Author's Review of PhD Dissertation

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KOVÁCS JUDIT

- Mathematical modelling of the human factor in risk assessment in the field of disaster management -

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DISCUSSION OF THE SCIENTIFIC PROBLEM

Risk assessment, a data driven process for determining the likelihood of a risk happening, as well as risk management are of the most important tasks nowadays to achive the maximal safety and security. When considering catastrophies in our civilized world,human factor has always had an important role among the possible causes . The human factor is always present among the main reasons of accidents. According to different papers, 45-80% of errors are due to the human factor. On the other hand, the views that ”human commits errors”, ”humans are the weak part of the system” or ”human actions have to be replaced by automation” are too simplistic. Man is able to cope with unforeseen situations, to analyse and to create solutions. Without human actions more incidents would lead to accidents. Safe behaviour does not mean the absence of errors but the positive human contributions to safety, even in the form of prevention. Therefore, the concept of human error should be correctly defined and used with utmost care.

Risk assessment has three different main types: human health risk assessment, environmental risk assessment and ecological risk assessment. When all these three types are combined, integrated risk assessment is used. Integrated risk assessment is the way for future, which can be simply concluded from the fact that human health, the environment and the ecological system mutually influence one another.

At the moment, there is no ”best” mathematical model for the phenomenon ”human factor”, though mathematical models are usually simple to use and able to calculate numerical values for the real problems, and that is why it should be essential to have a mathematical model for the human factor. The question is why there is no such an exact mathematical model. If it is possible, the exact model should be made. If it is impossible, then a proof is needed for it. My hypothesis is that there may not an exact, unique, and best mathematical model be made for the human factor. In this case, the existing models should be compared, and to improve them, new parts for the models are essential to be determined.

RESEARCH OBJECTIVES

To prove my hypothesis and conduct new scientific results, my objectives are the following:

1. To compare the possibilities of mathematical modelling of the human factor and to determine the limits of modelling.

2. To compose and prove theorems in connection with modelling the human factor.

3. To define new types of error in the field of integrated risk assessment.

4. To make recommendation for the possible use of the new scientific results in connection with the analysis of the human factor.

5. To make plans for the application of the results concerning the human factor in military and polytechnic higher education.

For my objectives I studied:

1. the possibilities of mathematical modelling concerning the human factor in risk assessment, with a special view for disaster management.
2. the existing models and the possibilities of completing them as well as the possibilities of introducing new models.

RESEARCH METHODS

1. Analysis of the relevant literature of the subject. Studies of the new scientific results of conferences.

2. Giving lectures about the subject and results in scientific conferences.

3. Consultation with experts of the subject.

SHORT DESCRIPTION OF THE STUDIES CONDUCTED

First chapter

Human performance has a significant impact on the reliability of several fields of systems. The human factor is always present among the main reasons of accidents. According to different papers, generally 45-80% of errors are due to the human factor.
The concept of human error has been correctly defined and human reliability analysis (HRA) has been given a principal role when analysing the causes of accidents.

Nuclear Energy Agency (NEA) also emphasizes the wider application and development of human reliability analysis methods.

Integrated risk assessment is the best way for meeting the challenges nowadays. I defined the concept of integrated risk assessment and the plan for the process of risk assessment in details. I analysed the role of the human factor in the process of risk assessment.

Second chapter

In the 2nd chapter I reviewed the basis of human reliability analysis and some methods dealing with the analysis of the human factor.
In the field of risk assessment the appropriate treatment of human interaction has a key role in understanding its part in total risk and in the sequences of accidents.
It is the human reliability analysis (HRA) techniques that principally deal with the analysis of the human factor. On the other hand, there are also other methods that aim modelling some aspects of the human factor. Most of HRA techniques consider the question of data-accessibility and integration into wider systems.
The aims of HRA techniques are the following:
(1) To identify and analyze the most important human interactions, and to fit them into safety asssessments.
(2) To quantify the probabilities of successes and failures.
(3) To provide lookout for developing human performance.
All of the techniques concerned with quantifying human reliability include the calculation of human error probability (HEP), and that is the main point in my research.

I reviewed some important HRA techniques, namely ATHEANA, CREAM, HCR, HEART, HERMES, THEA and THERP. Mathematical models of these methods are quite different.

All of the HRA methods deal with PSF-type factors. Analysing these factors is an important part of HRA methods. The description of other aspects of the human factor may also be regarded as a mathematical model. I showed several examples for that in the 2nd chapter.

Third chapter

Mathematical models of methods concerning the human factor are presented in the 3rd chapter. According to Seveso directives, mathematical modelling as a tool for aiding decision-making has a significant role when quantifying severe risks.
Mathematical models can usually be cathegorized into three cathegories: empirical models, analytical models and numerical models. All of these thre types, and also mixed types have examples among modelling the human factor. Applicability of the models is particularly characterized by technical quality and usability. The most serious problem that may occur concerning mathematical models is that users of the methods are not aware of the limits of the models, or in some cases, are even not aware of the use of the model. For this reason, it is very important to apply models that, or at least whose essence may be understood in widely use. Another important point of view is to evaluate users' feedback to improve models for a better availibility. On the other hand, the documentation of mathematical models should be available for users as a reference.
Mathematical models of the methods reviewed are quite different. Nevertheless, all of the methods are verified and validated.

