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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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Road and Rail Infrastructure V

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ERGONOMIC MODEL OF ACTION'S DETERMINANTS AND APPLICATION IN SECURITY SYSTEM (DYNAMIC INTUITIONISTIC FUZZY MULTI-ATTRIBUTE DECISION MAKING METHOD)

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Abstract

Security system management has been very interested in human cognition in order to control risks and enhance security rate in high level risk firms. "Situation awareness" (SA) models have been widely explored to explain and predict, generally according to qualitative methods, individual's decision making in complex environment. In the first part of this paper, we suggest an ergonomic model based on a review of Endsley's SA model that we name "action's determinants". We highlight Ergonomic factors as anthropometric features, vigilance degree, skills and workload to propose a tree blocs model of dynamic decision making. The objective of this study is to identify and model the elements that lead to a way of making of an operator exerting in complex security system. In the second part, an application of the model will be made according to the fuzzy intuitionistic dynamic multi-attribute decision making design method. The mathematical model, based on fuzzy sets and multi-criteria design methods, reinforce the real-world applicability and measurement of the ergonomic proposed model. This application of the model gives a tangible and numeric decision support system in choosing the adequate human resources to operate in a definite critical system. Finally, a practical case of application in railway will be detailed to illustrate the application and measurement of the model.

Keywords: Action determinants, Situation awareness, Dynamic intuitionistic fuzzy multi-attribute decision making (DIF-MADM), ergonomics, railway security system.

1 Introduction

System's security remains a major concern for firms called firms "at risk "(air and rail transport, energy and industry). In fact, failures and incidents that may occur in these environments have generally a huge impact on cost as well as people's safety. In railway, accidents that happen in exploitation conditions are statistically around 75 % due to the human factor [1]. This study aims to provide a model that relies on studies done on the situation awareness and that will allow to understand input elements of man decision in a complex system for better understanding of his cognitive choices and to respond to the question "why he did it this way?". The model provides the integration of cognition elements and complementarities with several ergonomic studies in complex systems. An application of the model is made regarding to dynamic intuitionistic fuzzy multi-attribute decision making method. The ergonomic suggested model, will serve as a basis for providing elements of performance assessment of each team member operating in a critical security environment. The projection of the model provides a tangible and measurable decision support tool for allocation of operators exerting critical tasks.

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2 Literature review

2.1 Introduction

Security system approach has undergone several changes from the technical design era to the migration to SMS, after which the improvement in the safety rate experienced a stagnation level; and then the integration of the OHF (organizational and human factors) [2] for systemic and global analysis of different components of security, including the human factor. Considered for a long time as a source of error, the human factor is reevaluated as a source of reliability and an essential component of security creation. Several studies have focused on explaining and predicting human decisions and performance in risky environments by focusing on so-called "deep causes" and improving the reliability as well as the performance of the human factor.

2.2 We talk about the loss of "situation awareness" instead of human error [3]:

The complexity and interdependence of the human factors with several elements of the same system make us wonder about the deep causes of an operator's choices. Figure 1 represents a simplified model, an information processing block by the operator, which gives a decision as an output of the process. The action taken subsequently may be seen as appropriate to the situation of the operator or it may lead to a system failure. In the second case, it cannot be considered as a "human error" rather than a failure of the overall system.

