QUALITATIVE MODEL OF PERFORMANCE SHAPING FACTORS IN HRA

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A lot of Human Reliability Analysis (HRA) methods calculate human error probability (HEP) based on different performance shaping factors (PSF). In calculating HEP, interdependency is generally ignored or addressed through varying parameters in linear or loglinear formulas [Groth 2009]. These dependencies could be more precisely represented by a qualitative model of PSF relationships. The aim of this paper is to describe the interdependence of the factors affecting human reliability using the method of qualitative modeling. Interdependencies between factors were based on different investigations. Appropriate qualitative relations were chosen for each pair of factors, and using a specific computer program, different scenarios were created.

KEYWORDS

human reliability analysis, human error, performance shaping factors, qualitative model

1 INTRODUCTION

The issues of human reliability are increasingly coming to the forefront of public interests, particularly in connection with various accidents or other adverse events. Development of Human Reliability Analysis Methods (HRA) has been actively launched after the accident at Three Mile Island (1979). From the eighties to the nineties of the 20th century, the development of HRA was mainly focused on the quantification of Human Error Probability (HEP), which is defined as the ratio of the number of errors of human factor and the number of chances for error.

Since the human reliability depends on working conditions, performance shaping factors (PSF) are being introduced within the framework of HRA methods. These conditions integrate both technical and organizational factors, and also the factors related to personality and environment. The number of factors in the individual methods is in the range from 8 to 60; in some methods, these factors overlap or even merge to create higher aggregates.

For quantitative estimation of PSF linear and logarithmic models are used; they integrate the HEP values and the weight of PSF, but do not count with dependencies between these factors [Hollnagel 1993]. One of the attempts to create a model taking into account the bonds was made by Katrina M. