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AUTO-DETECTING EXCEPTION STATE BASED ON PETRI NETS INSIDE RFID DATABASE APPLIED TO FMS

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Abstract. *Nowadays mass customization is a paradigm to be treated with increasing flexibility, and several Companies are already changing their process layout from classical transfer line to cellular manufacturing and flexible production. This change is generating a challenge related to the manufacturing support system, specially manufacturing planning and control. Adding flexibility to a manufacturing process results in increasing system complexity, which requires higher process visibility to deal with unexpected events and exceptions. This paper proposes an auto-detecting exception state approach based on Petri Net inside RFID distributed Database, called PNRD, as a formal structure to determine unexpected events automatically. There are two main features in this approach: the use of RFID tags as product expected database, and the application of Petri Net analysis to generate an auto-detection tool. These features allow RFID tags to store product flow and permits readers to identify tag-related activities through process flow. As a consequence, it generates a network independent mechanism. Based on these features, it is possible to structure RFID data capture in order to automatically identify faults and non-expected events. This approach to RFID reader data capture can be viewed in Petri Net as a direct analysis of locality for a specific transition in a specific product workflow.*

Keywords: *Petri Net, RFID, PNRD, FMS*

1. INTRODUCTION

Two centuries ago, the Industrial Revolution started, changing the power from landowners' hands to goods producers'. After that, there was another revolution that changed power from goods production to information, which means to companies and people who have control of the information flow. Fig. (1) presents a schematic representation of the economic evolution and its relationship with the technological approach, summarized with mechanization in industrial revolution and automation development introduced by Computers and Information Systems (IS).

After the Industrial Revolution, the populace starts migrating massively to the main cities, demanding more industrialized products. This migration generated a low cost and high production rate from companies to fit consumers demand. Such movements persist for several decades until the years where computers and information systems become the basis to support the boom in mechanical automation.

After the 1980s, the balance between supply and demand was strongly driven by the changing in consumption behaviors, and, in this direction, power changed from goods production to information. The paradigm of mass production shifted to mass customization (PineII 1994), in which products must be customized according to customers' needs, and the challenge lies in maintaining massive production costs in more complex systems.

As a consequence, several Companies have changed their process layout from classic transfer line to modern industrial arrangements, such as cellular manufacturing. This change generates a pressure in the traditional manufacturing support system, specially manufacturing planning and control integration demanding more accurate and flexible information systems.

However, flexibility addition in a manufacturing process also increases system complexity, which requires higher process visibility to deal with unexpected events and exceptions. Focusing on these requirements, this paper proposes an auto-detecting exception state approach based on Petri Net within a RFID distributed Database, called PNRD, as a formal structure to determine unexpected events automatically. There are two main features in this approach: the use of RFID tags composing the distributed database, and the application of Petri Net analysis to generate an auto-detecting tool.

This approach to RFID reader data capture can be viewed in Petri Nets as a direct analysis of locality for a specific transition in a specific workflow (Tavares 2005, Tavares *et al.* 2006 and Tavares *et al.* 2007). In this regard, this paper shows how to integrate Elementary Petri Nets in a RFID detection system (integrating tags and readers perception of a specific process).

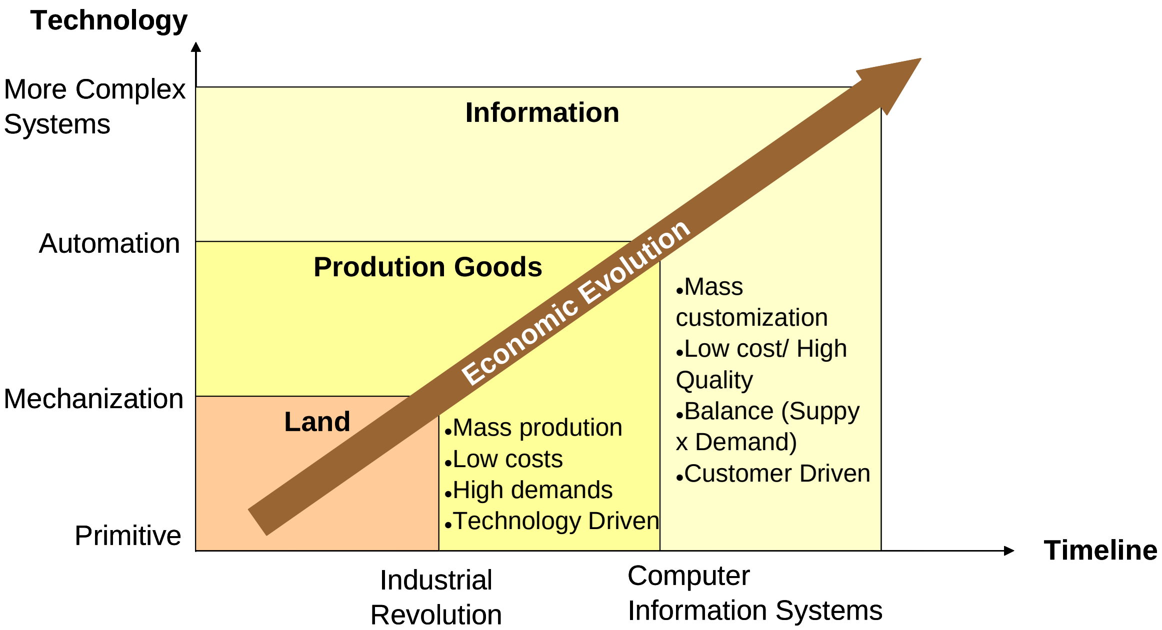


Figure 1. Economic Evolution (Tavares *et* Silva 2008)