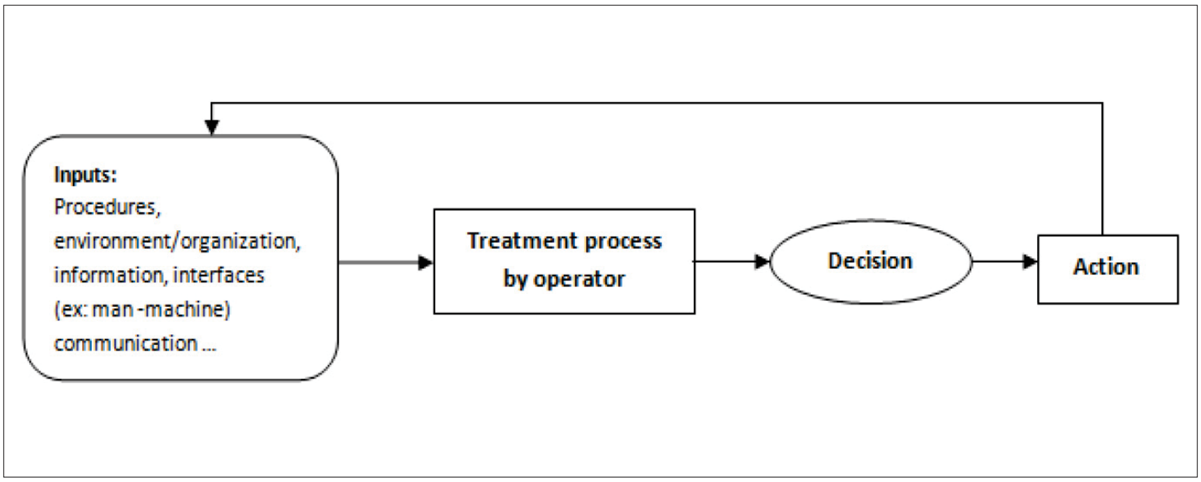

Figure 1 Simplified decision making process

Situation Awareness models were interested in explaining and modeling the operator's consciousness level of the elements of his environment, his treatment of input components and in mastering the situation taking into account the complexity of the studied system. This is generalized by his degree of mastery and understanding of "what's going on?" as often mentioned in the literature.
The popularity of SA models in cognition is due to its explanation (usually qualitative) of human cognition in a complex environment. There are many definitions of SA and the most used remains the one suggested by Endsley [4] which defined SA as a cognitive product (result of the process labeled SA assessment):
"The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The model presented by Endsley, schematizes the three levels of SA (perception, comprehension and projection) as well as different elements of the environment that influence the acquisition of SA and thereafter the person's decision and performance in a complex environment.

3 “Action’s determinants” model :

In this section, we propose an adapted ergonomic model of dynamic decision making. In this model, we are more interested to integrate all ergonomic factors of the person exerting in a complex system, as well as the elements of his “environment” having an impact on his decision-making and his performance. As Endsley pointed out, individuals vary in term of acquisition of SA. This is actually due to several factors such as experience, training, preconception and goals. In the following, we suggest a theoretical model that schematizes the individual factors, the three levels of the (SA) and also the different interfaces with the system components. This model will be named “action’s determinants” since it synthesizes elements that determine the operator’s performance of an action in a specific situation. The model of Action’s Determinants highlights the variability of decision making among operators as well as variability for the same operator in time due to the variability of individual characteristics.

