FUNDAMENTAL STUDY ON MODIFICATION PROCESS OF DESIGN PLAN FOR COMPUTER-AIDED PRODUCT DESIGN CONSIDERING WAYS OF USAGE

E. Morinaga, H. Wakamatsu, Y. Goto and E. Arai

Graduate School of Engineering,
Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan.

Corresponding Author's Email: morinaga@mapse.eng.osaka-u.ac.jp

Article History: Received 10 December 2018; Revised 24 February 2019; Accepted 19 April 2019

ABSTRACT: Globalization in industry has increased the number of troubles caused by using products in unexpected ways. It is important to avoid such troubles in advance by performing product design considering various ways of usage. To achieve this, it is necessary to predict various ways of usage, to detect troubles which may occur by using the product in those ways and to modify the current design plan so that those troubles are avoided. A set of methods are developed based on Petri net modeling of design plan for computer support of the former two processes. The last process basically depends on creativity and knowledge of designers. However, if there are patterns of modification, it would be possible to help designers to modify design plans with computers by exploiting those patterns. This research aims at finding patterns of modification from cases of modification of design plan in actual design. Definition of pattern of modification was discussed and given as a combination of the reason, the objective and the way of modification. 200 patterns were then obtained by classification of each of the three items. It was found that many cases of modification in actual design fit 9 of the 200 patterns. It is possible that those 9 patterns can be exploited for computer support of modification process.

KEYWORDS: *Ways of Usage; Behavior; Function; Petri Net; Modification Pattern*

1.0 INTRODUCTION

Product design is construed as a creative operation of generating an entity in the real world for satisfying required functions defined in the conceptual world. Relationships between the required functions and the entity are not constant but dependent on how the entity undergoes an action in the real world such on how the product is used. If there is a gap between the designer and a user and a product is used by the user in a way which the designer did not expect, it is possible that anticipated functions are not satisfied or that undesirable events occur.

Gaps between the design side and the users' side have been a topic of discussion in various field of engineering. For example, a method for discovering such gaps base on vector-space modeling was proposed in the research field of web site design [1] and identification of correlations of design intent and user response on stylistic recognition was discussed in the field of automotive design [2]. In the research field of product design, safety and usability design considering the gaps has been discussed and a method and system for analyzing gaps was developed based on temporal interval theory [3-4]. In the sustainable design field, the user-centered approach [5-6] was adopted and importance of user behavior studies was shown [7].

As a result of recent globalization in industry, the same kind of products are used in various physical and cultural areas. This has increased the number of troubles caused by using products in unexpected ways. It is necessary to avoid such troubles in advance by performing product design considering various ways of usage, and is important to develop methodology for computer support of such product design. The authors have dealt with the issue of gaps between designers and users from this point of view. A method for detecting functional failures considering ways of usage was proposed, in which the function structure of the product, behavior of its entity and cause-and-effect relationships among physical phenomena caused by a way of usage are modeled as a tree and Petri net, respectively, and they are then integrated and analyzed by qualitative simulation on the integrated Petri net [8]. The method was enhanced so that functions satisfied by no behavior of the entity can be dealt with [9]. In addition, a method for supporting Petri net modeling of behavior was developed [10]. Furthermore, prediction of unexpected ways of usage has been discussed based on analysis of functions from the point of view of "6W2H"and a method for predicting various ways of usage was proposed, which takes advantage of related keywords tools [11].

In order to avoid troubles caused by unexpected ways of usage in the product design phase, it is necessary to modify a current design plan properly if a failure may occur when the product is used in an unexpected way predicted. This process fundamentally depends on designers' creativity, knowledge and experience. But, if there are some patterns of modification, it would be possible to assist a designer by computers by exploiting those patterns. From this point of view, this research aims at finding such patterns from actual cases of modification.

The remainder of this paper is organized as follows: Section 2.0 describes methodology for finding modification patterns. Types of the reason, the objective and the way of modification are analyzed respectively and then pattern of modification is defined as combinations of them. In Section 3.0, modifications of design plan performed in actual designs are analyzed based on the definition and modification patterns utilized in those designs are extracted. Section 4.0 remarks the conclusion.

2.0 METHODOLOGY

In this paper, patterning of modification is discussed from the viewpoint of combination of the reason, the objective and the way of modification. The reason of the modification is the cause of the trouble, that is, the way of usage. The objective of the modification is how much the trouble should be solved. The way of modification is how the Petri net model of the current design plan is changed. This section describes types of these three items and then provides a definition of pattern of modification as combinations of those types.