This paper presents the RFID technology in section 2. Next, section 3 shows basic Petri Net definitions and formalization. Section 4 introduces Petri Net within RFID Database (PNRD) concepts and auto-detecting exception state calculus, while section 5 shows PNRD deployment. PNRD applied to Flexible Manufacturing System – FMS - Process example is presented in Section 6, followed by discussion and conclusion, acknowledgements and references.

2. RFID TECHNOLOGY

RFID is composed by a tag or label and by reader devices. Readers can be connected to a network; it is expected to be possible to continuously trace and track physical objects marked by RFID tags. Thus it can be viewed as part of a sensor network. A single overview of a typical RFID System is provided in Fig. (2).

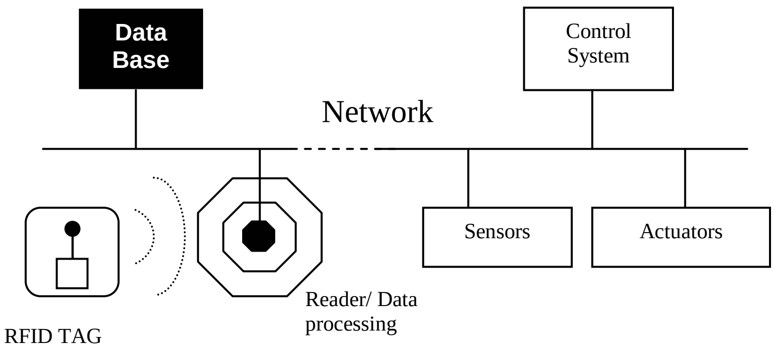


Figure 2. Schema of RFID System

Modern readers are pieces of equipment that have internal microprocessor and memory, connected to a set of antennas which recover the data stored in the tags through Radio Frequency data exchange, and they transfer this data from physical world to IS and databases. These readers, besides possessing simple filtering for reducing the amount of collected data, can also write data (Chokshi *et al.* 2003).

Since 2001, there is an initiative to disseminate RFID along Supply Chain, called EPC Network[1]. There have been a lot of new applications related with RFID trying to present its benefits and advantages (Zaharudin *et al.* 2002 and

[1] www.epcglobalinc.org

Hardgrave *et al*. 2005); although, based on the high expectation and low implementation rate that follows this process, it is evident that this technology has not generated enough from expected value (Tellkamp 2006). On the one hand, there is direct a consideration from more mature companies - which aim to solve their troubles instead of accepting a new fashion technology - that RFID should not be more suitable than the cheaper and very well known bar code. However, RFID must be applied in a different way, that is, RFID can be structured as a real-time Physical Distributed Database since it is able to read and modify product state information data synchronously with process workflow.

2.1. EPC Network

EPC Network is a suggestion for a Supply Chain Relationship Standard by EPC Global[2]. Figure (3) presents the EPC Network architecture. This architecture is composed by tags that are stimulated electromagnetically by readers and transmits a single number called EPC – Electronic Product Code. According the EPC Global specification, each tag stores only a key reference (Header Id, Manufacturer Id, Product Id and Product Serial Number), without any extra data (EPCTagData 2008). Fig. (4) presents EPC standard structure with 96 bits. Each “X” in Fig. (4) indicates 8 bits.

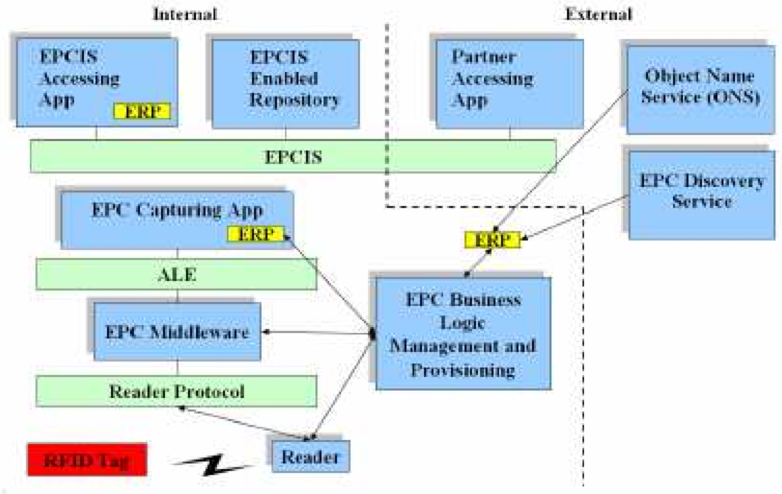


Figure 3. EPC Network Architecture (Cheong *et* Kim 2005)