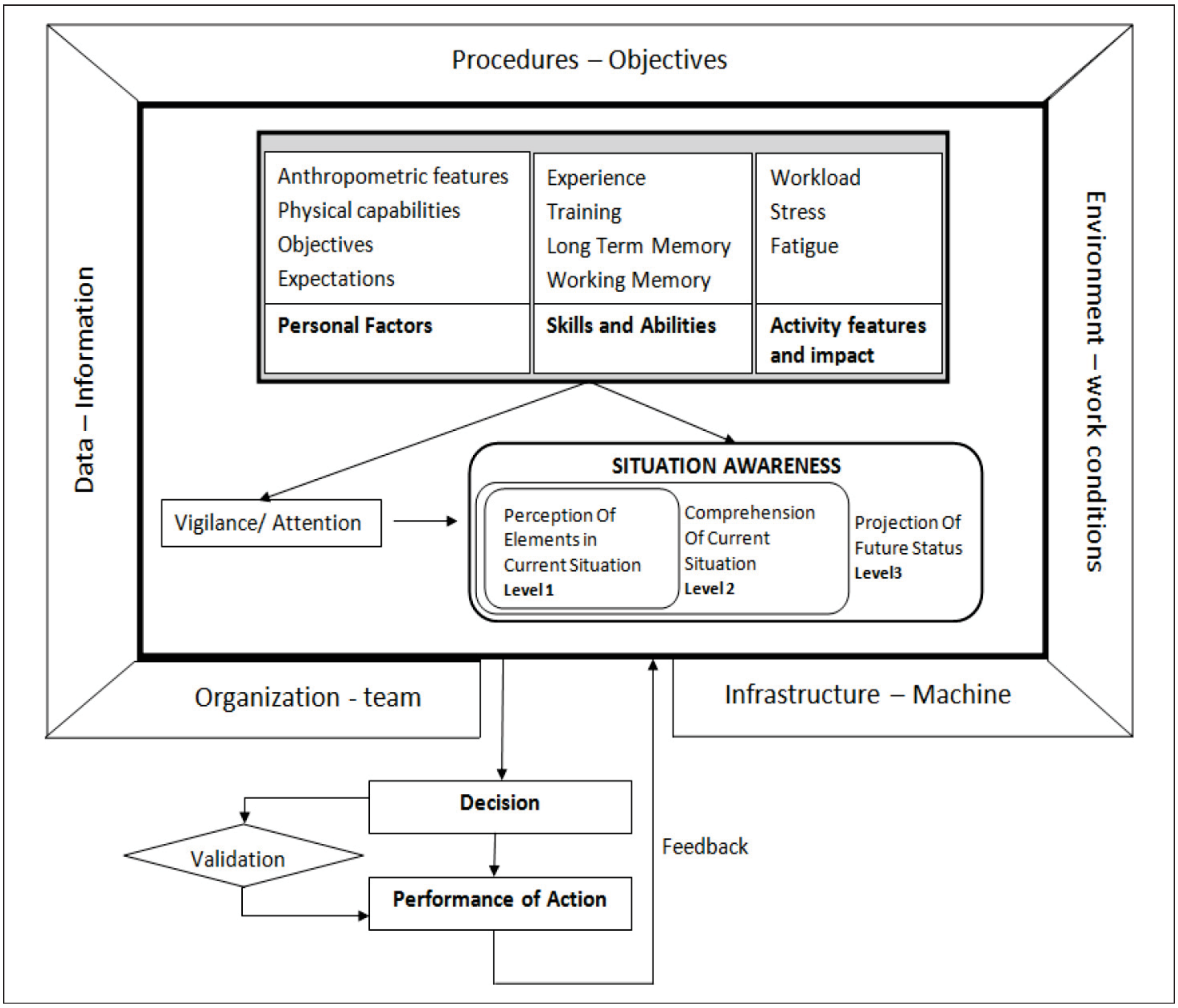

Figure 2 Model of Action’s determinants (Based on Endsley’s SA model)

We make a census of different elements that influence SA in the literature [5-8] including ergonomic factors influencing performance and decision-making, and we structure them into three blocks: Personal factors, skills and abilities and activity features and impact. These three essential blocks strongly influence SA, vigilance and attention and then performance. We model the external components of the system that influence the operator and his performance by blocks interfacing with the person. Since the components of the model have been widely developed in the literature, we will focus more, on the next part of this article, on the applicability and measurement of the model.

4 Application and measurement :

4.1 Introduction

The situation's determinants model evokes several fuzzy parameters which are non quantifiable by firm numbers and subject to variability over time. In this research, a transposition was carried out from an ergonomic and qualitative model to a mathematical one which is the dynamic intuitionistic fuzzy multi-attribute decision is making Model (DIF-MADM) [9-10].

4.2 Dynamic intuitionistic fuzzy multi-attribute decision making Model:

Let's consider:
$X = \{ x_1, x_2, \ldots, x_n \}$ A discrete set of n alternatives.
$A = \{ A_1, A_2, \ldots, A_m \}$ a set of m attributes whose weight vector is:

$$w = (w_1, w_2, \ldots, w_m) \tag{1}$$

where $w_j \geq 0$, and $\sum_{j=1}^{m} w_j = 1$ for j=1,2,…,m.

