

Human Reliability Assessment, Through Integral Risk Index



Social Science

KEYWORDS : Human reliability assessment, Risk assessment, Integral risk index, Quantitative risk assessment;

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ABSTRACT

The complicated production environment nowadays defines specific risk areas, which requires special attention to each of the risk factors, which provoke them, in order to determine their impact on the overall processes - both technological and managerial. The working environment leads to the development of additional risk factors due to the presence and the intervention of the human factor and the possibility of its influence on the process in a different then the planned direction. Human action cannot be ignored, despite the high automation of the processes and the seemingly less and less involvement of a direct human involvement. The man is a part of the working environment and of the process of its planning, engineering design, operational implementation and of any direct activities, done by managers, designers and operators, but also by external (sometimes accidental) participants, users and others.

Introduction

The human reliability assessment (HRA) is the common name for a range of methods and models which are used to predict the occurrence of human error and as a way of reducing the vulnerability of the system as a whole [1]. In all the methods and approaches of human reliability assessment is used the term „human error“ and is aiming to develop an assessment of the probability of its occurrence. On other hand the use of this term raises negative views of some scholars who state that „human error“ is not well defined and is very fuzzy concept because it cannot be specific category of human performance. Attribution of error actions to certain individuals, team or organization is essentially a social and psychological process, not an aim of a technical nature. [2].

The human reliability assessment in this study is interpreted as a way to predict what is the potential of a person, in the context of a particular job, to take actions, which could lead to the realization of a critical situation, or with other words how can be relied on a man for the sustainable functioning of a system. Human reliability is a complex index, because it includes many factors which influence the expression of human's potential, and on the same time are related with the reasons for human errors emerge. From one side these factors can be related with the technology used and the process- factors described quantitatively (temperature, moisture, noise level, etc.) on the other side they can be: physiological, emotional, personal characteristics, attitude or the „background“ of the human response to a particular action or operation - factors described qualitatively.

The biggest problem when assessing human reliability is how to include these quantitative data into qualitative model with objective and correct assessment.

We solved this problem with the most important result of our study - the mathematical model of risk index we created, which includes five of the most important factors, shaping human reliability and their qualitative assessment. The risk index gives us an objective possibility for comparing of the human reliability of people, employed in technological processes.

EXPERIMENTAL PART

BASIC FACTORS OF HUMAN RELIABILITY

We studied 50 employees, working in four technological plans in Bulgaria and we outlined five basic factors, each of which consists of component factors with greater influence on human reliability. They are ranged in accordance with their importance and are listed in table 1.

Table 1- Basic and component factors

No	Basic Factor	Component factors
r1	Professional characteristics (ProfC)	qualification, education experience skills
r2	Personal characteristics (PC)	openness consciousness extraversion agreeableness neuroticism
r3	Working environment (E)	ergonomy work organization climate control
r4	Physical State (PS)	physical health psychological health
r5	Behavior (B)	stimulant's usage/cigarettes alcohol usage

Factor 1 (r1) – Professional characteristics, or how the operator is trained to develop his duties and how his professional competence and experience, influences the performance of his direct tasks. This factor is quality presented, and for the minimal and the maximal values, which it can have are used quality levels corresponding to numerical values as shown in table 5 (very low, low, medium, high, very high), which are also converted to the interval [0, 1] - table 2.

Table 2. Quality levels of Professional characteristics (r1)

Quality level of r1	Interpretation	Values of r1
Very low risk	Five or more years of qualification, Five years of education, Five or more years of experience, Courses taken	[0-0,20)
Low risk	Five or more years of qualification, Five years of education, Five or more years of experience	[0,20-0,37)
Medium risk	Education-at least three years, Experience -three years; No courses taken	[0,37-0,63)

High risk	Course, related with the work duties, No education, No experience	[0,63-0,80]
Very high risk	No qualification, No education, No experience, No skills	[0,8-1,00]

Factor 2 (r2) - Personal characteristics, forms the ability of each employee to be part of a working team [3].

To determine the component factors of this factor we used five factor's model of personality [4, 5], created by Oliver John. Personal characteristics are a very important part of the human reliability, because although the working environment in any technology unit is very specific and highly standardized, the personal characteristics of the people employed in the process affect the way they behave and perform their duties in this limited environment.

The factor has five component factors (known as Big Five), in relevance with the model of Oliver John [6]

Neuroticism (N): the degree to which a person is anxious, irritable, aggressive, temperamental and moody;

Extraversion (E): the degree to which a person is nice, tolerant, kind, open and warm to others around;

Openness (O): the degree to which a person is curious, original, intellectual, creative and open to new ideas.