2.1 Types of Reason of Modification

Reason of performing a modification is the unexpected way of usage which may cause the trouble. Based on a research on prediction of unexpected ways of usage [11], unexpected ways of usage are classified into two groups. One is the group of those which arise from functions expected by the designer (Figure 1). A way of usage in this group is an action for exploiting an expected function for another object (Type 1-1), for another degree (Type 1-2) at another timing (Type 1-3) or in another environment (Type 1-4). For example, a user may use an electric kettle, which has a function "boil water" to boil milk or to boil much water than expected. There may be a user who uses the kettle before putting water in it and a user who uses it with putting it on direct fire. The other group is that of ways of usage which arise from unexpected functions via unexpected causal relationships among physical phenomena (Type 1-5) as shown in Figure 2. For example, a user may use an electric kettle with its lid open for increasing humidity in the room. Based on the discussion, it is possible to define five types as for reason of modification.

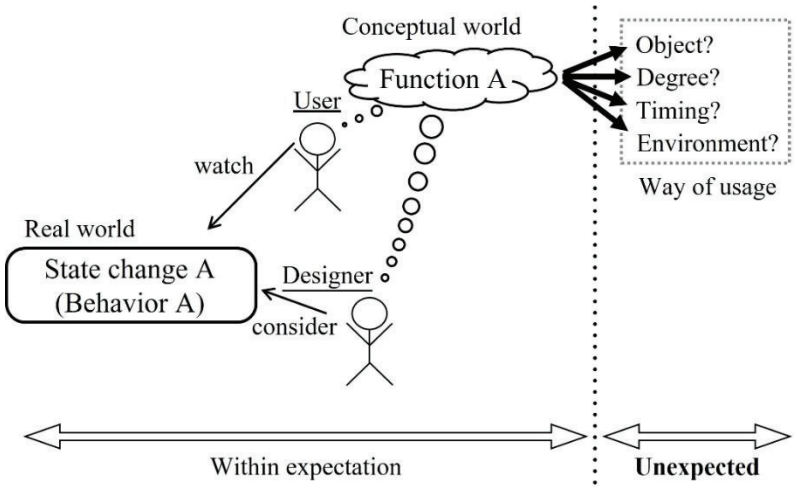


Figure 1: Unexpected way of usage which arises from expected functions [11]

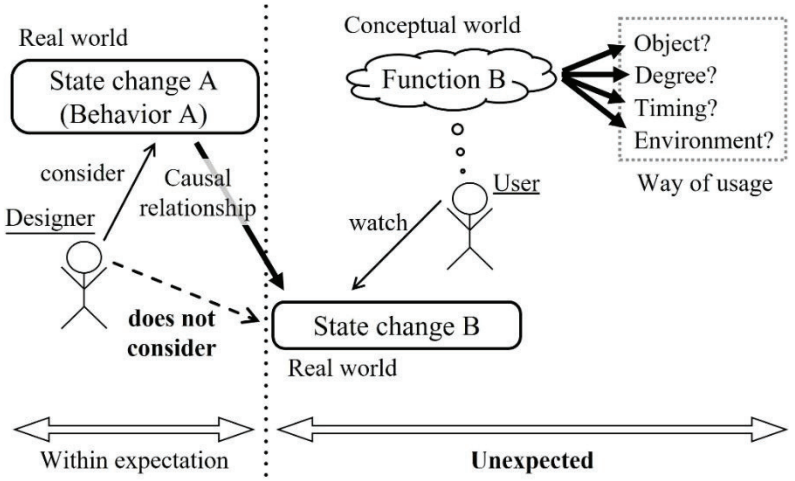


Figure 2: Unexpected way of usage which arises from unexpected functions via unexpected causal relationships among physical phenomena [11]

2.2 Types of Objective of Modification

Objective of a modification is to avoid the trouble which may be caused by the way of usage. In this research, from the qualitative point of view, the following three groups of troubles are taken into consideration: One is functional trouble in which a required function of the product is not satisfied. Another is accidental trouble in which the user or another person is injured. The other is mixed trouble in

which the product cannot satisfy its required function and a person is injured. It is ideal to modify a design plan so that the trouble is completely avoided. However, this generally requires a lot of effort and results in high cost, and therefore there are cases in which a design plan is modified so that no one is injured though a required function cannot be satisfied. The inverse type so that required function can be satisfied but a person is injured is not considered, since it would never be accepted from the viewpoint of corporate social responsibility. Based on these discussions, the following five types of objective of a modification can be defined:

i. Modification so that a functional trouble is completely avoided (Type 2-1).
ii. Modification so that an accidental trouble is completely avoided (Type 2-2).
iii. Modification so that a mixed trouble is completely avoided (Type 2-3).
iv. Modification so that an accidental trouble is avoided though a functional trouble occurs (Type 2-4).
v. Modification so that a mixed trouble is avoided though a functional trouble occurs (Type 2-5).

