MODELLING HUMAN FACTOR WITH PETRI NETS

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The human contribution to risk and safety of nuclear power plant operation can be the best understood, assessed and quantified using tools to evaluate human reliability. Human reliability analysis becomes an important part of every probabilistic safety assessment and it is used to demonstrate that nuclear power plants designed with different safety levels are prepared to deal with severe accidents. Human reliability analysis in context of probabilistic safety assess consists in: identify human-system interactions important to safety; quantify probabilities appropriate with these interactions. Nowadays, the complex system functions can be modelled using special techniques centred either on states space adequate to system or on events appropriate to the system. Knowing that complex system model consists in evaluate of likelihood of success, in other words, in evaluate of possible value for that system being in some state, the inductive methods which are based on the system states can be applied also for human reliability modelling. Thus, switching to the system states taking into account the human interactions, the underlying basis of the Petri nets can be applied with success and it can also be derived the likelihoods appropriate for these states. The paper presents the modality to perform human reliability quantification using Petri nets approach. This is an efficient mode to assess reliability systems because of their specific features. The example processed in the paper is from human reliability documentation without a detailed human factor analysis (qualitative). We present human action modelling using event trees and Petri nets approach. The obtained results by these two kinds of methods are in good concordance.

Keywords: Human interactions, event trees, Petri nets, human reliability, state space.

1. Introduction

The human factor modelling in the probabilistic safety analysis framework can be performed using different methods and models [4]. The start point of these methods is the THERP method [5]. It was elaborated in 1983 and it established

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the underlying of the human reliability field both from conceptual and quantification point of view.

The human factor quantification by THERP has accomplished using event trees approach. This represents graphical and mathematical the human actions which must be performed by operator in the system. The human actions modelling by event trees are still the accepted approach in the human reliability framework. The new techniques for human reliability assessment focus, mainly, to the evaluation of human behaviour during the accident [4, 6, 7 and 8].

In 1962, it appears the concept of Petri net based on the oriented graph theory. This concept is used in modelling of the dynamic systems where the transfer operations are considered without taking into account time in explicitly manner.

The logical formalism of Petri nets grows up during the time; it has developed a particular language for that (tokens, marking, transition/place live or dead, P-invariants, T-invariants and so on) and a specific manner for mathematical representation. The analysis of system applying the concept of Petri nets is a modality of evaluation based on system states. In [9], has ascertained that Petri nets can also be applied in human factor modelling due to their flexibility.

In this paper, we have studied human reliability by two inductive approaches based on event trees and Petri nets. The paper consists in following topics. After a short review of the methods used, we have presented how can be applied these methods to human reliability modelling taking an example from [16]. The Petri net 2.1 and Petri nets simulator are software programs used in human factor modelling by Petri nets.

2. Methods and examples

Event trees for human reliability

The modelling of human reliability has performed by event trees specific for this kind of evaluation. In the event trees, the limbs represent binary process of decision: the task is performed correct or incorrect. For each branches, the sum of probabilities must be equal to 1 [5].

The limbs in the event trees show how can be performed activities taking into account the performance shaping factors. These factors are represented by assigned values for probability to perform tasks successfully or not. The probabilities in the event trees are conditional probabilities, except first branch. To first branch, we can also be assigned a conditional probability if that represents an outcome from another event tree.

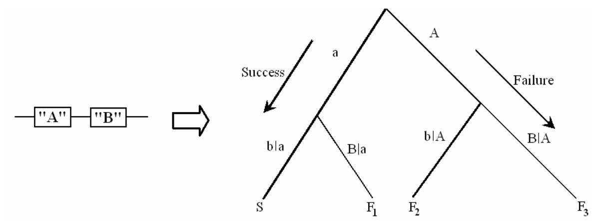


Figure 1 Event tree of human reliability analysis according with a series diagram, [5]

In Figure 1, we have an example: the operator/technician must perform two tasks, noted by "A" and "B". For example: the technician must perform a calibration of the transducer. For this activity, he must install the test equipment (task "A") and then he performs the calibration of transducer (task "B"). The operator will perform with success the prescribed tasks if he has performed correct both task "A" and task "B". The probability to perform correct task "A" and "B" is noted with a, respectively b, and probability to perform incorrect the task "A" and "B" is noted with A, B. Thus we have the following possibilities:

- b|a the probability to perform correct task "B", knowing that task "A" have performed successfully;
- B|a the probability to perform incorrect task "B", knowing that "A" have performed correctly;
- b|A the probability to perform correct task "B", knowing that task "A" have not performed correct;
- B|A the probability doesn't perform correctly both task “B” and task “A”.

For the example has previous presented, the notations used represent:

A - probability to install incorrect the test equipment and a - probability to do it correct

B - probability to perform an incorrect calibration and b - probability to perform a correct calibration.

The "S" and "F" represent the success, respectively failure ways. Any failure of system due to human action is obviously after the draw of event tree.

Since in human reliability analysis we have used conditional probabilities, the specific theory of Markov chains can be applied, the random variable named human error having a lognormal type density distribution [5].