Agreeableness (A): the degree to which a person is nice, tolerant; sensitive, trusting, kind and warm;

Conscientiousness (C): the degree to which a person is organized, systematic, punctual, achievement oriented and dependable [6]

For the purposes of the study we used the percentage and graphical representation of personality, according the five factor analysis of personality test (Big Five), which can be found at www.outofservice.com/bigfive/

The component factors values are chosen from the interval [0-100], but because of the specific features of the component factors they are interpreted in a way explained in table 3. Except the first component factor - Neuroticism, each of the component factors has better meaning with bigger values. Since for delegating the right value, we followed the rule, that as closest to 0 means less risk and on the contrary- the closest it is to 100- bigger risk, we turned the tendency of growing by adding the words "risk of". At this way while interpreting extraversion, which is better, assessed closer it is to 100, with the addition "risk of", we add the opposite meaning, or closer it is to 0, better it is (with less risk)

Table 3 - Personal characteristics' values interpretation

Personal characteristics component factors	Min. value (less risk)	Max. value (more risk)
Neuroticism	0	100
Explanation [6] Neurotic people have a tendency to have emotional adjustment problems and habitually experience stress and depression. People very high in Neuroticism experience a number of problems at work. For example, they have trouble forming and maintaining relationships and are less likely to be someone people go to for advice .[7]		
Risk of Extraversion	0-min value (less risk)	100- max.value (more risk)

Explanation -At its maximum level these people are effective managers, salesman and they demonstrate inspirational leadership behaviors [8]		
Risk of Openness	0- min value (less risk)	100- max.value (more risk)
Explanation - People high in openness seem to thrive in situations that require flexibility and learning new things. They are highly motivated to learn new skills, and they do well in training settings.[9]		
Risk of Agreeableness	0-min value (less risk)	100- max.value (more risk)
Explanation -People who are high in agreeableness are likeable people who get along with others. Agreeable people help others at work consistently, this helping behavior does not depend on their good mood.[10]		
Risk of Conscientiousness	0- min value (less risk)	100- max.value (more risk)
Explanation -Conscientious people not only tend to perform well, but they also have higher levels of motivation to perform, lower levels of turnover, lower levels of absenteeism, and higher levels of safety performance at work.[11]		

Factors *r1* and *r2* develop the ability of each worker to respond to emergency situations and to take decisions that can prevent or induce disaster.

Factor 3 (r3) Environment. This is a factor describing the components of the environment which most affect the performance of work duties of each worker, the realization or prevention of emergencies. This factor has four component factors that aim to describe the influence of all external factors depending on workplace organization and management of the work duties, which affect the execution of works and the implementation of crisis situation. These are:

Ergonomics - an indicator of the suitability of the working place to the job duties;

Organization of work - how to manage the workflow, what is the hierarchy of decision-making, which can lead to or prevent a critical situation

Climate - physicochemical indicators of the environment, which describe the degree of aggressiveness with which it affects to the performance of the employee- salinity, temperature, noise, odor, vibration;

Control - how the worker reports his activities, is he obliged to report to someone directly, is there a person to verify his decisions or actions, is he allowed to take decisions?

This factor is quality presented, and for the minimal and the maximal values, which it can have are used quality levels corresponding to numerical values as shown in table 5 (very low, low, medium, high, very high), which are also converted to the interval [0, 1]- table 4.

Table 4. Quality levels of Environment (r3)

Quality level of r3	Interpretation	Values of r3
Very low risk	High level of ergonomic of the working position, Effective work organization Not aggressive climate; High control;	[0-0,20]
Low risk	High level of ergonomic of the working position, Effective work organization Medium/High Aggressive climate; High control;	[0,20-0,37]

Medium risk	Good level of ergonomic of the working position, Good work organization Medium/High Aggressive climate; Average control;	[0,37-0,63)
High risk	Low level of ergonomic of the working position, Some work organization Medium/High Aggressive climate; Low control;	[0,63-0,80)
Very high risk	Low level of ergonomic of the working position, Bad work organization Aggressive climate; Low control;	[0,80-1,00]

Factor 4 (r4)-Physical State – This is a factor, describing the physical and the psychological health of the employee. The values are included in the interval [0-1], as shown in table 5

Table 5. Physical State (r₄) interpretation

Values of component factors	Quality level of r4	Explanation
[0-0,20)	Very low risk	Excellent physical health Excellent psychological health
[0,20-0,37)	Low risk	Vey good physical health Very good psychological health
[0,37-0,63)	Medium risk	Average physical health Average/good psychological health
[0,63-0,80)	High risk	Not good physical health Average/good psychological health
[0,80-1,00]	Very high risk	Poor physical health Average/bad psychological health

Factor 5 (r5) - Behavior—this factor consists of two component factors-alcohol abuse and stimulant’s usage.

