PN AS A TOOL FOR INNOVATION IN INDUSTRY: A REVIEW

Jesús Fernández de Miguel[a], Julio Blanco Fernández[b], Mercedes Pérez de la Parte[b]

[a] Grupo ECO3G, Logroño, La Rioja, Spain
[b] University of La Rioja. Industrial Engineering Technical School. Department of Mechanical Engineering. Logroño, Spain

[a] jesusfernandez@grupoeco3g.com, [b] julio.blanco@unirioja.es mercedes.perez@unirioja.es

ABSTRACT

PNs are a basic tool widely used in scientific and technical fields, in areas as diverse as automation, computer science, management, modelling, simulation, optimization, etc. Many important research groups around the world work both in the progress of the PN in themselves (behaviour, properties, analysis, etc.) and its application fields of science, industry, or services. However, such an important tool for industrial development experiences a lack of exploitation in the productive sector, compared with the potential applicability of Petri nets in industry and services management.

In this paper, we review the actual use of the PN in industry, especially in the high Ebro Valley, in Spain, where ECO3G company is dedicated to the management of innovation in the industry for many years and therefore it has information based on experience. The review is also extrapolated to the world, based on information in the scientific and technical literature, and in the mentioned ECO3G experience in innovation, and national and European research projects. It also presents special attention to the use of PN in patents and industrial property as well as the know-how in companies of different industrial sectors. Finally, an analysis of the cause of this lack of exploitation in the productive sector, and a study of ways to improve this current state, are developed.

Keywords: workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION

There are certain characteristics of the PN that make them especially suitable for modelling discrete systems, among which are:

- Easy representation of concurrent systems (with parallel evolutions and synchronizations)
- The ability to condensation in a simple model of an underlying state space that suffers the state explosion problem that makes it impossible in practice the exhaustive analysis of actual cases by capacity problems of computational effort.
- The duality of graphic/mathematical representation, which allows on one hand to intuitively and easily model by graphic systems, and secondly to analyze the properties of the model through mathematical and computational techniques
- The richness of existing modelling formalisms in the paradigm of the PN
- The richness of knowledge generated in previous research works on behaviour, properties, and techniques of analysis or simulation of PN.

From the foregoing it would appear that the PN constitute a tool fully integrated in the industry due to the benefits that could be obtained in productive systems, and some service companies, with their use. However its use in industry and services is much lower than expected, given its potential as a source of innovation.

In this paper, we review the actual use of the PN in industry, especially in the high Ebro Valley, in Spain, where ECO3G company is dedicated to the management of innovation in the industry for many years and therefore it has information based on experience. The review is also extrapolated to the world, based on information in the scientific and technical literature, and in the mentioned ECO3G experience in innovation, and national and European research projects.

It also presents special attention to the use of PN in patents and industrial property as well as the know-how in companies of different industrial sectors.

Finally, an analysis of the cause of this lack of exploitation in the productive sector, and a study of ways to improve this current state, are developed. All the analysis is developed in a general way, and also applied to the most important industrial sectors of La Rioja (the Country of the authors in Spain).

2. POTENTIAL APPLICABILITY OF PN IN THE AREA (LA RIOJA)

In this first phase of study we conducted an analysis of applications made in 5 sectors that clearly characterize the industry of La Rioja (Spain) and make it recognizable both nationally and in some cases internationally. So, these sectors have been chosen for its economic and strategic importance within the region, seeking to evaluate in this article their degree of

maturity for a potential introduction of the PN in their productive activity. Thus, as will be founded later, we have chosen the following sectors:

• Wine Production: the most recognizable industrial sectpor in the region through its designation of Origin Denomination and greater international presence through exports. It is also one of the most proactive R&D areas in recent years.

• Auxiliar Automotive industry: which encompasses all techniques characteristic of the automotive production; in La Rioja they are represented mainly in the rubber industry, metal, and chemical auxiliary. Their presence in the value chain is significant nationally through its connection to some of the major automotive plants in Spain and Europe.

• Footwear Sector: La Rioja, and more specifically its West region (Arnedo), are the basis of the footwear producer industrial district of Spain, and one of the top 5 in Europe, even being a leader in subsectors such as safety shoes. The growth of investment in R&D in this sector is significant.