Logical formalism type Petri nets

Petri nets have a very wide applicability because their generality and permissive features. Petri nets have applied with success in: performance evaluation, communication protocols, modelling and analysis of distributed-software systems, distributed-data base systems, concurrent and parallel programs, discrete-event systems, multiprocessor memory systems, data flow computing systems, human factors, neural networks, decisions models, [9].

The particular theory of Petri nets is presented in details in references [11-12-13]. In this paper, we have resumed only to the underlying notions required to understand the presented model.

Petri nets are graphical and mathematical modelling tool applicable to many systems. As a graphical tool, Petri nets can be used to view evolution of systems, similar to flow charts, block diagrams and networks. As a mathematical tool, it is possible to set up state equations and other mathematical models governing the behaviour of systems. A Petri net (N, M_0) is a particular kind of directed graph with an initial state called the initial marking M_0. The graph N of a Petri net is a directed, weight, bipartite graph consisting of two types of nodes called places and transitions, where arcs are either from a place to a transition or from a transition to a place. In graphical representation, places are drawn as circles, transitions as bar or boxes. Arcs are labelled with their weights (natural numbers). An arc with k-weight denotes a set of k parallel arcs. The marking of the nets assigns to each place a natural number. If a marking assigns to place p a number k, we say, *"p is marked with k tokens"*. The marking of nets is noted by M and it is a column vector with m x 1 dimension where m is total number of places.

In modelling, using the concept of conditions and events, places represent conditions and transitions represent events. The presence of a token in a place denotes that the establish condition for a place is true.

A stochastic Petri net (SPN) is a net where each transition is associated with an exponentially distributed random variable that addresses the delay from the enabling to firing of a transition. In a case of a net with several transitions simultaneously enabled, the transition with the shortest delay will fire first. Due to memory less property of the exponential distribution of firing delays, the reachability graph of a bounded SPN is isomorphic to a finite Markov chain, [13]. Thus, it is possible to compute steady state probability distribution and other performance parameters of system modelled. In this paper, we have resumed only to compute steady state probability.

The evaluation of system using Petri nets is accomplished following the steps [14]: - develop the model using a structural approach (either top-down or bottom-up procedure) depending on system modelled; - validate model using the results of structural analysis; - establish performance indices in terms of Petri net (places and transitions); - establish evolution of net to obtain corresponding Markov chain; - solving Markov process; - calculate performance indices.

All these steps are easy accomplished using specialised software programs to model system with Petri nets.

Example

Taking example from technical documentation about human reliability [16], we have modelled this applying specific feature of Petri nets. In modelling of systems with Petri nets concept we have used facilities of two software programs: for structural analysis of nets - *Petrinet 2.1* (developed by "Gh. Asachi" University using MatLab6.5 programmable mode) and for compute steady state probabilities - *Petri nets Simulator*.

The example refers to the event *Loss of high pressure injection system.* This event is an initiating event taking into account in the safety analysis for light water reactor and the human actions are post-initiating type. To model this type of actions, we have applied the procedure presented in [15].

In this event, the damage of the core would be occurred in 80 minutes if the injection of low pressure system does not actuated automate.

By the project of this NPP type, it has considered that the low pressure injection system would be also actuated manual. To do this, the operator must reach in the according area where the valve of the system is and he must open it.

The time necessary to operator to move in this area was estimated at 10 minutes, and the time required to open the valve was estimated at 5 minutes.

Considering these values, it results that in 65 minutes the operator must diagnose of the recovery action. We estimate a generic value of 0.00099 for the failure probability for the diagnosis phase of the recovery action. This value represents the median of the lognormal distribution. The uncertainty bounds for this estimation are: *LB = 0.00002* and *UB = 0.040*.

Knowing the following relation between the median and the mean value:

$$P(A) = P(A)_{mediana} \cdot e^{\frac{1}{2}\cdot\left(\frac{\ln UB}{1.645}\right)^2}$$

we have obtained *0.0026* which represent the diagnosis phase failure probability for the identified recovery action. The failure probability for the action phase we have derived from the next event tree:

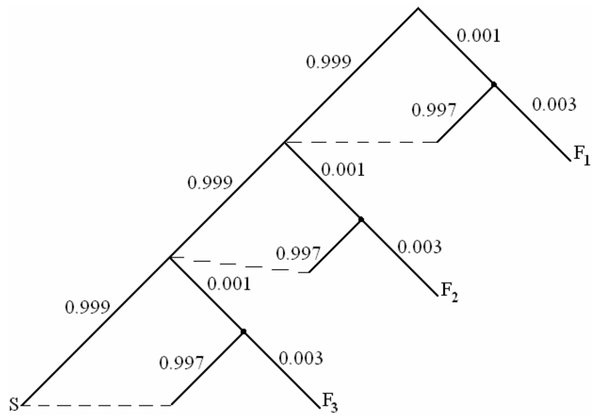


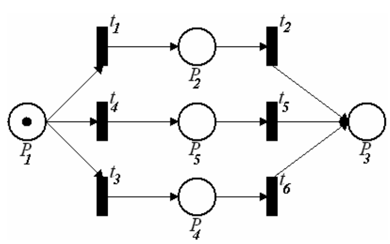
Figure 3 Event tree for human action for example

This event tree we have drawn using the following assumptions: - the operator would have directed someone to manually open the valve; - the operator will be monitoring a control room indicator (a flow meter) that will provide feedback to the operator as to the success of the second operator.