$P = \{ t_1, t_2, \ldots, t_p \}$ a set of considered periods whose weight vector is:

$$\lambda(t) = (\lambda(t_1), \lambda(t_2), \ldots, \lambda(t_p)) \tag{2}$$

Where $\lambda(t_k) \geq 0$, and $\sum_{k=1}^{p} \lambda(t_k) = 1$ for k=1,2,…,p.

$R(t_k) = (r_{ij}(t_k))_{n \times m}$ is the intuistionistic fuzzy decision matrix of the period t_k where $r_{ij}(t_k)$ is the value of the attribute j for the alternative i at period t_k.
According to intuistionistic method $r_{ij}(t_k) = (\mu_{r_{ij}(t_k)}; \nu_{r_{ij}(t_k)}; \pi_{r_{ij}(t_k)})$ where $\mu_{r_{ij}(t_k)}$ is the degree of satisfaction of the alternative x_i to the attribute A_j at period t_k, $\nu_{r_{ij}(t_k)}$ is the degree of non satisfaction of the alternative x_i to the attribute A_j, and $\pi_{r_{ij}(t_k)}$ indicates the degree of indeterminacy of f the alternative x_i to the attribute A_j. So that:

$$\mu_{r_{ij}(t_k)} \in [0,1], \quad \upsilon_{r_{ij}(t_k)} \in [0,1], \quad \mu_{r_{ij}(t_k)} + \upsilon_{r_{ij}(t_k)} \leq 1, \quad \pi_{r_{ij}(t_k)} = 1 - \mu_{r_{ij}(t_k)} - \upsilon_{r_{ij}(t_k)} \tag{3}$$

$$\text{for } i = 1,2,\ldots,n \quad j = 1,2,\ldots,m$$

The matrix $R(t_k)$ is then written:

$$R(t_k) = \begin{pmatrix} (\mu_{r_{11}(t_k)}; \nu_{r_{ij}(t_k)}; \pi_{r_{ij}(t_k)}) & \cdots & (\mu_{r_{1m}(t_k)}; \nu_{r_{ij}(t_k)}; \pi_{r_{ij}(t_k)}) \\ \vdots & \ddots & \vdots \\ (\mu_{r_{n1}(t_k)}; \nu_{r_{ij}(t_k)}; \pi_{r_{ij}(t_k)}) & \cdots & (\mu_{r_{nm}(t_k)}; \nu_{r_{ij}(t_k)}; \pi_{r_{ij}(t_k)}) \end{pmatrix} \tag{4}$$

The Dynamic Intuitionistic fuzzy weighed operator $R = (r_{ij})$ where:

$$r_{ij} = (\mu_{ij}; \nu_{ij}; \pi_{ij}) = \left(1 - \prod_{k=1}^{p} \left(1 - \mu_{r_{ij}(t_k)}\right)^{\lambda(t_k)}) ; \prod_{k=1}^{p} \upsilon_{r_{ij}(t_k)}^{\lambda(t_k)} ; \prod_{k=1}^{p} \left(1 - \mu_{r_{ij}(t_k)}\right)^{\lambda(t_k)} - \prod_{k=1}^{p} \upsilon_{r_{ij}(t_k)}^{\lambda(t_k)} \right) \tag{5}$$

Meanwhile, the negative ideal solution is $\alpha_i^- = (0,1,0)$ for the m selected attributes, we calculate distance between x_i and α^-, for i = 1, 2, … ,n :

$$d(x_i,\alpha^-) = 1/2\sum_{j=1}^{m} w_j(1-\vartheta_{ij}) \tag{6}$$

The closeness coefficient $c(x_i)$ is the distance between each alternative and the negative ideal solutionα^-.

$$c(x_i) = \frac{d(x_i,\alpha^-)}{d(x_i,\alpha^+)+d(x_i,\alpha^-)} = \frac{\sum_{j=1}^{m} w_j(1-\vartheta_{ij})}{\sum_{j=1}^{m} w_j(1-\pi_{ij})} \tag{7}$$

The higher c is the better the alternative x_i is.