2.3 Types of Way of Modification

Way of modification is that of changing occurrence of an event (such as a behavior or a phenomenon) which concerns to fulfillment of a function. There are three ways of the changing: One is preventing occurrence of an event, another is forcing a prevented event to occur, and the other is preventing occurrence of an event at a specific state of the product. Because a trouble caused by a way of usage is detected by qualitative simulation performed on Petri net model of a design plan in the functional verification method [8], it is natural to discuss these ways of the changing based on Petri net modeling.

Petri net basically consists of four kinds of components: place, transition, arc and token [12-13]. As shown in Figure 3, a place is connected to a transition by an incoming and/or outgoing arc. If all places connected to a transition by an outgoing arc include a token, the transition can fire. When it fires, all the tokens move to places connected by incoming arcs, and the distribution of tokens, which is called “marking” changes. Assigning a state of a constituent element of an entity to a place makes it possible to represent that the element is in that state by the place with a token and to represent a state of the entity by a marking. Because a change of marking corresponds to a

behavior of the entity and this can be performed by matrix operations on a computer, Petri net has been applied to qualitative simulation and analysis of various systems [14-19].

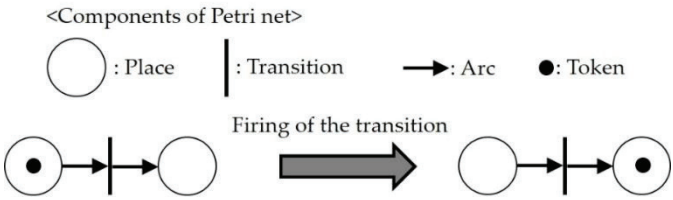


Figure 3: Components and basic structure of Petri net

The functional verification method for computer support of product design considering various ways of usage takes advantage of this feature of Petri net. Based on the Petri net modeling adopted in this method, an event is generally represented by a Petri net shown in Figure 4. In Figure 4, places P3 and P4 stand for states of a constituent element of the product or an entity in the real world and the information of those states are described by natural language. The token in P3 means that the element is in the state represented by this place. This token moves from P3 to P4 when transition T1 fires and therefore firing of T1 represents the event that the product or the entity changes its state from the state represented by P3 to that by P4. P6 represents a condition which should be satisfied for the event, and the token in P6 allows T1 to fire. P7 is connected to T1 with an inhibitor arc and a token in this place prohibits T1 to fire. Therefore, P7 stands for a contradiction condition for the event. P2, which appears same as P6, represents the area where the event occurs and the token in P2 represents that the product or the entity exists in that area. P1 and P5 are places for connecting this event to another one and therefore, these places control timing of the event.

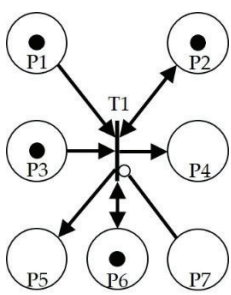


Figure 4: General representation of an event by Petri net

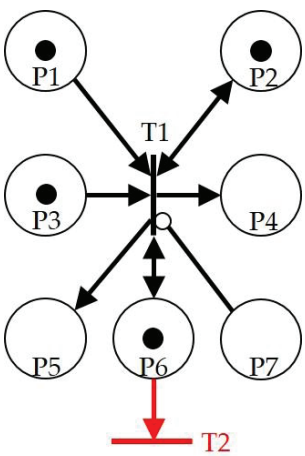
Based on this general Petri net representation of an event, the three ways of changing occurrence of an event are represented by eight kind of operations on Petri net as described as follows.