• Sector snuff: Imperial Tobacco has a plant in La Rioja that has nearly 2000 employees (representing a significant 1.5% of the population of the Community according to the latest data) and is now the largest company in Spain of the group and one of the most prominent in Europe. In recent years, Imperial Tobacco, earlier known as Altadis, has been gathering at its plant in La Rioja many production plants in Spain, gradually increasing investment and providing greater strategic importance to this factory. The special feature of this product makes that it is included in the food industry.

3. OVERVIEW OF THE APPLICATION OF PN

Research in PN is now at the point of greatest activity in the world, although it could stand a greater intensity of research groups in Asia, perhaps encouraged by a strong tradition in the introduction of new production techniques that improve productivity.

However, we determined that since the 90's there were some references focusing on the applicability, especially as a complement to the development of R&D activities in the productive environment. For example, in (Japan-USA, 1992) already pointed to the PN as a particularly useful tool in addition to production techniques such as mechatronics, microrobotics or CAD-CAM techniques. Surprisingly, the research on PN was originally closely tied to certain sectors of technics to which they intended to supplement, especially through a very focused approach to automate certain tasks or at least integrating them. So in 2001, works such as Zhan and Luo (2001) already pointed to the usefulness of PN in highly automated industrial environments, such as the snuff, proposing a PN modeling that would allow assessing the productivity of selected alternative processes, mainly in packaging lines. Jeng et al. (2004) seeking the application of PN in the development of new types of semiconductors in the electronics industry. It is particularly interesting the approach that the work gives to the use of PN as a

resource for the evaluation of alternatives after the research phase of R&D projects, avoiding costly processes of reanalysis and correction of the prototypes, with the consequent consumption of resources. In other sectors, such as footwear, Carpanzano et al. (2004) posed the NP as a complement to the development of a modular production that is controlled by flexible production systems (RMS) integrated directly into the production line. Finally, sectors such as furniture had similar proposals such as Gradisar and Music (2007) where, through tools such as MATLAB, proposed the definition of an algorithm to determine the most appropriate control strategy for a given environment and productive process. Thus, through these representative examples we can see how the transfer of PN counts with relevant background and case studies that allow us to appreciate the competitive advantage that they provide to the industry.

However, in the last years, it can be determined that there is a clear evolution towards a more experimental research and somewhere, more focused on sectors with higher technological capability and maturity in the production side, where the most representative example is the automotive. Influenced by Japanese production techniques arising under the Automobile Industry (JIT-Kanban, 5S, LEAN ...) the PN found in this sector increased responsiveness and a route application much more straightforward than in traditional sectors, as is highlighted in Miao and Xu (2009). References in this field are numerous in recent years (2009-2011), from the most theoretical ones, such as Zhang et al. (2010), which seeks to define the technique of detection and evaluation of the critical points of contradiction as the key to improving the definition of PN based on classic models in engineering solutions, to the most applied, such as Wang (2009), which works in the application of fuzzy PN in the production chain, especially in technical delivery, targeting a logistics guidance that subsequently has been consolidated.

In parallel, there are numerous research groups working in the development of PN powerful techniques of a more global approach, and from which can be implemented oriented tools for various industrial sectors, almost always with a productive approach. Representative examples of this more general research are Han et al. (2009) or Li et al. (2010) and Wang (2009), and even more and Chen Xiao (2010), applying DSM mathematical techniques, or Xu et al. (2010), who posed a transfer of know-how to the field of logistics, which currently represents one of the busiest lines in applied research in PN, especially in seaports, airports, docks or logistics centers of activity.