As a result of my research I put and proved the following statement:

There is no exact, unique, and best mathematical model for the human factor.

Existing models were compared, and to improve them, new parts for the models were determined in the 3rd chapter.

Fourth chapter

The results of the reasearch concerning the human factor may be applied for several fields of science. In the 4th chapter some applications in disaster management, emergency communication, determination of disturbance states and higher education were considered.

During the process of disaster assesment new challenges like globalization, technology development or terrorism appear. Thus, the development of disaster assesment processes meeting the criteria of the new challenges, or the reconsideration of disaster assesment may be required. To eliminate the errors occuring in the assesment, the analysis of the human factor may provide technical expertise. After the introduction of the disaster assesment and the role of the human factor, I analysed the disaster assesment teams and presented a possible solution.

I drew attention to the role of the human factor in the field of emergency communication. I suggested solution for the possible correction of human errors occuring during emergency communication.

I showed an example of the human factor causing a disturbance state. In this way I proved that the results concering the human factor may be applied in the method of the determination of disturbance states.

I showed that mathematical models of the human factor may be part of mathematics subject in military and polytechnic higher education.

SUMMARY OF CONCLUSIONS

The main point in my research is quantifying human reliability including the calculation of human error probability (HEP).
I completed the known problems of determining HEP by the question of responsibility.

Integrated risk assessment is the best way for meeting the challenges nowadays. I determined the concept of integrated risk assessment and the plan for the process of risk assessment in details. I analysed the role of the human factor in the process of risk assessment. I suggested that even the affective part of the human factor should already be considered at the first step of the process of integrated risk assessment.

The HRA methods reviewed use quite different mathematical models. There are models of basic mathematics (for example HEART), there are models applying probabilistic distributions (for example HCR), and also, there is a method which to some extent query the need and chance of mathematical modelling (THEA).
Despite of all these differences, all of the methods were validated in practise.
So, totally different mathematical models approach to equally well applicable and not interchangeable human reliability assessment methods. As I proved that there is no best mathematical model for the human factor, it follows that mathematical models of human reliability analysis and the human factor may be developed permanently.

Human error is a general concept, which includes every situations when the planned sequence of mental or physical actions fails to achieve its planned and desired aim, and this failure is not due to any kind of stochastic circumstances.
Human error is failure of a human action due to internal human failure mechanisms.This concept is to loosely describe any sub-optimal human performance.Two main groups of human errors are error of commission (wrong human action) and error of omission (missing human action). Human error as the consequence of the difference between the planned and realized action or performance, may be categorized as slip, lapse and mistake. A separate group of errors is violation, when the action is not allowed, prohibited or not apropriate. Latent error may also play an important role, although this type of errors is usually difficult to identify because of its distance even in time and in space from the evolved event. Human failure is the failure of a defined human action in an HRA model. There may be many reasons for failure compared to human error. Human failure may affect components- that is called fault, and processes, when disturbance occur. A failure that is assessed to result in unacceptable consequences such as unavailability or wrong function leading to personal or property damage is called critical failure.
In this categorization the role of violation is not handled as important as it is in reality. In Reason’s categories the violation of deliberate making harm is not considered being a human error. In reality these deliberate actions

may have serious conclusions, and their number is continously increasing. So I suggested that in some cases and after appropriate analysis, the violation of deliberate making harm should be treated as a human error. It is very important for these types of violation, so that they may have a part in researches in connection with the human factor.

On the other hand, general violation is also a serious problem. I created a simple mathematical model for that, respecting the connection between violation and the number of rules to be kept. There is a number of rules to be kept, weighted by the difficulty of keeping them, K that should be analysed in the given situation. There exists a number K_0 for which: when $K< K_0$, no violation happens (or only with negligible probability), when $K> K_0$, violation happens (with considerable probability). The objective is to make a system of sufficient rules for the given task where $K< K_0$.

All of the reviewed HRA methods deal with PSF-type factors. Analysing these factors is an important part of HRA methods. Among PSF-type factors I emphasized stress factor. In connection with stress, fatigue and human performance I concluded the following:

The cumulative effect of stress and fatigue in some cases is bigger than the sum of the single affects, while in other circumstances the two affects compensate each other. Namely:

1. When considering extremely big stress, the cumulative affect ($_h$) of fatigue (F) and stress (S) is largely bigger than the sum of the single effects. $(\mathrm{F}+\mathrm{S})_\mathrm{h} >> \mathrm{F}_\mathrm{h} + \mathrm{S}_\mathrm{h}$

2. When considering low level and optimal stress, the effect of fatigue reduces the level of human performance (T) in direct proportion. $\mathrm{T}|\mathrm{F}_\mathrm{h} = \frac{\mathrm{T}}{\mathrm{F}_\mathrm{h}}$, when $\mathrm{S}_0 \le \mathrm{S}_\mathrm{h} \le \mathrm{S}_{\mathrm{opt,max}}$.