X	XXX	XXX	XXXXX
Header Id	Manufacturer Id	Product Id	Serial Number

Figure 4. 96 Bits Electronic Product Code Structure GID-96 (EPCTagData 2008)

EPC Network suggests readers must be controlled by EPC Business Logic Management and Provisioning, which interacts with other applications. EPC Data from readers must follow a protocol and there is a need for filtering and local storage provided by EPC Middleware or Savant. After this first data treatment, data amount is reduced by Application Level Events - ALE (EPCIS 2007). ALE provides interfaces with control filters and data collected exchange applications. EPC Information Service Capturing Application supervises low-level applications and contextualizes business information by integration tolls related with business process (Cheong *et* Kim 2005).

EPCIS has a special feature called EPCIS Events (EPCIS 2007) which specifies each type of activity related with reader data capture within EPCIS. Contextualized information goes to EPCIS that is a product repository database, and assists product data exchanged with partners by Partner Accessing Application. EPCIS has interfaces with other applications and with data search mechanisms. There is EPC Discovery Service, which certifies data transfers, and the Object Name Service (ONS) – that is a Domain Name Service (DNS) – for products.

From an external point of view, EPC Network intends to integrate Companies with electronic message exchange. Traub *et al.* (2005) present an Extended EPC Network as shown in Fig. (5). It can be noticed that Communication Network is based on standard messages such as EANCOM, from EPC Discovery Service, which is vital to structure the collaborative network, as well as a data certification system, expected to be reached by GS1 Global Registry – GDS[2].

There are many references which extend Supply Chain (SC) as Guide *et al.* (1997), Aitken *et al*. (2003) and PLM (2003) as presented in Fig. (6) which starts with Raw Material Production, followed by manufactured parts and products. These approaches extend product use and consumption by customers and introduce repair, remanufacture, recycle and disposal activities to generate a cycle in the SC. In this context, the challenge is related to product termination data management, that is, the entire SC flow must present not only the material and information flow up to

[2] www.gs1.org

Customer use and consumption, but also the recoverable product flow with a specific goal, to reduce disposal rate. Without suitable information, disposal rate grows as well as environmental impact.

Disposal rate reduction could be assisted by EPC Network information. Although, Gen2 Standard[3] introduces a function called “kill tag” to hinder tag information data capture after Customer acquisition in order to avoid Customer Identification. This assists Customer privacy but can also make EPC Network unusable to reach product termination process management requirements. However, the way EPC Network is structured, there is not a suitable integration between product and process information, and an effective product termination management is still an open problem.

Another key point is the fact that nowadays collaboration among Companies is treated confidentially, and it is quite difficult to believe that Companies are going to release product information without any kind of regulation or restriction to other Companies.

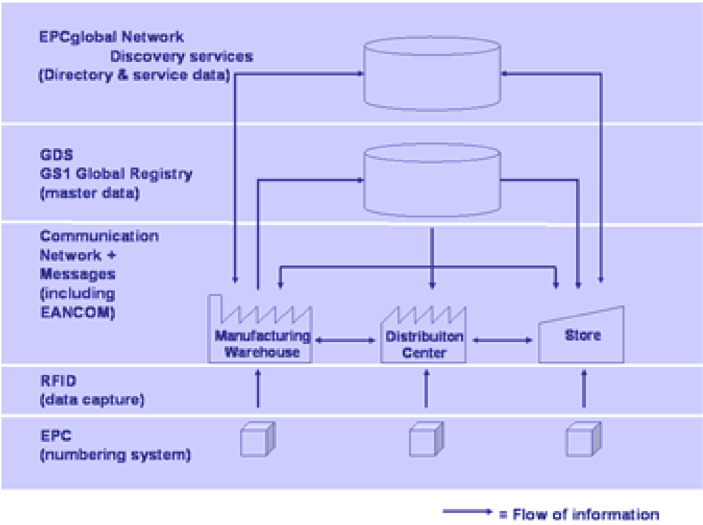


Figure 5. Extended EPC Network (Traub *et al.* 2005)

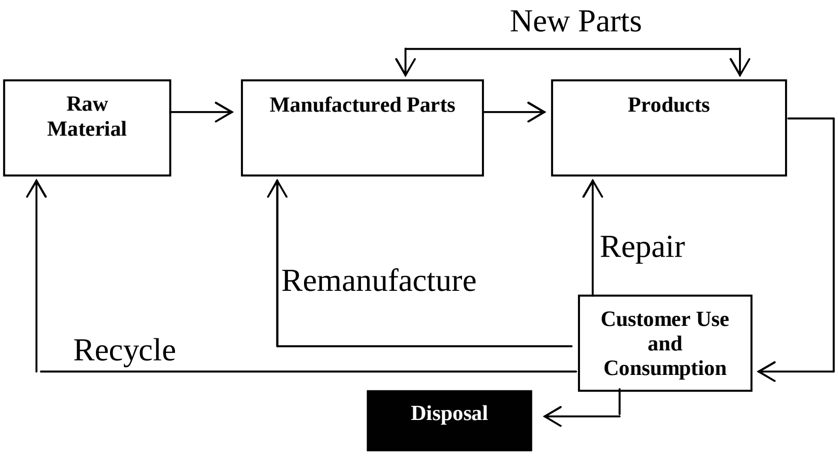


Figure 6. Extended Supply Chain Environment based on (Guide *et al.* 1997)