Finally, in this overview is intended to highlight the link between PN with applied R&D projects in industry, a trend that has manifested itself more strongly nowadays. Bartz (2010) proposed an improvement in the management of the information accumulated in the development of R&D project exemplified in the case of the automobile. Especially interesting is the

contribution of the work in the search for synergies through the application of techniques WfMC (Workflow Manager Coalition). This also allows a more precise analysis of the different possibilities around a project with a more flexible decision-making and effective management emerged from the data acquired during the analysis of the production process. Currently the firm cooperation in R&D in both national and European projects is essential for peak performance in their development. Applied and reference examples that illustrate the effectiveness of PN in research and development is the case of China's research project about optical LAMOST (Modeling of control system based on LAMOST for Petri net workflow, X. Lu) or Costa et al. (2010) which highlight some of the PN modeling tools more useful for decision making in a project, supported by graphical and multilanguage code editors.

4. PETRI NETS AND INDUSTRIAL PROPERTY. PATENTS

A search of the most important patents around the PN has been developed as a basis for this work. It is difficult to find patents around the PN as advances are usually framed mainly in the field of Intellectual Property through publications such as those discussed above. Still, the application of PN in certain production processes means that there are interesting references to cases of successful applied research in PN. The results are essentially codes G06 (computers, calculators and counting) and especially G05 (Control systems or automatic control in general; functional elements, monitoring or testing devices or elements).

The geographic distribution of these patents, as in the case of articles presents a greater intensity in the Asian region, with significant references to leading companies in sectors as disparate MICROSOFT CORP (Constructing Petri Nets from traces for diagnostics, US2008320437 (A1)), SCHNEIDER ELECTRIC Automotion (Method for orchestrating services of a service-oriented orchestration and automation system machine, US2010292810 (A1)), SAMSUNG (Configuring learning petri nets, EP1335320 (A2)) and even EXXONMOBIL (System and method for abnormal event detection of continuous operation in the Industrial Processes, WO2006031635 (A2)) that have patents applied directly to their main lines of work which are closely linked to the most cutting edge in the industry today. Such records allow us to appreciate that macroindustrial level, the PN has not only proven its effectiveness, but the companies that have chosen to integrate them have ended up reaching patents reflect the success and utility of PN as a tool .

Within the references can be found in the attached document include, for direct application to fields of industry Virtual Production Control System and Method and Computer Program Product thereof (US2011040596 (A1) is a reference to recent virtual control system a manufacturing industry, Information processing method for Evaluating and using

biochemical pathway models using clinical data (WO02099569 (A2)) which shows the usefulness of PN in the evaluation methods or fields of biochemistry and method for System abnormal event detection of continuous operation in the Industrial Processes, WO2006031635 (A2) of 2006 already laid the foundations for industrial operation from the use of PN.

In addition, other references as traces from Constructing Petri Nets for diagnostics, US2008320437 (A1), or Method to Improve Unfolding in Petri Nets, US2009172013 (A1) represent the results of experimental research lines and emerging result of the search for a deeper knowledge in the field of methodology and definition of the PN.

5. METODOLOGY

The introduction of PN in R&D projects of La Rioja should be closely linked to a flexible methodology that allows business to appreciate their added value without consuming a large amount of resources. Keep in mind that with few exceptions, such as Imperial Tobacco, we speak of SMEs with a very short experience in terms of R&D and that assess the return on investment in these technologies through the results of billing partners.

Similarly, being traditional sectors, a methodology of integration of PN into the Business activities should be seeked more than a methodology of implementation, looking for an easy transition. This will need to define an integration strategy. This strategy, through the University of La Rioja, the Administration or the social agents involved in research should seek to organize the integration initiatives to support more effectively the strategies of both lines of business and technology in the companies. That is, to seek the development of the technology without consuming resources that could make companies perceive a threat to their business activity. Thus, in a first phase of diagnosis, we define the response of each company or sector to some fundamental questions:

• How can PN provide greater business value through the integration of applications or their improvements?

• Where do we start? What is the critical technical area that needs to be revised or which is the one that the company intended for R&D?

• In what order should be integrated processes and applications that the company can carry out easily?

• How to take advantage of the investments?

• Can the company receive aids from the Administration to facilitate the transition?

• How to ensure that investment in integration is maintained over time?

• How to organize the integration effort? Does the company have staff trained to understand or at least apply the methodology defined by the PN?

• How to ensure that they are aligned with the defined strategy? Does the company have ability or experience in cooperation other companies, Universities, or agents of innovation?

• Is it necesary prior training?

