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HUMAN FACTOR MODELING USING MARKOV METHOD

BY

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Abstract. The model notion can be found in many domains, even though its origin is technological. For the human factor modelling, the Markov chains with continuous parameter might be used, considering the time as continuous variable and the space as discrete variable. The Markov method of the human factor operation is modelled starting from the Rasmussen data processing mode. The paper presents a particular approach of the human factor modelling taking into account that their operation states are represented by system nodes. The branches between systems nodes are double oriented and represent the repair and failure rate of the elements. By this failure or repair rate the transition is done between system nodes. Finally, as a reliability indicator, the probability of the human factor in a successful action was determined.

Key words: human factor; Markov chain; reliability.

1. Introduction

The elaboration of a complete human factor models it’s a very present desideratum; taking into account the complexity of a human being and its way of thinking, the accomplishment of this complex model will be also a challenge for the future. According to Fig. 1, the structure of a general model of data processing should contain the following main components (Rotariu *et al*., 2002): peripheral working memory (PWM); central working memory (CM); knowledge base (KB); buffer memory (BM), as an element of the knowledge data base.

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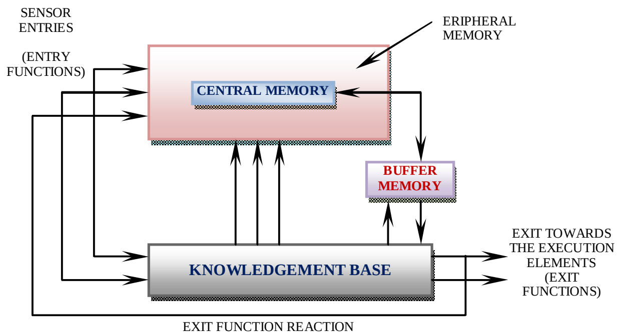

Fig. 1 – Block scheme of data processing model.

The entry functions include a table of specialized captors, through which excitation state is transmitted to the peripheral memory. The exit functions are composed by action elements which transform the stored instruction into motive activities and orientate the perception with impact on the exit of the knowledge base. There are some reaction loops between the entry and exit functions. Regarding the human factor modelling, the recent literature indicates different approaches, such as: a fuzzy Bayesian network method (Li *et al.*, 2012), the performance influencing factors (PIFs) or performance shaping factors (PSFs) methods (Groth *et al.*, 2012), artificial neural networks (Subhashini *et al.*, 2011), and particle swarm optimization method (Liu *et al.*, 2014). In this context, the paper presents a particular approach regarding the human factor modelling using the Markov chains.

2. Human Factor Decision Based on Data Processing Model

Most of the data processing model is composed by texts that follow the diagram (the most important model component), becoming more knows than the model itself. The most common models are Leplat, Fig. 2 (Leplat, 1997), double Ladder Rasmussen (Rasmussen, 1986), and three level behaviour (Iosif, 1996; Rotariu *et al.*, 2002).

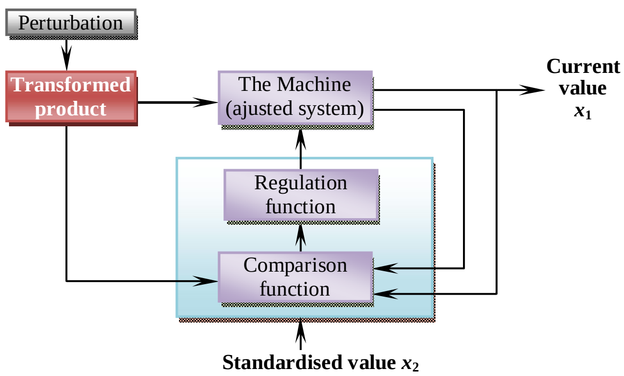

Fig. 2 – Leplat model of human operator.

2.1. Leplat Model

According to Fig. 2, the author insists on two functions of the human factor (operator): comparison and regulation functions. The operator compares the current value of x_1 and the standardized value x_2 (comparison function) and then transforms the resulting information into an action supposed to regulate the system to reach the standardized value (regulation function).

2.2. The Rasmussen Double Ladder Model

The double ladder Rasmussen scheme, shown in Fig. 3, is formed of a reasoning sequence of the human operator. The goal is to bring back the system to its state of functioning before an accident or incident.