3. PETRI NET DEFINITION

Petri Nets (PN) (Murata 1989) have quite useful expressive power for modeling (graphically or mathematically) the manufacturing process, as well as a great capacity to formally verify the properties of the modeled system (Liu et al., 1994; Santos Filho *et* Miyagi, 1995; Silva *et* Miyagi 1996; Zhou, 1995; and Rozinat *et* van der Aalst, 2006).

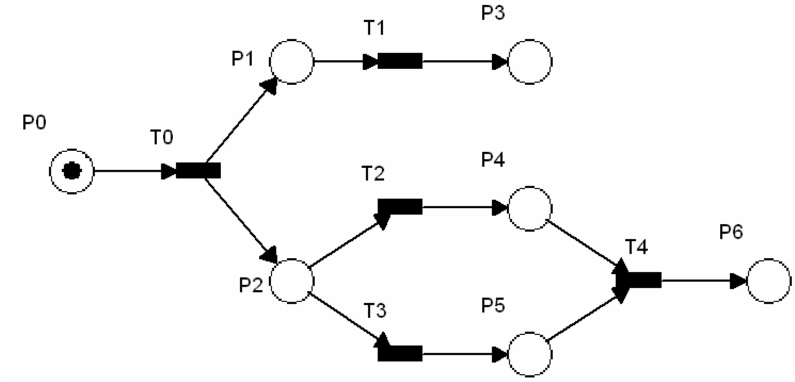
Fig. (7) shows a Petri Net representation and its correspondent matrix equation or incident matrix A^T. These PN characteristics allow the transformation of such processes into computable sequences that models the productive processes.

A prescription commonly adopted for the modeling of a productive system using a PN representation can be:

- Identification of resources, operations or activities in the system;
- Establishment of sequences of the activities in each step;

[3] www.epcglobalinc.org

- Representation of the product states, generally for Places that are connected by Arcs to Transitions, which indicates the beginning and ending of activities belonging to the process;
- Definition of the resource through Places and their connection to the beginning and ending of each operation represented by Transitions;
- The specification of the initial MARKING.



$$A^T = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 1 & 0 & -1 & -1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 7: Graphic and algebraic representation of a productive process in Petri Net

3.1. Incident Matrix and State Equation

According to Murata (1989), for a Petri Net N with n transitions and m places, the incident matrix $A^T = [a_{ij}]$ is an n x m matrix of integers and its typical entry is given by Eq. (1).

$$a_{ij} = a_{ij}^{+} - a_{ij}^{-} \tag{1}$$

where $a_{ij}^{+} = w(i,j)$ is the weight of the arc from transition i to its output place j, and $a_{ij}^{-} = w(j,i)$ is the weight of the arc to transition i from its input place j.

In writing matrix equation, marking M_k is an m x 1 column vector. The j^{th} entry of M_k denotes the number of tokens in place j immediately after the k^{th} firing in some firing sequence. The k^{th} firing or control vector u_k is an n x 1 column vector of $n - 1$ 0's and one nonzero entry, a 1 in the i^{th} position indicating that transition i fires at the k^{th} firing. Since the i^{th} row of the incident matrix A denotes the change of the marking as a result of firing transition i, it is possible to write state equation for a Petri Net as Eq. (2).

$$M_k = M_{k-1} + A^T u_k, k= 1, 2, \ldots \tag{2}$$

4. PETRI NET INSIDE RFID DATABASE – PNRD

PNRD is an evolution of Tag Extended Petri Nets (Tavares *et* Silva 2008). In practical terms, Tag Extended Petri Nets (TEPN) can be viewed as a Petri Net where RFID data is a tagged token, and the RFID reading activity is related to a transition that connects product or object pre and post conditions. This approach is necessary to generate an Architecture which checks pre-conditions and changes product actual state automatically, adding information inside tags (Tavares *et al.* 2006). Fig. (8) represents a TEPN schema of Reader X1 related with Transition1 and its pre (State 1) and post states (State 2) concerning EPC Number 1.10.11.01.

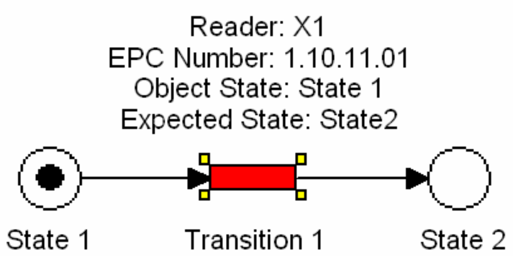


Figure 8: Example of TEPN Schema (Tavares *et* Silva 2008)

PNRD proposes Elementary Petri Net (EPN) as the formal representation that fits automatic unexpected events identification of each individualized tagged object or product. Tag reading is as a single observation of a stimulus for the reader to capture a set of tags, which, after filtering, can be perceived as a string of numbers. Similarly, the writing action is a stimulus for the reader to change the current information in the tag, after a corresponding filtering.