• Is the company capable of perceiving the received added value through the use of PN to deal with future phases of the research and the innovation?

Once defined the particular scope of the proposal in each sector through the diagnosis, the development of a PN model is the next step, in companies with capacity to develop it, prioritized by the needs and the benefits of a detailed description of the behaviour and the knoledge of how key initiatives could be undertaken for research proposals to facilitate the evolution of the maturity level of integration required to support the proposed initiatives. At this point we should also assess the investment capacity of the company before moving to the next phases. Not surprisingly, obtaining a model would constitute for 90% of the companies a significant progress in its strategic capacity of production management.

Later, in a more advanced stage of the research, the following stages could be to perform simulations, analysis, implementation, and a final phase of the optimization of the process studied under the PN model in order to obtain the final diagnosis. All these phases depend on the outcome of further analysis of individual sectors, and particularly their degree of maturity and the awareness that the industrial structure of La Rioja and the Government have towards this type of research initiatives.

In summary, the methodology of strategic development for the diagnosis-modelling phase consists of three levels of information acquisition, which are consolidated to yield an overview of the baseline, the state of the art and skills of each company or sector, the gap between the current models and the models obtained by PN, and a plan of initiatives to reduce this gap . This process can be seen in Figure 1.

Data collection and the diagnosis is made through three fundamental points:

• Current business and productive strategy: must be done with site visits to each company or industry in order to define the vision and business systems. Current ways of business, production model, systems and technology, experience in R&D issues and business needs; it is done with sessions of interviews to the various areas involved and their managers

• Architecture or state of applications and technology: based on questionnaires given to the responsible for application and production areas. Formats should be simple, very protected, allowing us to capture data from the production or R&D project for further analysis as accurately as possible.

• Development of diagnosis: With the information gathered, the analysis of the current situation in each company or sector will be developed, where the technical maturity will be evaluated, as well as the sensitivity to the integration of new technology, its perception, or the elements of methodology of integration previously used by the organization that may be useful, as well as the objectives of subsequent phases.
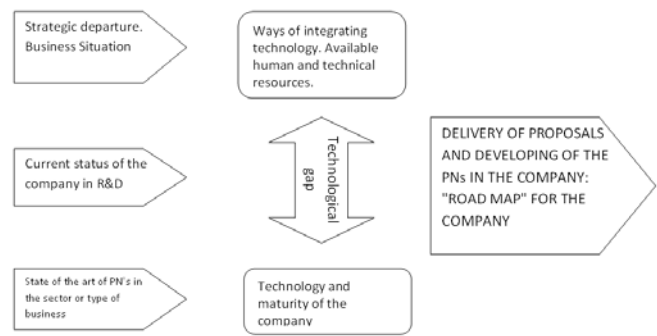

Figure 1: Methodology of analysis of PN implementation in companies of La Rioja

Finally, it would be very interesting to develop a deliverable for Business named "Strategy and foundations of a PN model for profuction management", which quantifies technical gap, the technical means available and necessary, and a series of proposals reflected in a starting "road map" that the companies should take to achieve the successful implementation of the methodology of pre-PN phase of modeling, simulation and analysis. Additionally a "cash flow" or plan of ROI showing the added value provided globally by the PN process, including potential or repayable financial support of the Administration, Could complement the document.

6. CONCLUSIONS AND MAIN RESULTS.

Accordingly to this preliminar analisys, industry from La Rioja is based primarily on the so-called "traditional" sectors, especially if we value that the production of wine, shoes and furniture, account for over 50% of economic activity in La Rioja. Additionally, these companies have a strategic organizational model and very traditional: the transition from the first generation of many SMEs to the second generation, better trained and adapted to the new methodologies, is being much slower than in other regions, mainly because the good economic figures before the crisis occasioned that the crisis affected La Rioja later than the other regions.

Therefore, in order to deal with projects like the proposed around the PN, the region has a first line of strategic-cultural handicap because R&D has been seen by many of the companies more as a complement (or even something unnecessary) than to normal and neccesary activity. This has led many companies to face later incorporation into the new strategic models, despite the existence of financial and human resources provided by the authorities that have facilitated and facilitate nowadays the transition.

