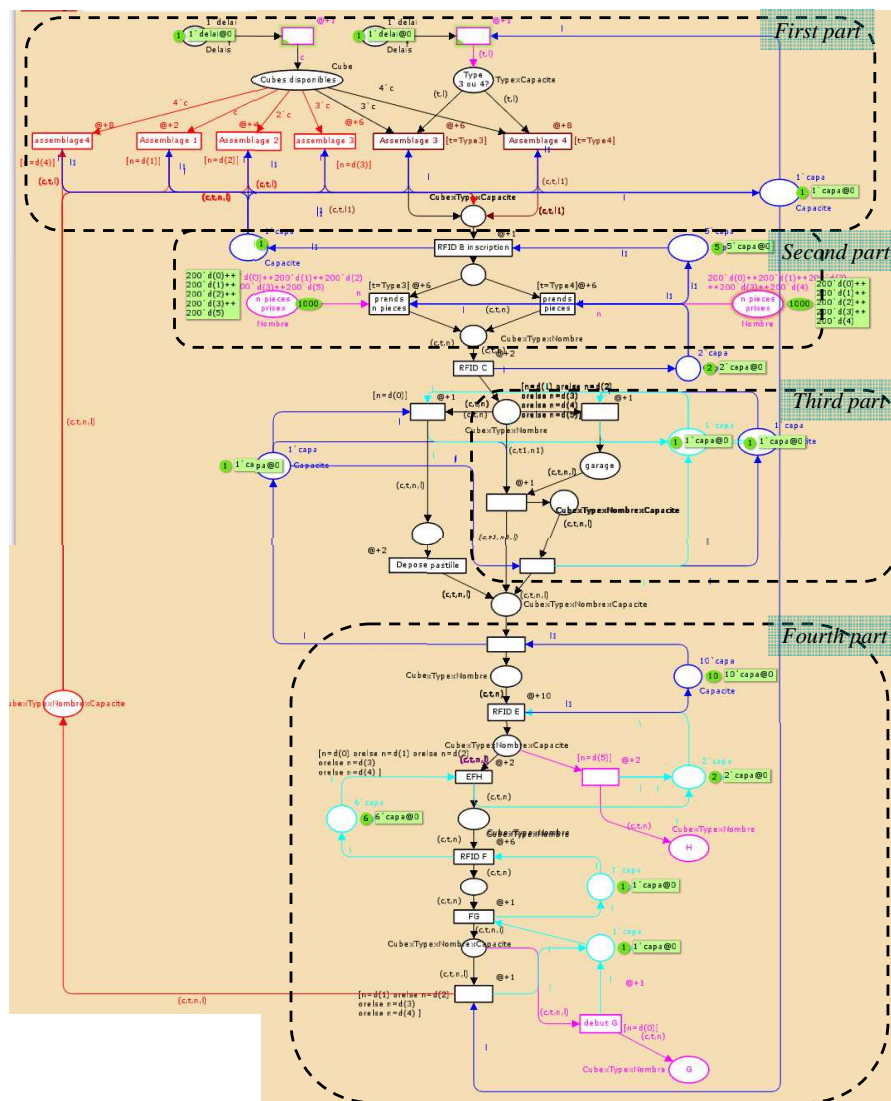


Figure 4: Petri net model of scenario 2