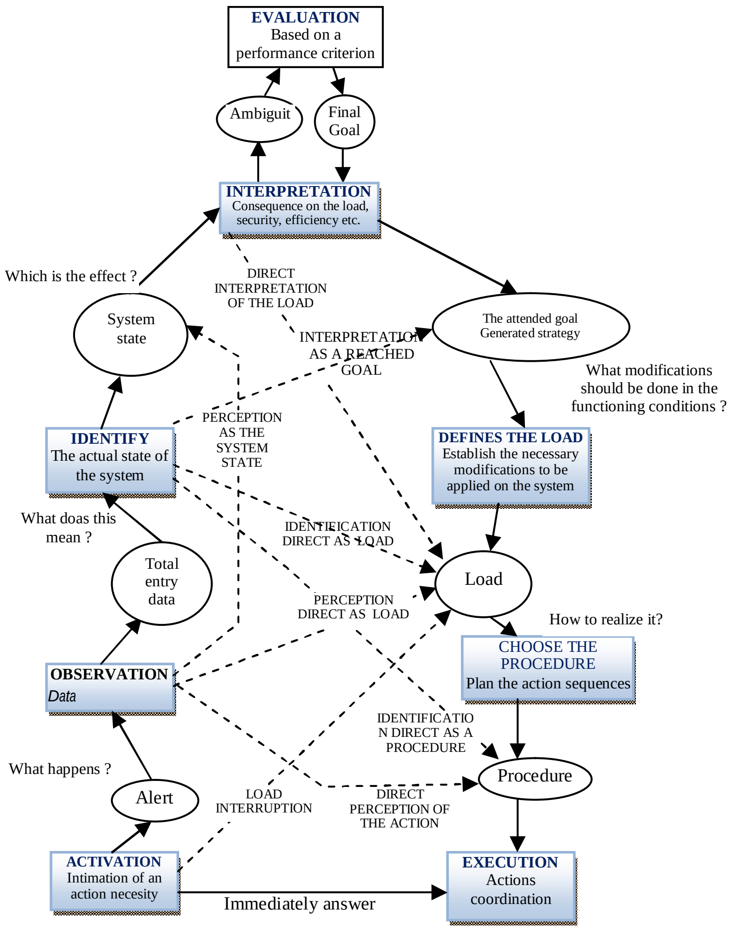

Fig. 3 – Double ladder Rasmussen model.

2.3. The Three Level Behaviour Model

Another known model realised in the same manner (boxes and arrows), is "*the three levels of human behaviour*", as shown in Fig. 4.

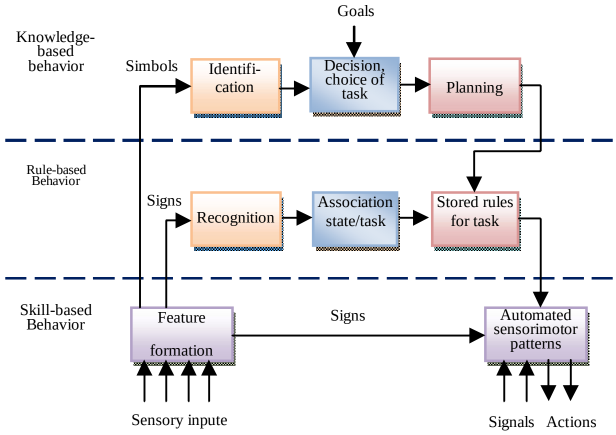

Fig. 4 – Three levels human behaviour diagram.

First level – knowledge-based behaviour – takes into account the skills achieved by experience and training. The second level – rule-based behaviour – considers the rules and the procedures as known by the human operator and applicable in known situations, that the operator has already deal with. The third level – skill-based behaviour – considers the operator acknowledgements. Those acknowledgements allow the operator to find new solutions for situations that she/he never deal with before. The three levels human behaviour diagram is considered less applicable in practice, especially due to its simplicity.

3. Human Reliability Modelling using Markov Chains

To analyse human reliability, the Markov chain with a continuous parameter is used.

3.1. The Three Level Behaviour Model

The general model that uses the Markov chains (Rotariu *et al.*, 2002) assumes that the time space is continuous and the state space is discrete. The model reflects the system dynamics and its trajectory in the state space. The model is governed by two categories of probabilities:

a) $p_i(t)$ represent the vector of absolute state probability, being equal with the system state range. The absolute probabilities are the measure of the event of the system to be found in state i at moment tt.

b) $p_{ij}(t, t + \mathrm{d}t)$ matrix of transition probabilities between two pair states, matrix of the same rank as the vector.

The probabilities of transition represent the measure of the event that the system, in *i* state at moment *t* passes to a *j* state at moment t + dt. The input data for this model are the failure λ_i and repair μ_i rates of the elements. Using these rates, the absolute probabilities of the system states can be calculated. From these absolute probabilities results the reliability indicators. To calculate the absolute probabilities, the next model, known as the Kolmogorov equations, is used:

$$P_j(t+\mathrm{d}t) = P_j(t)P_{jj}(t,t+\mathrm{d}t) + \sum_{i \neq j} P_{ji}(t,t+\mathrm{d}t). \tag{1}$$

From the definition of the transition rate results:

$$P_{ji}(t,t+\mathrm{d}t) = \lambda_{ij}(t)\mathrm{d}t. \tag{2}$$

The equation can also be written as the following system:

$$\left|p_i^{'}(t)\right| = \left|q_{ij}\right| \cdot \left|p_i(t)\right|. \tag{3}$$

The differential equation system (3) can be solved by knowing the limit conditions. As a consequence, it is necessary to introduce the p_i (0) initial state vector. All its terms are 0 except the term corresponding to the initial state which is 1.