3. When considering moderately high level of stress, the cumulative effect of stress and fatigue compensate each other. $\mathrm{T}|(\mathrm{F}+\mathrm{S})_\mathrm{h} = \mathrm{T}$.

I developed mathematical models with respect to the following principles:
It is very important to apply models that, or at least whose essence may be understood in widely use. Another important point of view is to evaluate users' feedback to improve models for a better availibility. On the other hand, the documentation of mathematical models should be available for users as a reference.

CREAM-the basic method uses basic mathematics, and so some parts of the mathematical model are just mentioned in the method. For the seek of the above principles, I developed the details. I showed the practical use of CREAM-the basic method by analysing an imaginary process.

From the available data of the method HCR I concluded the following formulas:

The shape-parameter may be given by $\beta_j = 0{,}1j^2 - 0{,}6j + 1{,}7$
The location parameter may be given by $c_{\gamma j} = -0{,}1j + 0{,}8$ $\quad$ $j=1, 2, 3.$
The scale-parameter may be given by $c_{\mu j} = 0{,}19j + 0{,}22$

So I concluded that the location parameter and the scale-parameter have a linear connection with respect to mental processing.

In the available literature of HEART there is no formulas for error probability. Using the available data and a specific example from literature I developed the mathematical formula of human error probability applied in HEART method:

$$\text{Human Error Probability} = \min\left\{1;\ HEP \cdot \prod_{i=1}^{38}\left((\max EPC_i - 1)\cdot APOA_i + 1\right)\right\}$$

As a conclusion of the "Doubling rule" in THERP method I pointed out that the role of the first error is significant in evolving accidents. So I suggested to introduce the concept of "first error", and the emphasis of the importance of the first error.

In connection with the preference of uniform distribution of the risk I proved that during the perception of cumulative risk, the cognitive human dislocation towards the direction of the preference of uniformism may be mathematically modelled by minimalization of the sum.

I worked out the modification for the SÖN-formula of the subjective probability of hazardous incidents:

$$\psi_m = \frac{\lg(n+1)}{\sum_{i=1}^{n} a_i \lg(n-i+2) + \lg n + \sum_{i=1}^{n} \lg\left(1+(\bar{a}-a_i)^2\right)}.$$

I showed several fields of science where the results of the reasearch concerning the human factor may be applied, namely in disaster management, in emergency communication, in the method of determination of disturbance states and in higher education.

During the process of disaster assesment new challenges like globalization, technology development or terrorism appear. Thus, the development of disaster assesment processes meeting the criteria of the new challenges, or the reconsideration of disaster assesment may be required. To eliminate the errors occuring in the assesment, the analysis of the human factor may provide technical expertise. After the introduction of the disaster assesment and the role of the human factor, I analysed the disaster assesment teams and presented a possible solution.

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I showed that mathematical models of the human factor may be part of mathematics subject in military and polytechnic higher education.

THESES

Thesis 1. I proved that there is no exact, unique, and best mathematical model for the human factor.

Thesis 2. I developed the missing details of the mathematical model for CREAM-the basic method and showed the practical use of CREAM-the basic method by analysing an imaginary process. Using the available data and a specific example from literature I developed the general mathematical formula of human error probability applied in HEART method. From the concluded formulas for the method HCR I proved that the location parameter and the scale-parameter have a linear connection with respect to mental processing.

Thesis 3. In connection with the preference of uniform distribution of the risk I proved that during the perception of cumulative risk, the cognitive human dislocation towards the direction of the preference of uniformism may be mathematically modelled by minimalization of the sum.I worked out the modification for the SÖN-formula of the subjective probability of hazardous incidents.

Thesis 4. I demonstrated that in some cases and after appropriate analysis, the violation of deliberate making harm should be treated as a human error. I created and introduced the concept of the ”first error”. I created a mathematical model for eliminating violation.

Thesis 5. I worked out the theorem about the cumulative effect of stress and fatigue on human performance.

Thesis 6. I was the first to suggest that even the affective part of the human factor should already be considered at the first step of the process of integrated risk assessment.

Thesis 7. To eliminate the errors occuring in disaster assesment, I worked out the optimal form of assesment teams.

RECOMMENDATION

I recommend to use the results of my dissertation first of all for developing HRA methods.
I showed that mathematical models of the human factor may be part of mathematics subject in military and polytechnic higher education. That is why I recommend to introduce the mathematical models of the human factor in military and polytechnic higher education.

I showed several fields of science where the results of the reasearch concerning the human factor may be applied. In these fields I recommend the continuous application of new results.

On the other hand, there are several fields of science where the human factor is less emphasized or neglected, though even in these fields the role of the human factor is vital. To recover these fields and the general consideration of the human factor, including the continuous application of new results is the way for future.

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