Therefore, in general, we can say that the industry of La Rioja lacks mature enough to tackle a research project of optimization of the production based on PN (ranging from modeling to optimization). It is therefore

necessary to address the first phase of awareness the support of the Administration and later to deal modelling projects on companies that presents a sufficient level of maturity through specific programs related to projects or implementations of projects of R&D, as a supplement to for example the implementation of nacional regulations UNE 166000 (Management of R&D and innovation). So a series of conclusions and general recommendations (as well as some more specific ones) are made in this work, for the analyced sectors, in order to promote the integration of PN techniques in the industry of La Rioja.

6.1. General recommendations

The industry of La Rioja must become sensitized in the application of innovative techniques and the tools provided by the PN for the implementation of R&D projects. In order to achieve greater maturity, it would be interesting to carry out some of these initiatives:

•Campaign awareness pre-production enhancement techniques. Disclosure of them, especially the PN through specific workshops or presentations, in situ, in an informative and forthcoming way.

• To adopt systems and formats that fit the business profile of La Rioja industry. If the initial maturity is low, we should perform a simple and close approximation to the strategic management of the companies that show, especially through case studies similar to those described above, the interest of the PN for modelling, simulation and optimization. Approaches would also be interesting in order to perform return on investment that the company should carry out in PN, demonstrating their added value.

• To seek support from national and regional administrations and to work in cooperation with companies and industry organizations for the development of PN. Bringing the triple helix model (Industry, University, Government) to companies in a tangible and easily way. Given that La Rioja has a University and an active Development Agency, it would be interesting to carry out a series of audits on industrial organization and R&D in which the balance of the interest of the inclusion of PN within the Rioja business network could be determined.

• That such cooperation includes, where possible, tools of financial support that at least allow companies to assess their baseline pre-PN modeling with a low cost. This would be particularly interesting to search for knowledge transfer from the incorporation of technologists from the University of La Rioja, because of its proximity and experience to businesses. We also consider that such support should take precedence collaboration between companies, the aforementioned incorporation of technologists, and that the studies should be addressed as a whole (or cluster) in order to optimize resources and achieve that the PN have a

global impact instead of only local (without particular solutions).

• As seen below, support for research in some of the most characteristic sectors should increase, like wine, which has found an interesting niche development that should be addressed as a way of obtaining value for the sector and by extension for La Rioja.

We now proceed to discuss in Table 1 specific proposals for each of the sectors analyzed in. It is noted that there are some priority sectors of application, such as wine or snuff, if what is sought is that research has a high degree of novelty. However, if the focus is on modernizing the production model in La Rioja, the focus should be more towards furniture and footwear as most representative sectors.

REFERENCES

1992 Japan - USA Symposium on Flexible Automation

Advances in Materials Manufacturing Science and Technology XIII: Modern Design Theory and Methodology, MEMS and Nanotechnology, Material Science and Technology in Manufacturing, Materials Science Forum, Volume 628 629, 2009, 734p

Bartz, R. 2010 Contribution to a workflow-based information management in automotive testing and data análisis, Proceedings of the IEEE International Conference on Industrial Technology, 2010, Article number 5472558, Pages 1026-1031

Carpanzano, E.a , Cataldo, A.a , Tilbury, D.b 2004 Structured design of reconfigurable logic control functions through sequential functional charts, Proceedings of the American Control Conference, Volume 5, 2004, Pages 4467-4471

Chen, J.a , Zhang, L.-W.b , Luo, J.-Q.b 2009 Study on reconfiguration cost modelling of Reconfigurable Manufacturing System IET Conference Publications Volume 2009, Issue 556 CP, 2009

Cicirelli, F., Furfaro, A., Nigro, L. 2010 A service-based architecture for dynamically reconfigurable workflows, Journal of Systems and Software, Volume 83, Issue 7, July 2010, Pages 1148-1164

Cicirelli, F., Furfaro, A., Nigro, L. 2010 Using time stream Petri Nets over a service architecture for workflow modelling and enactment Spring Simulation Multiconference 2010, SpringSim'10, 2010, Article number 131