To avoid the ordinary unique solution, the following condition is added: $\sum p_i = 1$ (the system states form a complete set of events) which replaces one of the system equations. The system once solved, the $\left|p_i\right|$ vector contains the constant probabilities of the system states. This vector can be used to obtain the other indicators.

3.2. The Markov Model of Human Factor Operating

The elaboration of a Markov model of the human operator functioning starts from the Rasmussen model of data processing. Using the equations presented above, the states graph is built, as shown in Fig. 5. In this graph are marked the 9 states used by the human operator to process the information. This state characterizes its way of functioning, a multitude of transitions being possible. The combinations of states and transitions between the states ran through in the sequence of data processing define the knowledge level of the operator, including him in one of the three categories of comportment, as they were defined in §**3.1.** When dealing with a great number of activities, shortcuts could be entered in the general model, the operator running just some of the states and transitions previously presented.

The same thing can be done at different levels, according to the operator experience and its skills. Taking into account what was mentioned above, we can have beginner, quite experienced and experienced operator.

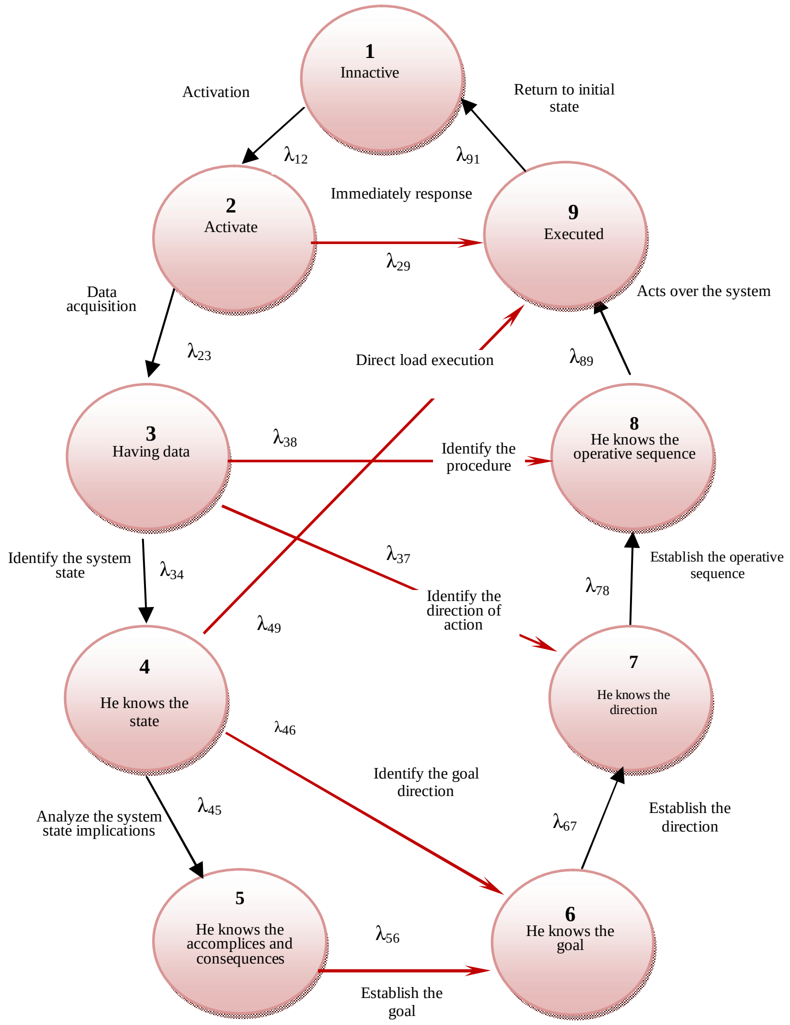

Fig. 5 – Human operator states graph.

a. *The beginner operator* will use its previous knowledge or will eventually read a diagram to know which key or button must switch; this is the case of the operator that acts based on its knowledge. The following sequence of states corresponds to this type (Fig. 6):

$$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7 \rightarrow 8 \rightarrow 9 \rightarrow 1.$$

The same way of acting might be seen at the experimented operator but in case he affronts a special situation, he has never dealt with before. Solving this situation is possible only using the knowledge achieved and after a complete analysis of the situation.

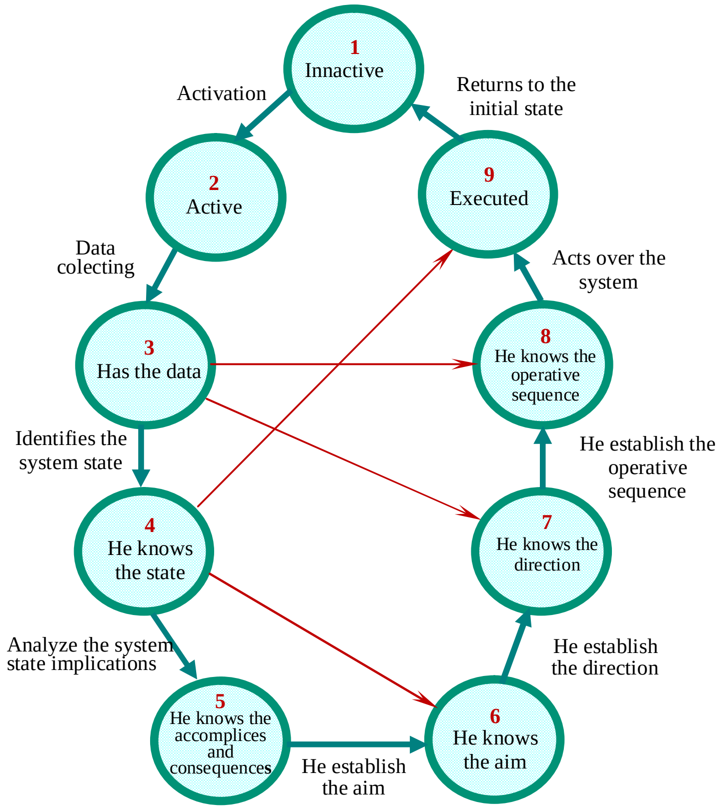

Fig. 6 – States graph for a beginner operator.

b. *The quite experienced operator* has a certain experience in the installation or in the command room. He won't use the diagram anymore; he only needs simple reasoning and eventually will apply the rules already known to face a situation. This is the case of the operator that acts based on rules. To this type of operator might correspond a multitude of states sequences, the number of states depending on its knowledge of the installations, on its preparing level, as well as on the type and complexity of the incident. A possible state sequence is presented in Fig. 7, respectively the following sequence:

$$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 9 \rightarrow 1$$

c. *The experienced operator* has a lot of experience in the same unit. He is capable to immediately identify what button must be switched. In some case he acts based on its experience, being unable to explain why he acts in one way or the other. This is the case of *the operator that acts based on automatism*. The sequence of states that corresponds to this case is the following one (Fig. 8):

$$1 \rightarrow 2 \rightarrow 9 \rightarrow 1$$

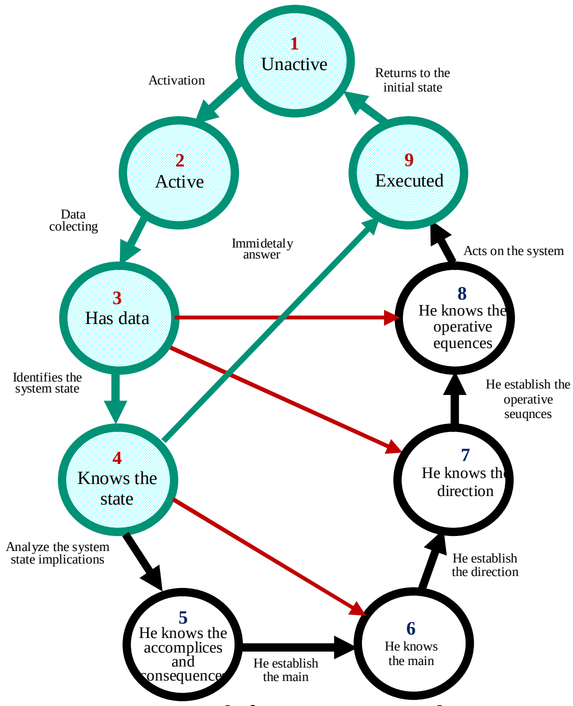

Fig. 7 – States graph for an experienced operator.

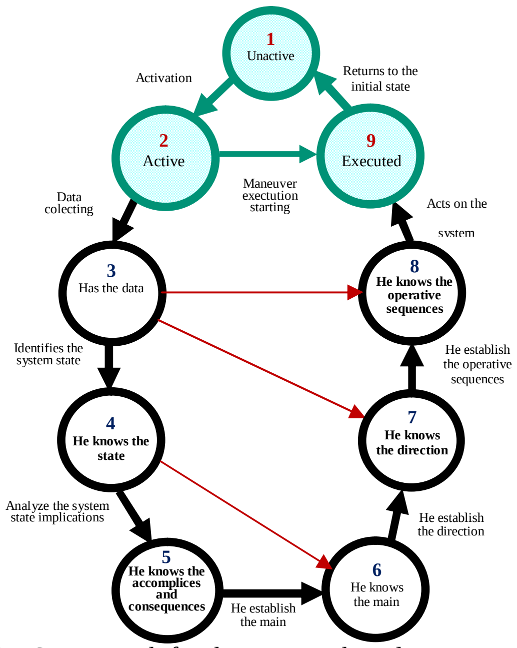

Fig. 8 – States graph for the operator based on automatism.

4. The Probabilistic Analysis of the Human Operator

It is important to determine the level of experience of the operator in order to analyse its errors. As a reliability indicator of the human operator it is of interest to determine the probability of the human operator to be at the moment t in the final state 9. Solving the equation number 3 allows us to represent the probabilities $p_i = f(t)$.

It is obvious that, while running the sequence 1-9 in the states graph, the operator can stop at one intermediate state, if he doesn't have enough experience to get to the final state equivalent to solving the incident or the malfunction that occurs in the installation. Further, it is presented the calculation resulted from the relation 3 for each of the three graphs.

a. *The graph of the beginner operator* (Fig. 6). To calculate the states probabilities, the following system is needed:

$$\begin{bmatrix} -\lambda_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda_{12} & -\lambda_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda_{23} & -\lambda_{34} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda_{34} & -\lambda_{45} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda_{45} & -\lambda_{56} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \lambda_{56} & -\lambda_{67} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \lambda_{67} & -\lambda_{78} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{78} & -\lambda_{89} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{89} & -\lambda_{91} \end{bmatrix} \cdot \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \\ p_6(t) \\ p_7(t) \\ p_8(t) \\ p_9(t) \end{bmatrix} = \begin{bmatrix} p_1' \\ p_2' \\ p_3' \\ p_4' \\ p_5' \\ p_6' \\ p_7' \\ p_8' \\ p_9' \end{bmatrix}. \quad (4)$$

Taking into account that the transition times T_{ij} between the states have the following values (in seconds): $T_{12} = 5$ s, $T_{23} = 20$ s, $T_{34} = 10$ s, $T_{45} = 60$ s, $T_{56} = 20$ s, $T_{67} = 10$ s, $T_{78} = 30$ s, $T_{89} = 20$ s, $T_{91} = 1{,}000$ s, the failure rates (λ_{ij}) will be calculated taking into account the transition $\lambda_{ij} = 1/T_{ij}$, as follows:

$$\begin{bmatrix} -0.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.2 & -0.05 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.05 & -0.1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & -0.016 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.016 & -0.05 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.05 & -0.1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1 & -0.033 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.033 & -0.05 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.05 & -0.001 \end{bmatrix} \cdot \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \\ p_6(t) \\ p_7(t) \\ p_8(t) \\ p_9(t) \end{bmatrix} = \begin{bmatrix} p_1'(t) \\ p_2'(t) \\ p_3'(t) \\ p_4'(t) \\ p_5'(t) \\ p_6'(t) \\ p_7'(t) \\ p_8'(t) \\ p_9'(t) \end{bmatrix}. \quad (5)$$

The initial condition vector $p_i(0)$ will have the first value different from zero, $p_1(0) = 1$. In these conditions, the matrices system (5) can be solved. We applied the Euler method that approximates the solution of the differential equations. The results of the probabilities calculation are shown in Table 1. Also, the variations diagrams are represented in Fig. 9.

Table 1
The 9 States Probabilities.

T,[sec]	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9
0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.018	0.232	0.153	0.117	0.013	0.035	0.019	0.002	0.410
40	0.000	0.037	0.056	0.092	0.028	0.063	0.091	0.026	0.604
60	0.000	0.005	0.013	0.033	0.021	0.041	0.124	0.057	0.701
80	0.000	0.001	0.002	0.008	0.011	0.017	0.101	0.069	0.787
100	0.000	0.000	0.000	0.002	0.005	0.007	0.069	0.060	0.853
120	0.000	0.000	0.000	0.000	0.002	0.002	0.040	0.043	0.907
140	0.000	0.000	0.000	0.000	0.001	0.001	0.024	0.030	0.939
180	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.010	0.979
200	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.006	0.985