For instance, from the tag point of view, readings can be modeled by an Elementary Petri Net, as a sequence of transitions for each multiple tagged token. In the reader point of view, each transition is a stimulus to read (and write) information from the tags and evaluate if it has to change the information state.

As each transition can be related with redundant perception point, it is necessary to define two distinct types of transitions: perceived and non-perceived. For example, a shipment process of 30 free units properly identified can be viewed as a Petri Net with three distinct transitions: load, transport and delivery; and four places: free unit, loaded unit, transported unit, and delivered unit. This example is shown in Fig. (9).

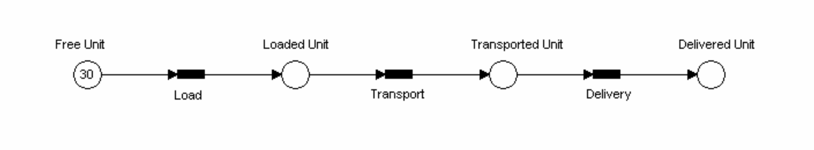


Figure 9: Petri Net Shipment Process of 30 Free Units

If only Load transition is perceived with RFID readers, transport and delivery transitions are non-perceived ones. In this direction, there is a simplified perceived Petri Net, which only presents perceived transitions. In this example, Fig. (10) presents correspondent simplified perceived Petri Net. Usually, other transitions are perceived and checked manually or the whole process is intended to be conducted after truckload. Nevertheless, the larger the number of readers inside the process, the more perceived transactions it has.

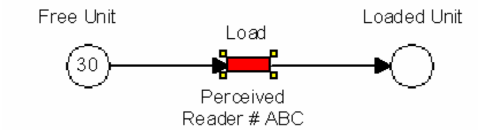


Figure 10: Simplified Perceived Petri Net of Shipment Process

4.1. PNRD Formalism

The PNRD approach aims to verify, validate and point out refinement requirements to Perceived Petri Nets system models based on RFID data capture. So as to attain this purpose, PNRD distributes Petri Net system model within RFID components, that is, in the tag and in the reader internal memory, adding an enabler of automatic-detecting exception state.

Each tag holds more than a single Id, as predicted by EPC Global (EPCTagData 2006) but store the required and some alternative processes the product has to face. Formally, the extra information is composed by the product incident matrix A^T (expected product process flow), and the product actual state M_k. Optionally, product timestamp or a specific date such as expiration date is included within the product RFID tag. Each reader receives a table of control vector u_k in advance for each product id, product actual state, and timestamp.

It is possible to formalize RFID Perception as a set of reader/antenna id, tag id, timestamp, pre and post-state, as presented in Eq. (3).

$$RFID\ Perception = \{tag_{id}, reader_{id}, timestamp, pre_S, pos_S\}, \quad (3)$$

where $tag_{id} \in T$, Tag Id set; $reader_{id} \in R$, Reader/Antenna Id set; $pre_S \in PreS$, Pre-state set; and $pos_S \in PosS$, Post-state set.

Reader processor has a special duty: to calculate the tag next state M_{k+1} based on Eq. (2). Part of the data is gathered from the tag memory after an initial reading (incident Matrix, actual state mark and timestamp). Another part comes from reader antenna transaction relationship, i.e. control vector u_k for each product id, product actual state, and timestamp stored within the reader memory. M_{k+1} state is calculated. If this calculus has a unitary State Vector as a result, it is suitable and this datum can be stored as a new M_k within the tag memory. If M_{k+1} calculus results in a non-unitary state vector, it is unsuitable and, as a direct consequence, it is possible to automatically highlight an exception state related with previous expected process workflow. Although PNRD identifies an exception state, it does not distinguish the cause of this effect.

Nevertheless, a single reader antenna can be related with more than one perceived transition, depending on the tag id, time, pre and post state. For instance, if there is only one reader antenna at the warehouse entrance, and material management is based on this reader antenna perception, there are two activities related with it: material entry and departure. In the same direction, if there is any expiration date, within product RFID data, it is possible to identify unsuitable products to be disposed, depending on reading timestamp. Conflicts arise when the same reader antenna is related to more than one transition concerning the same tag id pre-state. In this case, it is necessary to apply a decision algorithm to define which transition must be chosen. This paper will not deal with the decision making process.

Figure (11a) shows an example of Petri Net equation distributed along tag and reader related with pre and post states before reading. Figure (11b) represents PNRD after reading the tag attributes.