Costa, A.a c , Gomes, L.a c , Barros, J.P.b c c , Oliveira, J.a , Reis, T.a 2010 Petri nets tools framework supporting FPGA-based controller implementations , Proceedings - 34th Annual Conference of the IEEE Industrial Electronics Society, IECON 2008, 2008, Article number 4758345, Pages 2477-2482

SECTOR	STRATEGIC MATURITY	MATURITY IN R&D	APPLICABILITY OF PETRI NETS	ADDED VALUE OF PETRI NETS
Wine Sector	**Medium-Low**. Big companies are adapted to the new environment but there are plenty of small traditional wineries	**Medium**. There are R&D projects mainly related to big companies. Currently there is a tendency to increase investment in this area, although there are still many companies that do not have wine experts or technicians and R&D departments.	**Very high**. There are hardly any references. The traditional origin of production processes has hindered the technology transfer.	It is recommended the bid for product differentiation, using the PN to study the impact in production and distribution of new wines based on R&D from new varieties.
Auxiliar Automotive Sector	**Medium-High**. It is a sector heavily influenced by the groups to which they provide, which are generally part of the same group. Thus many companies already assume management techniques from its parent companies. In any case it is a sector that traditionally has bet, also in La Rioja, by advanced management techniques.	**Medium-High**. There are R&D projects for years and many companies have their R&D to continuously generate ideas. However a need exists for greater cooperation between companies although there are already ongoing corrective measures.	**Medium**. In this case the degree of novelty of the application of PN is quite low. Locally, it may be considered a productive innovation, although it PN integration would consist, in the first phase, mainly in integrating solutions or models already implemented successfully.	PN are recommended to be used as support tool for optimization and improvement of productive activety. Also as supplement in the R&D carried out in this sector.
Footwear Sector	**Medium-Low**. The sector in La Rioja presents a significant gap between large firms with capacity and experience in strategic management and other family companies in a intergenerational transition period.	**Medium**. In the last 5 years, companies have tried, more or less, to develop, internasly or with their suppliers, improvements to compete with the Asian market. In addition, the presence of the Technology Centre in the environment is a basic support.	**Medium-High**. PN can be considered a new and important support in decision-making in R&D, especially in the case of safety footwear.	In this case it is proposed that PN are used to support the transition from classical to a production model based on the R&D through a gradual adjustment: NP are proposed as a tool for analysis and development of projects.
Snuff Sector	**Very high**. Imperial Tobacco is a multinational group that applies the most modern production techniques and R&D results both to productive and strategic management.	**Very high**. It has different areas of R&D and is continually developing new projects to adapt to legislation and consumer, or as a strategy of differentiation.	**High**. While there are solutions in the industry previously, Imperial Tobacco has both the capacity and interest enough to develop projects based on PN from modeling to optimization. Perhaps this is the most suitable plant for this in La Rioja.	In this case the contribution that can bring Petri nets is much lower than in other sectors less mature. That is why we must seek that PN add value in any area of special interest, highlighting the possible improvement in product distribution and logistics.
Furniture Sector	**Medium-Low**. In La Rioja some traditional companies coexist with companies applying more productive techniques. However, the most tipical profile is a cooperative or a family company with classic strategic-functional structure.	**Medium**. There exists very interesting R&D projects in course, but generally developed through collaboration with suppliers or on topics of little technological interest. It is facing an evolution in R&D to provide competitive advantage	**Medium**. There exist previous success cases and companies that have sensitivity towards innovation. However, it is necessary a strategic and productive evolution in the short to medium term to advance from only modeling to simulation and optimization.	The Rioja furniture companies need to vary its traditional production model to proprietary products, characterized by modularity, flexibility of production and innovation. All these values can be provided through PN models.

Table 1: Summary of analysis of PN applicability in the main industrial sectors of La Rioja

Gradišar, D.a b , Mušič, G.a   2007   Production-process modelling based on production-management data: A Petri-net approac, International Journal of Computer Integrated Manufacturing, Volume 20, Issue 8, December 2007, Pages 794-810

Han, K.-H.a , Yoo, S.-K.b , Kim, B.c 2009 Integration of UML and Petri Net for the process modeling and analysis in workflow applications Proceedings of the 13th WSEAS International Conference on Computers - Held as part of the 13th WSEAS CSCC Multiconference, 2009, Pages 255-262

Jeng, M.a , Xie, X.b , Chung, S.-L.c 2004 ERCN* Merged Nets for Modeling Degraded Behavior and Parallel Processes in Semiconductor Manufacturing Systems, IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans. Volume 34, Issue 1, January 2004, Pages 102-112

Kleyner, A.a , Volovoi, V.b   2010   Application of Petri nets to reliability prediction of occupant safety systems with partial detection and repair Reliability Engineering and System Safety Volume 95, Issue 6, June 2010, Pages 606-613

Li, X.-P.a c , Zhao, W.b c c , Liu, D.-X.a c c , Yuan, C.-Y.a , Zhang, S.-K.b c c , Wang, L.-F.b c c , 2010, A supply chain modeling technology based on RFID discovery service   , Tien Tzu Hsueh Pao/Acta Electronica Sinica Volume 38, Issue 2A, February 2010, Pages 107-116

Mendes, J.M.a , Restivo, F.a , Leitão, P.b , Colombo, A.W.c 2010 Petri net based engineering and software methodology for service-oriented

industrial automation IFIP Advances in Information and Communication Technology Volume 314, 2010, Pages 233-240

Miao, Z., Xu, K.-L.   2009   Research on control policy for lean production systems based on petri net, 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2009 Volume 2, 2009, Article number 5370440, Pages 557-560

Telmoudi, A.J.a , Nabli, L.b , M'hiri, R.c   2009   Modeling method of robust control laws for manufacturing system to temporal and non temporal constraints through Petri nets, International Review on Computers and Software, Volume 4, Issue 2, March 2009, Pages 266-277

Wang, H., Dong, T., Zhang, J., Wang, H.   2010   Simulation and optimization of the camshaft production line based on Petri net   Advanced Materials Research Volume 139-141, 2010, Pages 1506-1509

Wang, J. 2009   Automotive supply chain performance influencing path analysis based on fuzzy petri net , 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2009 Volume 1, 2009, Article number 5368162, Pages 359-362

X.Lu2010   Modeling of control system for LAMOST based on Petri net workflow, Proceedings of SPIE - The International Society for Optical Engineering, Volume 7738, 2010, Article number 77381I

Xiao, R., Chen, T.   2010   Research on design structure matrix and its applications in product development and innovation: An overview, International Journal of Computer Applications in Technology Volume 37, Issue 3-4, March 2010, Pages 218-229

Xu, Y., Zhang, M., Tang, S., 2010 Research on workflow model of cooperation between 4PLs and 3PLs based on Petri-net 3rd International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2010; Kunming; 26 November 2010 through 28 November 2010; Category number P4279; Code 83865

Yu, X.-L., Jiang, J., Xia, B.-Q., Pan, Z.-K.   2010   Petri-net-based analysis method for grid services composition model CICC-ITOE 2010 - 2010 International Conference on Innovative Computing and Communication, 2010 Asia-Pacific Conference on Information Technology and Ocean Engineering 2010, Article number 5439240, Pages 180-184

Zhan, Y.-D., Luo, Y.   2001 Modeling   and simulation research of material handling automatic system based on Petri Net   , Xitong Fangzhen Xuebao/Acta Simulata Systematica Sinica, Volume 13, Issue 4, 2001, Pages 501-504

Zhang, D., Zhang, P., Jiang, P., Tan, R.   2010   Contradictions determination method in product design using Petri net 5th IEEE International Conference on Management of Innovation and Technology, ICMIT2010; Singapore; 2 June 2010 through 5 June 2010; Category number CFP10795-ART; Code 81208

Zhao, N., Dong, S., Ding, W., Chen, L. 2010 The modularization of the tobacco distribution center simulation ICLEM 2010: Logistics for Sustained Economic Development - Infrastructure, Information, Integration - Proceedings of the 2010 International Conference of Logistics Engineering and Management Volume 387, 2010, Pages 2271-2277