i. Ways of Preventing Occurrence of Event on Petri net Model

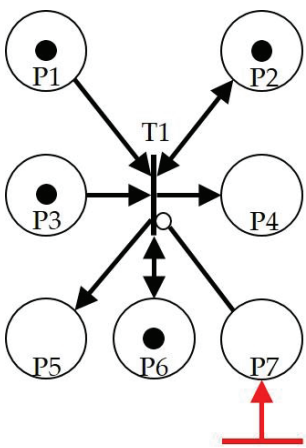
On the Petri net model of an event shown in Figure 4, preventing occurrence of the event is to prevent firing of the transition T1. There are four operations to achieve this prevention. One is to remove the token in P6 by adding a transition T2 as shown in Figure 5(a) and make the condition for occurrence of the event false (Type 3-1). Another one is to put a token in P7 by adding a transition T3 as shown in Figure 5(b) and make the contradiction condition for occurrence of the event true (Type 3-2). It is also possible to prevent firing of T1 by adding another condition P8 with no tokens (Type 3-3) as depicted in Figure 5(c) or by adding another contradiction condition P9 with a token (Type 3-4) shown in Figure 5(d).

ii. Ways of Forcing Event to Occur on Petri net Model

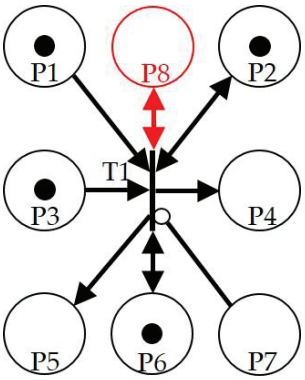
There are two ways of forcing an event on the Petri net model. The first way is to make the condition true by adding a token to P6 as shown in Figure 6(a) (Type 3-5). Another way is to make the contradiction condition false by removing the token in P7 as shown in Figure 6(b) (Type 3-6).



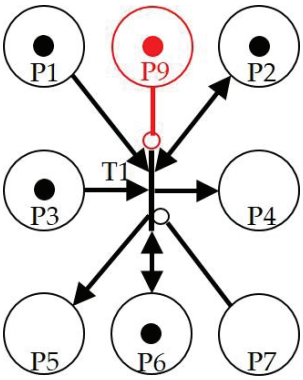
(a) Preventing the event by contradiction true condition



(b) Preventing the event by activating its contradiction condition



(c) Preventing the event by adding a new false condition

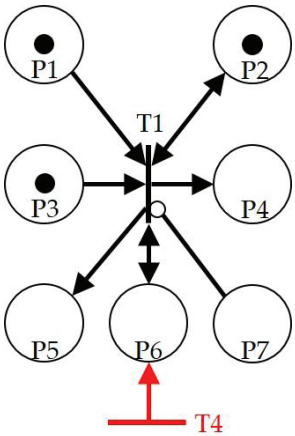


(d) Preventing the event by adding a new

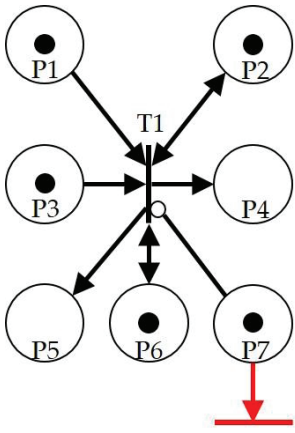
Figure 5: Operations on Petri net for preventing occurrence of the event

iii. Ways of Preventing Occurrence of Event at a Specific State on Petri net Model

An event the occurrence of which is prevented by the ways described in this section can never occur. But, there is an event which is necessary for satisfying a required function, though it may cause troubles when it occurs at a specific state. This kind of events should be prevented only at the state. There are two ways to achieve this prevention. They are to add a sequence of events which are caused by the specific state and the resultant state of which plays a role as a condition (Type 3-7) shown in Figure 7(a) or a contradiction condition (Type 3-8) in Figure 7(b) of the target event.