Figure (11a) presents tagObj as Tag class object with the following attributes: tag Id 1.2.1.1010, M_k [1,0] (related with P0), A^T, and timestamp time1. readerT1 is a Reader class object with u_k [1] related with tag Id 1.2.1.X, where X means all tag Ids which start with 1.2.1, and several schemas to M_{k+1} calculus. After the reading process, it is possible to notice a new M_k ([0,1]) related with P1, and a new Timestamp time2. Naturally, A^T remains the same.

However, there are some requirements to be fit before the M_{k+1} calculus. These requirements are presented in the next section, PNRD deployment.

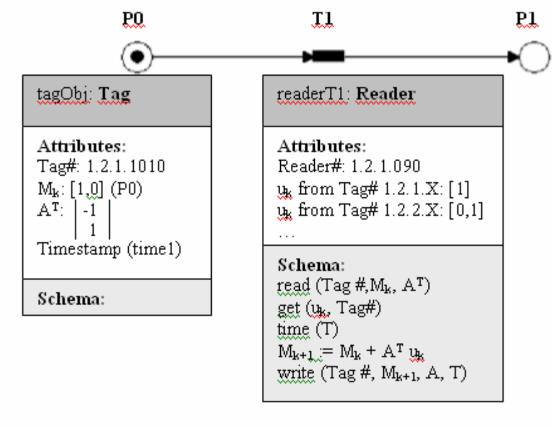


Figure 11a: PNRD Representation Before Reading

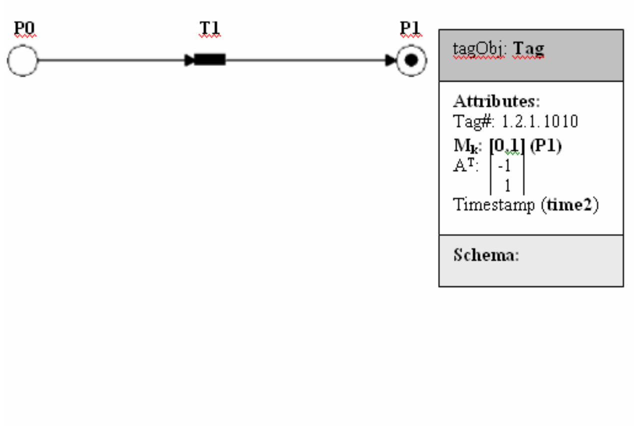


Figure 11b: PNRD Representation After Reading

5. PNRD DEPLOYMENT

5.1. PNRD Methodology

PNRD application has some mandatory requirements such as to map the process flow in advance, including knowing undesirable events; plan expected perceptions; determine and identify perception points; integrate reading events with system model perception points, and RFID technical issues, such as physical barriers; frequency, tag position, and tag type (active or passive) definition.

The PNRD methodology is separated into two parts: design (expected states definition), and execution (analysis of actual states). PNRD data requirement for each part is presented as follows:

a) Design (expected states definition)
   a. Process Mapped in Petri Nets, including expected exceptions (Basic High Level Petri Net - BHLPN);
   b. Definition of each specific product process (Elementary Petri Net - EPN);
   c. Identification of each reader (perception point) inside this EPN (transition identification);
   d. Definition of each product tag incident matrix and initial marking and reader control vector;
   e. RFID technical issues resolution.

b) Execution (actual states analysis)
   a. RFID HW and SW deployment;
   b. Auto-detecting exception based on PNRD approach;
   c. Data consolidation from expected execution.

Unexpected exception treatment is not included in PNRD methodology.

5.2. PNRD Implementation

Following EPC UHF RFID Protocol (2005), tag memory shall be logically separated into four distinct banks. A logical memory map is shown in Fig. (12). Memory banks are:

- Reserved memory shall contain the kill and/or access passwords, if passwords are implemented on the tag;
- EPC memory shall contain a CRC-16 (Check-Digit), Protocol-Control (PC) bits, and a code (such as an EPC, or hereafter referred as an EPC) that identifies the object to which the tag is or will be associated;
- TID memory shall contain an 8-bit ISO/IEC 15963 allocation class identifier;
- User memory allows user-specific data storage, optionally.

PNRD additional data is stored at User memory bank, preferentially.

6. PNRD APPLIED TO FMS PROCESS

Flexible Manufacturing System – FMS – process planning has alternative or flexible flows as a special feature.

When this kind of process is modeled by Petri Nets, there is a conflict concerning control system which is closed related with alternative definition. Figure (13) present schematic Petri Net for an alternative flow from place P1 (for instance a raw material) to place P4 (e.g. finished product) and its correspondent incident matrix. Each transaction represents a piece of equipment and is linked to a specific reader antenna.