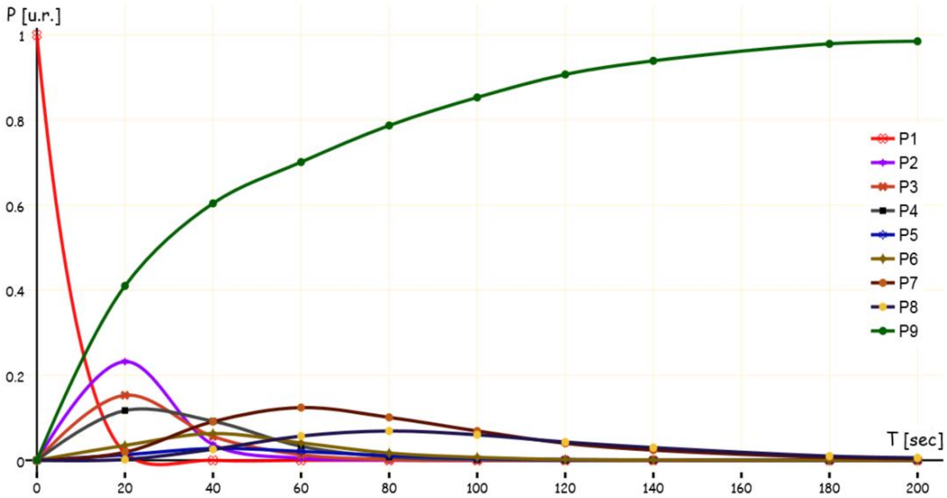

Fig. 9 – The success probabilities graphic variation for the beginner operator.

Analyzing the graph in Fig. 9, $p_1(t)$ decreases fast towards 0 so the activation of the operator is done very fast, while $p_9(t)$ increases to 1 in a longer time range (for this example about 500 s), the operator being forced to run all the phases of the model until he takes an action in order to solve the problem.

b. *The graph of the quite experienced operator* (Fig. 7). Taking into account the transition $\lambda_{ij} = 1/T_{ij}$ and the transition time values: $T_{12} = 5$ s, $T_{23} =$ $= 20$ s, $T_{34} = 10$ s, $T_{49} = 20$ s, $T_{91} = 1{,}000$ s, the system becomes:

$$\begin{bmatrix} -0.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.2 & -0.05 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.05 & -0.1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & -0.033 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.033 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.001 \end{bmatrix} \cdot \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \\ p_6(t) \\ p_7(t) \\ p_8(t) \\ p_9(t) \end{bmatrix} = \begin{bmatrix} p_1^{'}(t) \\ p_2^{'}(t) \\ p_3^{'}(t) \\ p_4^{'}(t) \\ p_5^{'}(t) \\ p_6^{'}(t) \\ p_7^{'}(t) \\ p_8^{'}(t) \\ p_9^{'}(t) \end{bmatrix}. \qquad (6)$$

The probabilities $p_1(t)$ ... $p_5(t)$ results are presented in Table 2 and Fig. 10. In this case $p_1(t)$ decreases fast towards 0 after the operator was activated, while $p_5(t)$ increases to 1 in a longer time range (for this example about 200 s), the operator being forced to run 5 phases of the model until he takes an action in order to solve the failing.

Table 2

The 5 States Probabilities

T, [s]	p_1	p_2	p_3	p_4	p_5
0	1.000	0.000	0.000	0.000	0.000
20	0.015	0.449	0.232	0.242	0.062
40	0.001	0.182	0.145	0.398	0.274
60	0.002	0.071	0.063	0.344	0.519
80	0.003	0.032	0.026	0.229	0.710
100	0.004	0.021	0.014	0.145	0.816
120	0.004	0.019	0.010	0.097	0.869
140	0.005	0.018	0.009	0.060	0.908
160	0.005	0.018	0.009	0.045	0.923
180	0.005	0.018	0.009	0.037	0.931
200	0.005	0.019	0.009	0.033	0.935

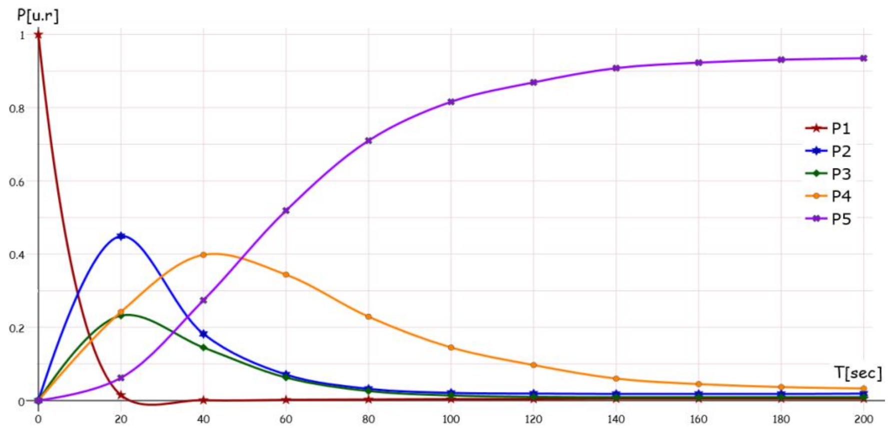

Fig. 10 – The success probabilities graphic variation for the quite experienced operator.