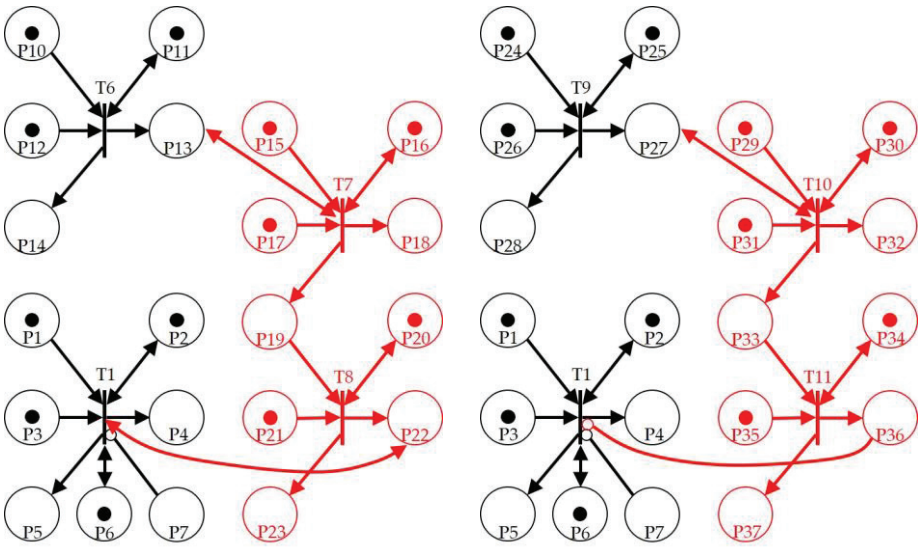


(a) Forcing the event to occur by making its condition true



(b) Forcing the event to occur by deactivating its contradiction condition

Figure 6: Operations on Petri net for forcing the event to occur



(a) Preventing the event by adding a sequence of events which are caused by the specific state and the resultant state of which is a condition of the target event

(b) Preventing the event by adding a sequence of events which are caused by the specific state and the resultant state of which is a contradiction condition of the target event

Figure 7: Operations on Petri net for preventing the event only at a specific state

2.4 Definition of Modification Patterns

Based on the above discussions, there are 5, 5 and 8 types about the reason, the objective and the way of modification, respectively. Therefore, it is possible to define 200 (5*5*8) patterns of modification of a design plan as combinations of those types.

3.0 RESULTS AND DISCUSSION

31 cases of modification in actual design [20] were analyzed from the point of view of the patterns defined in the previous section. They were grouped into 9 of the above 200 patterns as follows.

As a result of using an air conditioner, the filter becomes wet and gets mold on itself. This may make users sick, which is regarded as an accidental trouble. As a solution for this problem, the design plan was modified so that the filter was sterilized by being heated. In this case, the type of reason of modification is unexpected causal relationships

among physical phenomena and the type of objective is "ii". This modification is represented by the Petri net modeling method as shown in Figure 8 and Table 1. The type of the way of modification is preventing an event by adding a contradiction condition and a contradiction condition P9 has been added to the event that the filter gets mold. As described above, this case can be regarded as an example of the combination of Type 1-5 of the reason, Type 2-2 of the objective and Type 3-4 of the way of modification.

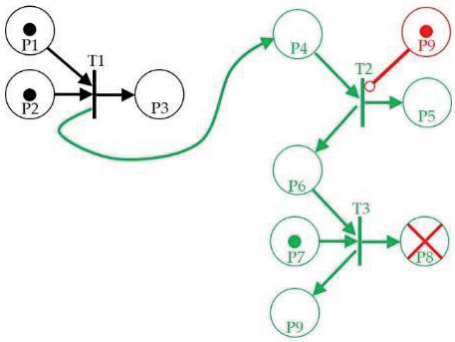


Figure 8: Petri net model of the modification of the design plan of air conditioner

Table 1: Definition of places

ID No.	State
P2	The air conditioner is not running.
P3	The air conditioner is running.
P5	The filter has gotten mold.
P7	The user is healthy.
P8	The user is sick.

Table 2 shows the result of grouping the 31 cases of modification into the 200 patterns. They were grouped into 9 patterns. It is expected that modification of the Petri net model of the current design plan based on the pattern may result in a natural modified design plan if the types of the reason and the objective meet one of these patterns, though the designer still needs to generate a detailed way of realizing the modified behavior or physical phenomena represented by the modified Petri net.

Table 2: The patterns of modification found from the cases of modification in actual design

Type No. of the reason	Type No. of the objective	Type No. of the way	Number of cases (31 cases)
1-1	2-5	3-8	6
1-1	2-4	3-6	4
1-5	2-4	3-8	2
1-2	2-4	3-8	4
1-3	2-4	3-7	7
1-1	2-3	3-4	2
1-1	2-2	3-4	1
1-1	2-2	3-1	2
1-5	2-2	3-4	3

4.0 CONCLUSION

In order to provide a methodology for computer support of product design considering various ways of usage in advance, this paper has dealt with the issue of computer support of the modification process of a design plan to avoid a trouble which may be caused by a way of usage. Although this process fundamentally depends on designers' creativity, knowledge and experience, if there are some patterns of modification, it would be possible to assist a designer by means of computers by exploiting those patterns. From this point of view, this research aims at finding patterns of modification from cases of modification of design plan in actual design. In this paper, pattern of modification was regarded as a combination of the reason, the objective and the way of modification and 200 candidates of the pattern were defined by detailed classification of those three items. By investigation of cases of modification in actual design, it was found that nine of those candidates have the potential to be exploited to obtain a reasonable modified design plan. The nine patterns found by this research can provide only a reasonable modified plan on the Petri net model of the original design plan. The designer still needs to generate a detailed way of realizing the modified plan represented as a modified Petri net. This issue will be discussed in a future work.