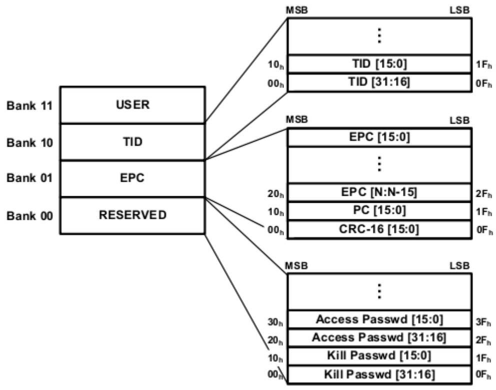
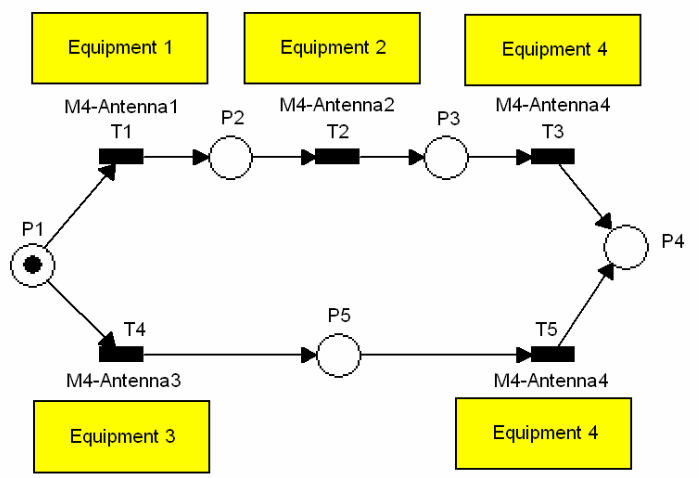


Figure 12: Tag Memory Banks (EPCUHFRFID 2005)



$$A^T = \begin{bmatrix} -1 & 0 & 0 & -1 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

Figure 13: Petri Net Model Related With one Alternative Flow and Corresponding Incident Matrix

PNRD was implemented in Java and the software was inserted as part of a Design Lab project called DEMIS – Distributed Environment Manufacturing Information System. It was integrated with one M-4 ThinkMagic Reader with 4 antennas and one M-5 ThinkMagic Reader with 2 antennas. It has two configuration files, called Config.xml, identifying valid reader/ antenna to perceived process; and Context.xml which defines reader transaction relationship, presented in Fig. (14).

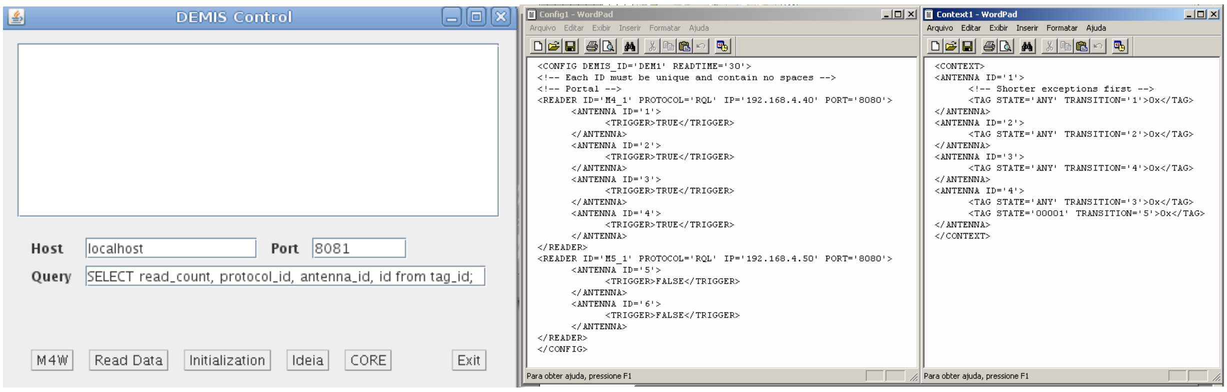


Figure 14: DEMIS Front End, Config.xml and Context.xml files

M4-Antenna 4 is associated with two distinct transactions, T3 for alternative flow (T1-T2-T3) and T5 for alternative flow (T4-T5). In this sense, if Antenna4 pre-condition is P5, then it is linked with T5, otherwise, it is associated with T3, as shown in Context.xml in Fig. (14). For this reason, M4-Antenna4 is not a conflict to PNRD.

P1 is a state in conflict for control system and there is a need to choose one of these alternatives by production schedule. Concerning P1 Conflict, PNRD gets process perception, and thus perceives the conflict already solved, getting tag data of antenna M4-Antenna1 or M4-Antenna3 and verifies if tag flow complies with the designed or predicted workflow.