c. *The graph of the experienced operator* (Fig. 8). Taking into account that the transition times between the states have the following values: T_{12} =5 s, T_{29} = 20 s, T_{91} = 1,000 s, the system becomes:

$$\begin{bmatrix} -0.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.001 \\ 0.2 & -0.05 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.05 & 0 & 0 & 0 & 0 & 0 & 0 & -0.001 \end{bmatrix} \cdot \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \\ p_6(t) \\ p_7(t) \\ p_8(t) \\ p_9(t) \end{bmatrix} = \begin{bmatrix} p_1^{'}(t) \\ p_2^{'}(t) \\ p_3^{'}(t) \\ p_4^{'}(t) \\ p_5^{'}(t) \\ p_6^{'}(t) \\ p_7^{'}(t) \\ p_8^{'}(t) \\ p_9^{'}(t) \end{bmatrix}. \quad (7)$$

The probabilities results are shown in Table 3 and the variations diagrams for the probabilities $p_1(t)$, $p_2(t)$ and $p_3(t) = p_9(t)$ are shown in Fig. 11.

Table 3
The 3 States Probabilities

T, [s]	p_1	p_2	p_9
0	1.000	0.000	0.000
20	0.020	0.468	0.512
40	0.004	0.187	0.809
60	0.004	0.081	0.915
80	0.005	0.041	0.954
100	0.005	0.027	0.968
118	0.005	0.023	0.973
143	0.005	0.020	0.975
161	0.005	0.020	0.975
179	0.005	0.020	0.975
200	0.005	0.020	0.976

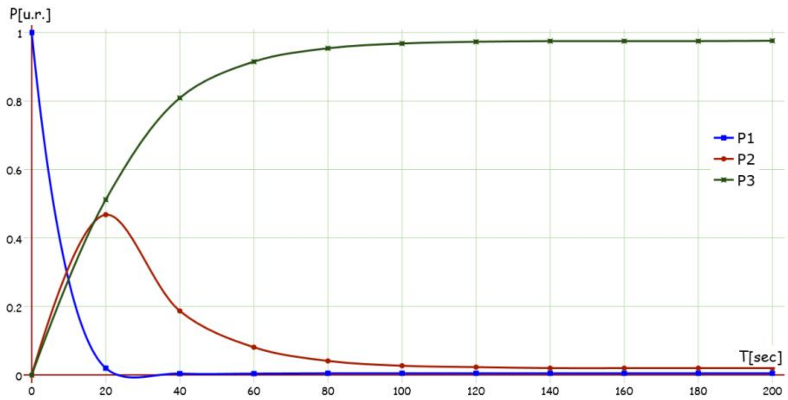

Fig. 11 – The success probabilities graphic variation for the experienced operator.

The $p_1(t)$ decreases fast towards 0 after the operator was activated, while $p_9(t)$ increases to 1 in a shorter time necessary for action. Also, the graph could have some shortcuts (in ex. 3 shortcuts – see Fig. 12).

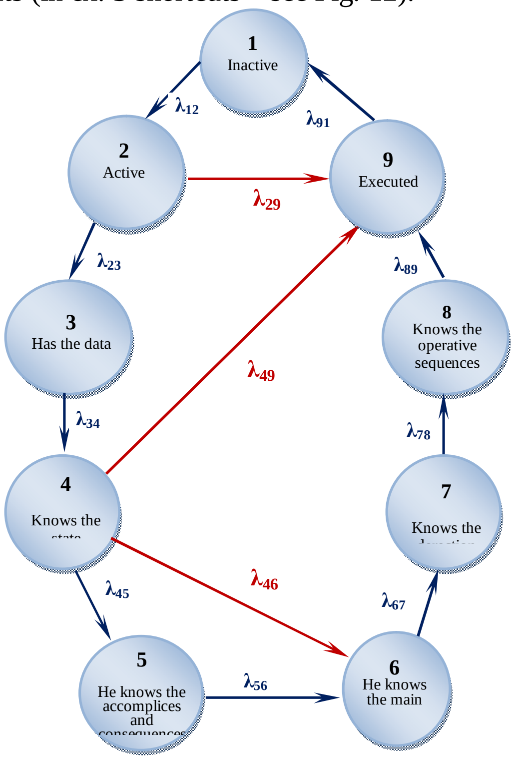

Fig. 12 – State graph for 3 shortcuts.