4.3 Projection of the model:

Our model projection is made regarding the elements that impact the SA process as well as the vigilance level and subsequently the performance of the operator. In this section, we propose a numeric methodology for performance assessment of operators according to the criteria of action's determinants model.

Anthropometric features Physical capabilities Objectives Expectations	Experience Training Long Term Memory Working Memory	Workload Stress Fatigue
Personal Factors	**Skills and Abilities**	**Activity features and impact**

Figure 3 Three blocks of ergonomic characteristics

The three characteristics blocks are the basis of attributes selection and have to be adapted within the context of each firm. The choice of criteria and the method of rating related to each criterion remain specific to the organization. The suggested numeric model offers the possibility of weighting each criterion according to its importance and to the studied case.
The chosen criteria are considered as attributes of the mathematical model, and their notation will be made according to the intuitionist method that takes into consideration the degree of satisfaction of the operator to the attribute, degree of non satisfaction of the operator to the attribute as well as indeterminacy of the operator to the attribute. The choice of the intuitionist methodology is based on the fact that the ergonomic criteria in question always assume values which are not strict and which involve a degree of subjectivity and uncertainty.
Another projection regarding to the dynamic model is that the rating data can spread over a significant period (years, months …). These periods can be weighted according to their importance, criticality and impact.
In term of suggested model output, we obtain a ranking of the operators(according to the weighted chosen criteria) which serves as scientific basis and tools of decision-making for operators' selection for a critical task.

5 Case illustration of the adapted model:

Our study will be projected in the environment of a railway company where the safety aspect is essential in the management of the operating traffic. The specific case that we discuss in the following deals with the problem of assigning human resources to critical job of train driving. Indeed, we detail the situation where the manager is constrained to assign train drivers depending on the criticality of the train to be performed according to skills, experience and physical capabilities of drivers and the workload related thereto.

5.1 Selection of alternatives and attributes

In this illustrative case of study, we consider a team of five train drivers that we refer to in the following as alternatives X_1, X_2, X_3, X_4, X_5. The challenge is to determine a classification of these drivers according to their degree of mastery of train driving in critical situations.
We use as a basis the " action's determinants " model to bring out the selected criteria for the ranking of the employees that will be referred to " the attributes ". Based on the model mentioned above, we choose three individual factors blocs for the selection of our three attributes A_1, A_2 ,A_3, where:

- A_1 Is the personal factors attribute. The rating assigned to each employee for this attribute combine the age criteria with the physical ability. The age group of the current employees is between 20 and 60 years old, and the older an employee is, the lower he will be rated, and vice-versa.
- A_2 Is the skills and ability attribute. The calculation of the score is based on a combined judgment of team and the individual competence from one hand, and on the competence level in relation to the number of incidents which have occurred to the employee in the selected periods on the other hand.
- A_3 Is the activity features and impact attribute. More specifically, this attribute will be calculated in relation to the workload of each employee of the chosen team. Having a direct impact on the stress level and the fatigue level, the workload will be quantified depending on the number of operations and road switching performed by the driver.

The rating should be done by a committee of experts consisting of line managers, security and physical ability managers, and HR managers.

5.2 Selection of studied periods

The presented data relates to 2015, 2016, 2017, named respectively t_1, t_2, t_3. The weight vector $\lambda = (\lambda(t_1), \lambda(t_2), \lambda(t_3)) = (0.35; 0.25,0.4)$ reflects the criticality of each year, given that 2015 was a high rainfall year so that the railway network experienced significant flooding, and that 2017 was characterized by a series of upgrade works performed on the whole network, which made the train handling operations more critical. The two factors impose even more performance and vigilance in the railway sector.