We have estimated the following values for probabilities: - error in message from the operator: *HEP = 0.001*; - operator fails to monitor feedback (recovery action): *HEP = 0.003*; - second man misunderstands message: *HEP = 0.001*; - operator fails to monitor feedback (recovery action): *HEP = 0.003*; - second man selects incorrect valve: *HEP = 0.001*; - operator fails to monitor feedback (recovery action): *HEP = 0.003*.

In this case, the probability of failing to accomplish the action phase is: $8.991.10^{-6}$, and the success is: *0.99988*. The total failure probability for the recovery action is equal with: *0.0026089*.

For this example, we have constructed the following Petri net:



It can see that the net is compacted and it has 5 places. The P_1 place is according to that state in which the low injection system is actuated and the P_3 place corresponding to the opposite state. The P_2, P_5, P_4 places are intermediate states. The net is marked with one token in the P_1 place.

The structural analysis of the net has conducted us to the following: - the net is the machine-state; - the net is not live; - the net is conservative; the net has not T-invariants; - the net is not repetitive.

The incidence matrix for this net is:

$$[C]_{5x6} = \begin{bmatrix} -1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & -1 & 0 \end{bmatrix}$$

The initial marking of net, $M_0 = [1 \quad 0 \quad 0 \quad 0 \quad 0]$, is modified by firing the transitions. This feature of net is presented by the Token Game facility of the program used:

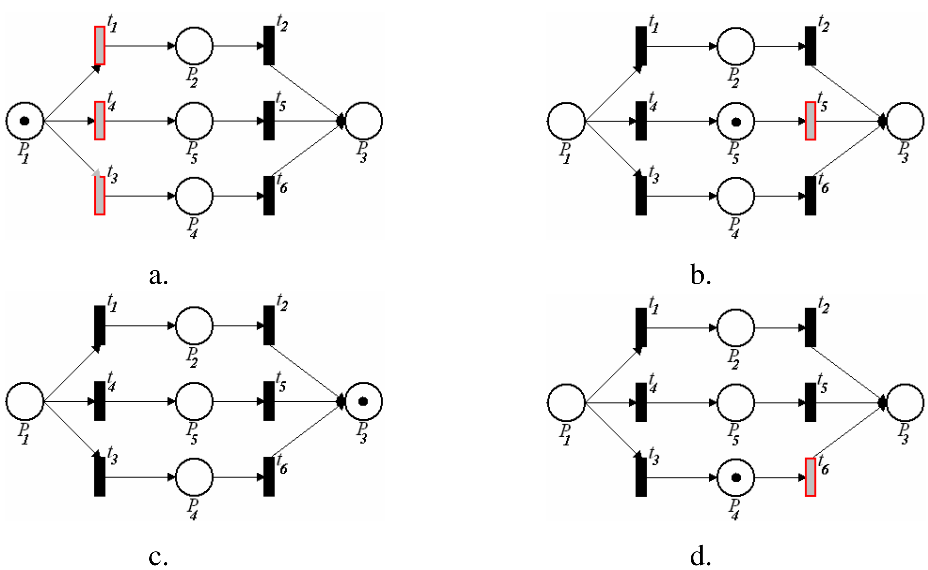


Figure 4 Token Game facility for Petri net constructed

In the previous pictures we have presented the following:

a. The t_1, t_4, t_3 transitions are enabling because the one token is in the P_1 place

b. The t_4 transition is firing. The token from the P_1 place have moved in P_5 place. This place corresponds to the situation in which the second man misunderstands the message. Thus, the t_5 transition becomes enabling.

c. The t_5 transition was firing. The token have moved in P_3.

d. Starting from the a. picture, the t_3 transition was firing. The token have moved in P_4 place which corresponds to situation: second man selects incorrect valve. The t_6 transition becomes enabling and firing transition have conducted to the failure state.

The probabilities of the specific states are: - probability to accomplish the action: *Probability{#P1} = 0.9970;* - probability of failing: *Probability{#P3} = 8.991.10*$^{-6}$*;* - probabilities for intermediate states are: *Probability{#P2} = 9.97.10*$^{-4}$, *Probability{#P4} = 9.96.10*$^{-4}$, *Probability{#P5} = 9.95.10*$^{-4}$.

It can see that the results obtained by this approach are the same with those obtained by event tree.

3. Conclusions

In this paper we have presented how can be applied logical formalism type Petri nets in modelling of the human factor taking examples from technical documentation. The outcomes with this method are identically with the result obtained by event trees approach. It is the first step in applying Petri nets formalism in human factor modelling. To model human factor with Petri nets implies to define the system states and to use a specialized software program. The inductive method described here can be applied to accomplish a preliminary calculus for human factor that can be detailed further using the acknowledged method. This work can be continued in future by development a specialised software using Petri nets concept.

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