REFERENCES

[1] T. Nakayama, H. Kato and Y. Yamane, "Discovering the gap between Web site Designers' expectations and users' behavior", *Computer Networks*, vol. 33, no. 1-6, pp. 811-822, 2000.

[2] K. Hyun, J. Lee and M. Kim, "The gap between design intent and user response: identifying typical and novel car design elements among car brands for evaluating visual significance", *Journal of Intelligent Manufacturing*, vol. 28, no. 7, pp. 1729-1741, 2017.

[3] T. Murakami, T. Yasumi, N. Togo, K. Ueda and Y. Sano, "Safety and usability design method based on gaps between designer and user," in ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, New York, USA, 2014, pp. 1-9.

[4] T. Yasumi, N. Togo, T. Murakami, K. Ueda and Y. Sano, "Safety and usability design method based on gaps between designer and user", *The Transactions on Human Interface Society*, vol. 17, no. 4, pp. 411-419, 2015.

[5] M. Maguire, "Methods to support human-centered design", *International Journal of Human-Computer Studies*, vol. 55, no. 4, pp. 587-634, 2001.

[6] S. Evans, *Empathic Design Tutor*. Bedfordshire: Cranfield University Publisher, 2002.

[7] T. Tang and T.A. Bhamra, "Understanding consumer behaviour to reduce environmental impacts through sustainable product design," in Design Research Society Conference, Sheffield, UK, 2008, pp. 183/1-183/15.

[8] E. Morinaga, T. Akasaka, H. Wakamatsu, E. Arai and H. Abiru, "Framework for functional verification in product design considering ways and situations of use", *Transactions of the Institute of Systems, Control and Information Engineers*, vol. 28, no. 3, pp. 116-122, 2015.

[9] E. Morinaga, H. Wakamatsu, E. Arai and H. Abiru, "Behavior analysis method for product design support," in 2014 International Conference on Electronics Packaging, Toyama, Japan, 2014, pp. 736-739.

[10] E. Morinaga, H. Wakamatsu, H. Abiru and E. Arai, "Behavior modeling method for functional verification of product considering ways of usage", *Journal of Advanced Mechanical Design, Systems and Manufacturing*, vol. 11, no. 5, pp. 1-16, 2017.

[11] E. Morinaga, H. Wakamatsu, M. Mega and E. Arai, "Prediction of ways of usage of products for functional verification in product design", *Journal of Smart Processing*, vol. 7, no. 3, pp. 88-93, 2018.

[12] J.L. Peterson, *Petri Net Theory and the Modeling of Systems*. New Jersey: Prentice Hall, 1981.

[13] W. Reisig, *Petri Nets, An Introduction*. Berlin Heidelberg: Springer, 1985.

[14] W. Reisig, *Understanding Petri Nets: Modeling Techniques, Analysis Methods, Case Studies*. Berlin Heidelberg: Springer, 2013.

[15] J.-M. Proth and X. Xie, *Petri Nets: a Tool for Design and Management of Manufacturing Systems*. New Jersey: John Wiley & Sons, 1997.

[16] J.A. Cecil, K. Srihari and C.R. Emerson, "A review of petri-net applications in manufacturing", *The International Journal of Advanced Manufacturing Technology*, vol. 7, no. 3, pp. 168-177, 1992.

[17] J. Billington, M. Diaz and G. Rozenberg, *Application of Petri Nets to Communication Networks*. Berlin Heidelberg: Springer, 1999.

[18] C. Chaouiya, E. Remy and D. Thieffry, "Petri net modelling of biological regulatory networks", *Journal of Discrete Algorithms*, vol. 6, no. 2, pp. 165-177, 2008.

[19] V. Valero, M.E. Cambronero, G. Díaz and H. Macià, "A Petri net approach for the design and analysis of web services choreographies", *The Journal of Logic and Algebraic Programming*, vol. 78, no. 5, pp. 359-580, 2009.

[20] M. Nakao, *100 Selected Cases of Failures*. Tokyo: Morikita Publishing, 2005.