The values of the component factors are moving in the interval [0-100]. The interpretation is related with the percentage of the presence of this factor in the person. For example in there is a person, who rarely use alcohol, he will receive value - 5 (5% of presence of this factor in this person’s physical profile), on the contrary if we have someone, who drinks every weekend, he will receive value - 70 (70% of presence of this factor in this person’s physical profile

Materials and methods

FOR THE CALCULATION of the integral risk index R_{int} , is created a mathematical model. This model is based on the method - Linear combination of private criteria (LCPC) and on hierarchical model of basic and their constituent factors.

Human reliability (HR) is defined on the base of the integral risk index - R_{int} ($R_{int} \in [0, 1]$) on the following formula:

$$HR = 1 - R_{int} \tag{1}$$

From the formula is obvious that the lower risk indicator is the higher human reliability is.

Determining the WEIGHTS OF THE basic risk factors

AMONGST the full range of risk factors there had been defined a set of five basic risk factors r_i ($i=1, \dots, M$), ($M=5$), which are most important for obtaining of a complex assessment of risk associated with human reliability. In our case-technological

processes sphere, we selected five of them, but the model allows the additionally adding of other factors, taking into account the specifics of the activity.

We chose five basic factors r_i and for each of them was determined the level of its relative importance (weight) w_i ($\sum_{i=1}^5 w_i = 1$) - table 6.

Table 6. Weights of the basic factors

Basic factors r_i	Weight
r_1 – Professional characteristics (ProfC)	w_1
r_2 – Personal characteristics (PC)	w_2
r_3 – Working environment (E)	w_3
r_4 –Physical State (PS)	w_4
r_5 – Behavior (B)	w_5

The factors are ranked according their decreasing importance, the worth (weight) of the ith factor w_i is defined by the rule of Fishbern.

$$w_i = \frac{2(M - i + 1)}{(M + 1)M} \tag{2}$$

We chose the rule of Fishbern to determine the weights of the basic factors because of its easy application and at the same time the possibility of inclusion of expert opinion of a risk expert, who can rank the factors, by listing them, in accordance with their importance. In the present study this order is obtained as a result of a research done in four technological plants in Bulgaria.

The five basic factors r_i contain a subset of component factors (S-factors). In our case S-factors are quality attributes. For each S-factor is determined its weight p_i compared to the base factor (the sum of the weights of all S-factors of a basic factor is equal to one).

Because the meanings of the risk factors we chose are set in different units and different scales of measurement, which makes their immediate generalization impossible, the current values of the basic and subordinate factors are normalized. In our mathematical model for that we used the method of replacing the absolute values of the factors with relative values in the interval [0, 1] by the following formula:

$$x_{i01} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3}$$

In those cases where the factors are quality attributes, which have no quantitative assessment, are set numerical values corresponding to quality levels (very low, low, medium, high, very high), which are also converted to the interval [0, 1]- table 7

Table 7. Normalized values of the quality levels of the factors

Quality levels of the factor	Normalized values
Very low	[0-0,20)
Low	[0,20-0,37)
Medium	[0,37-0,63)
High	[0,63-0,80)
Very high	[0,80-1,00]

We calculate the aggregate value A_i^N of every basic factor r_i , consisting component factors (S -factors) on the following formula:

$$A_i^N = \sum_{k=1}^N p_k x_{k01} \quad (4)$$

whereas:

N – number of the S -factors ($k = 1, \dots, N$) for the relevant basic factor r_i ,

p_k – weight of the k -th S -factor in the generalization,

x_{k01} – normalized value of the k -th S -factor.

We define the integral risk index R_{int} on the following formula:

$$R_{int} = \sum_{i=1}^M (w_i \cdot A_i^N) \quad (5)$$

whereas:

w_i – relative importance (weight) of the base factor (indicator)

r_i ; $\sum w_i = 1$

A_i^N – aggregated (current) value of the i -th basic factor r_i

M – number of the basic factors in the studied problematic situation.

It is important to point out that the requirement of our model is that all risk factors and their component factors should vary in the same direction - the higher value means a higher level of risk, and there should be no correlation between the factors from the relevant level.