To calculate the states probabilities, we must take into account the transition time between the states: T_{12} = 5 s, T_{23} = 20 s, T_{34} = 10 s, T_{45} = 60 s, T_{56} = 20 s, T_{67} = 10 s, T_{78} = 30 s, T_{89} = 20s, T_{91} = 1,000 s, T_{29} = 20 s, T_{46} = 20 s, T_{49} = 30 s.

$$\begin{bmatrix} -0.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2 \\ 0.2 & -0.1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.05 & -0.1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & -0.01 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.016 & -0.05 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.05 & 0.05 & -0.1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1 & -0.033 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.033 & -0.05 & 0 \\ 0 & 0.05 & 0 & 0.033 & 0 & 0 & 0 & 0.05 & -0.2 \end{bmatrix} \cdot \begin{bmatrix} p_1(t) \\ p_2(t) \\ p_3(t) \\ p_4(t) \\ p_5(t) \\ p_6(t) \\ p_7(t) \\ p_8(t) \\ p_9(t) \end{bmatrix} = \begin{bmatrix} p_1'(t) \\ p_2'(t) \\ p_3'(t) \\ p_4'(t) \\ p_5'(t) \\ p_6'(t) \\ p_7'(t) \\ p_8'(t) \\ p_9'(t) \end{bmatrix}. \quad (8)$$

The results are shown in Table 4 and the variations diagrams are represented in Fig. 13.

Table 4
The Probabilities for the Complete Graph

T, [s]	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9
0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.018	0.232	0.153	0.117	0.013	0.035	0.019	0.002	0.410
40	0.000	0.037	0.056	0.092	0.028	0.063	0.091	0.026	0.604
60	0.000	0.005	0.013	0.033	0.021	0.041	0.124	0.057	0.701
81	0.000	0.001	0.002	0.008	0.011	0.017	0.101	0.069	0.787
100	0.000	0.000	0.000	0.002	0.005	0.007	0.069	0.060	0.853
121	0.000	0.000	0.000	0.000	0.002	0.002	0.040	0.043	0.907
139	0.000	0.000	0.000	0.000	0.001	0.001	0.024	0.030	0.939
182	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.010	0.979
200	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.006	0.985

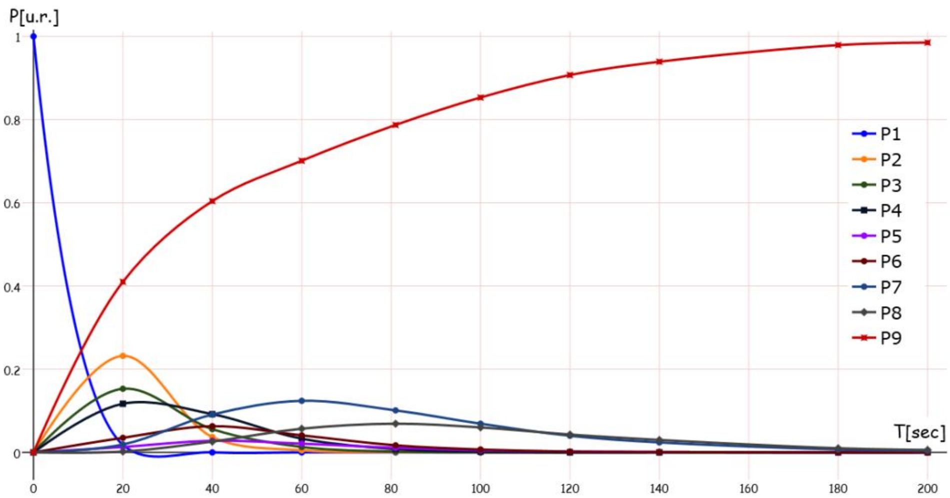

Fig. 13 – The probabilities graphic for 3 shortcuts.

5. Conclusions

The probabilities calculated can be used to model the human operator behaviour in technical systems which can be entered in the system as an element with known probability. Now the problem is to increase the success probability of this element – using different methods like its periodical instruction and testing using different models of simulators.

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MODELAREA FACTORULUI UMAN UTILIZÂND METODA MARKOV

(Rezumat)

Noţiunea de modelare se regăseşte în multe domenii, chiar dacă originea sa este tehnologică. Pentru a modela factorul uman, pot fi utilizate lanţuri Markov cu parametri continui, considerând timpul ca variabilă continuă şi spaţiul ca variabilă discretă. Metoda Markov privind funcţionarea factorului uman este modelată pornind de la modul de procesare a datelor Rasmussen. Ţinând seama că stările de funcţionare a operatorului uman sunt reprezentate prin noduri, în lucrare este prezentată o abordare particulară de modelare a acestuia, ţinând seama că legăturile dintre noduri sunt dublu orientate, caracterizate de rata de succes şi cea de defect. Trebuie remarcat faptul că rata de succes sau de defect face ca tranziţia să se realizeze între două noduri ale sistemului. In final, se exemplifică modul de determinare a probabilităţii în care factorul uman se află într-o stare de succes.