5.3 Results

$$R(t_1)=\begin{pmatrix}(0.40 & 0.57 & 0.03) & (0.80 & 0.07 & 0.13) & (0.40 & 0.45 & 0.15)\\(0.30 & 0.63 & 0.07) & (0.20 & 0.62 & 0.18) & (0.35 & 0.55 & 0.10)\\(0.20 & 0.75 & 0.05) & (0.70 & 0.15 & 0.15) & (0.25 & 0.65 & 0.10)\\(0.85 & 0.12 & 0.03) & (0.80 & 0.10 & 0.10) & (0.70 & 0.15 & 0.15)\\(0.73 & 0.20 & 0.08) & (0.50 & 0.35 & 0.15) & (0.85 & 0.07 & 0.08)\end{pmatrix}$$

$$R(t_2)=\begin{pmatrix}(0.43 & 0.55 & 0.03) & (0.83 & 0.07 & 0.10) & (0.30 & 0.47 & 0.23)\\(0.33 & 0.61 & 0.07) & (0.23 & 0.60 & 0.17) & (0.28 & 0.48 & 0.25)\\(0.23 & 0.73 & 0.05) & (0.73 & 0.10 & 0.17) & (0.28 & 0.58 & 0.15)\\(0.88 & 0.10 & 0.03) & (0.88 & 0.09 & 0.035) & (0.80 & 0.08 & 0.13)\\(0.75 & 0.17 & 0.08) & (0.70 & 0.25 & 0.05) & (0.70 & 0.15 & 0.15)\end{pmatrix}$$

$$R(t_3)=\begin{pmatrix}(0.45 & 0.52 & 0.03) & (0.88 & 0.05 & 0.08) & (0.45 & 0.40 & 0.15)\\(0.35 & 0.58 & 0.07) & (0.30 & 0.58 & 0.12) & (0.30 & 0.53 & 0.18)\\(0.25 & 0.70 & 0.05) & (0.75 & 0.09 & 0.17) & (0.45 & 0.48 & 0.08)\\(0.90 & 0.07 & 0.03) & (0.90 & 0.07 & 0.03) & (0.80 & 0.05 & 0.15)\\(0.78 & 0.15 & 0.08) & (0.75 & 0.20 & 0.05) & (0.65 & 0.18 & 0.18)\end{pmatrix}$$

$$R=\begin{pmatrix}(0.427 & 0.543 & 0.030) & (0.840 & 0.061 & 0.099) & (0.398 & 0.434 & 0.168)\\(0.327 & 0.603 & 0.070) & (0.248 & 0.599 & 0.154) & (0.312 & 0.520 & 0.168)\\(0.132 & 0.723 & 0.144) & (0.725 & 0.110 & 0.165) & (0.343 & 0.556 & 0.101)\\(0.878 & 0.091 & 0.031) & (0.865 & 0.084 & 0.050) & (0.770 & 0.081 & 0.149)\\(0.752 & 0.167 & 0.080) & (0.667 & 0.257 & 0.076) & (0.750 & 0.122 & 0.128)\end{pmatrix}$$

We calculate the closeness coefficient:
$c\ (X_1) = 0.620$; $c\ (X_2) = 0.372$; $c\ (X_3) = 0.494$; $c\ (X_4) = 0.856$; $c\ (X_5) = 0.741$

We rank the alternative's closeness coefficient:
$c\ (X_4) > c\ (X_5) > c\ (X_1) > c\ (X_3) > c(X_2)$

The operators are then ranked by performance order according to the chosen weighed criteria:
$X_4 > X_5 > X_1 > X_3 > X_2$.

6 Conclusion

The proposed model of “action’s determinants” gives an ergonomic schematization of an operator in interaction with all interfaces and his environment and takes into consideration individual characteristics. This modelisation serves us a basis for evaluation of capabilities in critical situations. The model is assimilated to a MADM problem which supposes uncertainty and indeterminacy of data types. It is based on fussy sets with intuisionistic data form that matches with the ergonomic tree blocks characteristics data type. The use of DIF-MADM is filling the gap in measurement of performance by SA models. The given mathematical illustration can be modulated depending on firm’s activity, main criteria evaluation, objectives, rating and evaluation scale and method. Since we are studying ergonomics in risky domain, numerical results should be completed and analyzed by managers before implementation.

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