The assessment of the human reliability (HR) through the integral risk index (R_{int}) and formula (1), can be presented in the range [0-10], for the sake of its easy interpretation and use. This requires the resulting assessment to be multiplied by ten-table 8.

Table 8. Human reliability assessment through R_{int}

Value of R_{int}	Value of HR	HR assessment
[0,0-0,20]	(8,00-10]	Very high
[0,21-0,37]	(6,3-8,00]	High
[0,37-0,63]	(3,70-6,30]	Medium
[0,63-0,81]	(2,00-3,70]	Low
[0,81-1,00]	[0-2,00]	Very low

ASSESSING OF HUMAN RELIABILITY

CASE STUDY

54 years old operator in a refinery. He has 31 years of experience in the refinery, he graduated from a college of chemistry, he has no additional qualifications or courses taken, but he has vast skills because of his long working experience in the refinery as an operator. He is very serious smoker. The mathematical model of the risk index is applied as shown in Figure 1, the integral

risk index is shown in Figure 2.

$$HR = 1 - R_{int}$$

$$HR = 1 - 0,26$$

$$HR = 0,74$$

The received result of the assessment of the human reliability of the operator - 0.74 means high-human reliability (table 8) and the obtained value of the integral risk index 0.26 places this person at the low-risk zone.

CONCLUSION

The mathematical model was verified as useful and correct by the feedback we have from some of the evaluated people. The aim was to connect the result, received by the model with the real professional profile of the person. The problem here was the fact that in many of the cases, where there was a human error, related with low level of human reliability, which subsequently led to an accident, no one of the people involved felt free to share this with us. Nevertheless, by the information we gathered after the study we can make a strong parallel between the high level of human reliability and the low number of accidents in the production. If the model is implemented in the production's plant activities and the employees are examined on every six months, this would make quite clear feedback on the relevance of the assessment and the real situation, which can cause risk of different scale. This would undoubtedly point the weak points in every one's performance of the work duties and give possibility for their overcoming with less effort and less investments.

ACKNOWLEDGEMENTS: The obtained results were granted within the funding of the Scientific and artistic creative activities' fund of University "Prof.d-r Assen Zlatarov", Burgas, Bulgaria within a project NIH 259/2011-2014, named "Human reliability assessment

Figure 1- Basic and component factors values for Case 1

Input			Results		Integrated assessment
First level	Integral risk index				
Number of the basic factors			5	0,26	
Nr	Title of the basic factors	Weight of the basic factor	Number of factors from second level	Aggregate (current) value	Weighted value
1	Professional characteristics	0,33	3	0,22	0,07
2	Personal characteristics	0,27	5	0,28	0,07
3	Working environment	0,20	4	0,27	0,05
4	Physical state	0,13	2	0,30	0,04
5	Behavior	0,07	2	0,30	0,02
		1			

Basic Factor	Component factors	Subjunctive assessment of the basic factor					Normalized value	
		High	Current value	Medium	Low	Very low		
Working environment	Responsibility	0,3	0,8	0	1	Low risk, this indicator	0,3	
	Work organization	0,25	0,8	0	1	First level of complexity after the operator	0,3	
	Control	0,25	0,8	0	1	Low risk due to the surrounding environment	0,3	
	Control	0,25	0,8	0	1	Low risk due to the surrounding environment of the tool used based for various control parameters of the tool used	0,3	
		1	Aggregate value of the basic factor				0,27	
Physical state	Psychological health	0,5	0,8	0	1	in excellent psychological health	0,3	
	Physical health	0,5	0,4	0	1	but not that stage because of the age	0,4	
			1	Aggregate value of the basic factor				0,3
Behavior	Accident status	0,5	10	0	100	Low accident rate	0,1	
	Stricter usage	0,5	0	0	100	Serious operator	0,3	
			1	Aggregate value of the basic factor				0,3
	Personal characteristics	Open of opinions	0,2	10	0	100	Open to other person	0,1
		Risk of consequences	0,2	0	0	100	Very consequences	0,3
Risk of consequences		0,2	0	0	100	Extensive	0,3	
		1	Aggregate value of the basic factor				0,3	
Professional characteristics	Quality of work	0,2	0	0	100	Correctly agree with other's opinion	0,3	
	Quality of work	0,2	0	0	100	Correctly agree with other's opinion	0,3	
	Quality of work	0,2	0	0	100	Correctly agree with other's opinion	0,3	
			1	Aggregate value of the basic factor				0,2

Figure 2. The integral risk index for Case 1

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