Applying these configuration files (Config.xml and Context.xml) and adding additional data to tag Id 0x0012, this tag went through Equipment 1 and Equipment 4, respectively. Figure (15) shows some fragments of DEMIS log.txt file.

```
…
XML: Doc Config.xml Root Element is CONFIG
[2008/08/28 16:20:39.540] DEMIS_ID DEM1: 6 antennas on 2 readers, 30s new read timeout.
[2008/08/28 16:20:39.557] Reader 0 ID M4_1: 4 antennas,
[2008/08/28 16:20:39.560] (0) '-- antenna 0, global ID 1, trigger:true
[2008/08/28 16:20:39.561] (1) '-- antenna 1, global ID 2, trigger:true
[2008/08/28 16:20:39.566] (2) '-- antenna 2, global ID 3, trigger:true
[2008/08/28 16:20:39.567] (3) '-- antenna 3, global ID 4, trigger:true
[2008/08/28 16:20:39.568] Reader 1 ID M5_1: 2 antennas,
[2008/08/28 16:20:39.569] (4) '-- antenna 0, global ID 5, trigger:false
[2008/08/28 16:20:39.571] (5) '-- antenna 1, global ID 6, trigger:false
XML: Doc Context.xml Root Element is CONTEXT
[2008/08/28 16:20:39.597] :. Antenna 1 configuration --> 1 exceptions .:
[2008/08/28 16:20:39.618]          '--- tag 0x exception on pass  ANY, control vector is 1
[2008/08/28 16:20:39.620] :. Antenna 2 configuration --> 1 exceptions .:
[2008/08/28 16:20:39.621]          '--- tag 0x exception on pass  ANY, control vector is 2
[2008/08/28 16:20:39.622] :. Antenna 3 configuration --> 1 exceptions .:
[2008/08/28 16:20:39.624]          '--- tag 0x exception on pass  ANY, control vector is 4
[2008/08/28 16:20:39.630] :. Antenna 4 configuration --> 2 exceptions .:
[2008/08/28 16:20:39.631]          '--- tag 0x exception on pass  ANY, control vector is 3
[2008/08/28 16:20:39.633]          '--- tag 0x exception on pass  00001, control vector is 5
…
[2008/08/28 16:20:39.956] /192.168.4.40:8080<--querry-- "SELECT  antenna_id, id from tag_id WHERE protocol_id='GEN2';"
…
 [2008/08/28 16:20:40.251] /192.168.4.40:8080--message-> "1|0x0012CC8F"
…
[2008/08/28 16:20:40.372] /192.168.4.40:8080<--querry-- "SELECT data FROM tag_data WHERE id=0x0012 AND protocol_id='GEN2'
AND antenna_id=1 AND mem_bank=1 AND block_number=3 AND block_count=5;"
[2008/08/28 16:20:40.489] /192.168.4.40:8080--message-> "0x8236006004406E000000"
…
[2008/08/28 16:20:40.784] [3] Tag 0x0012 antenna 1 rule: 0x, State: ANY--> Transition: 1
[2008/08/28 16:20:40.784] [4] Writing Tag 0x0012...
…
 [2008/08/28 16:20:41.197] [5] Tag 0x0012 updated to: 0x8236006004406D000000
Old State:      10000
Current State:  01000
-1  0  0 -1  0
1 -1  0  0  0
0  1 -1  0  0
0  0  1  0  1
0  0  0  1 -1
...
[2008/08/28 16:21:18.563] /192.168.4.40:8080--message-> "4|0x0012CC8F"
…
[2008/08/28 16:21:19.084] [3] Tag 0x0012 antenna 4 rule: 0x, State: ANY--> Transition: 3
[2008/08/28 16:21:19.084] [4] Tag 0x0012 workflow exception! ****
...
```

Figure 15: Fragments of DEMIS log.txt file

From "2008/08/28 16:20:39.540" to "2008/08/28 16:20:39.633" Config.xml and Context.xml were interpreted. "2008/08/28 16:20:39.956" was the reader query followed by its answer at "2008/08/28 16:20:40.251": "1|0x0012CC8F", meaning that Antenna 1 read "0x0012CC8F" data string, where "CC8F" is 16bits CRC reading check valid digits from 0012 tag Id. Additional data in a DEMIS format "0x8236006004406**E**000000" was gotten after another query at "2008/08/28 16:20:40.372".

DEMIS found tag Id 0012 transition relationship at "2008/08/28 16:20:40.784", and updated Tag additional data to "0x8236006004406**D**000000". In other words, current state was changed at "2008/08/28 16:20:41.197" from 10000 (P1) to 01000 (P2) and Incident Matrix remained the same.

At "2008/08/28 16:21:18.563" tag Id "0x0012CC8F" was read by Antenna 4, related with Transition 3. Automatically, DEMIS presented "workflow exception!" error at "2008/08/28 16:21:19.084".

7. DISCUSSION AND CONCLUSION

This paper presented the PNRD approach and a FMS process example, as PNRD conceptual proof. PNRD is able to auto-detect exception states based on Petri Nets within RFID Database, although it does not distinguish the cause from this effect. PNRD can be viewed as more than RFID check digit related to process; it is an automatic system model compliance tool. The Unique Id based on network-connected database has huge problems with information amount, parallelism of data process when applied to system model compliance, and dependency of external network connection. However, part of this problem will be solved by the current tendency to provide tags with more memory and therefore more possibilities for combine data.

PNRD focused on network independence requisite, so it splits system model into several EPN. It is necessary to study how to integrate several EPN to a HLPN concerning the whole process. In the same way, Control System and PNRD must be investigated and suitably integrated considering that PNRD conflict is different from that of control system. To avoid PNRD conflicts there must be different antennas related with different transactions for the same pre-state in conflict. PNRD must be applied to real FMS process to be proved in practice.

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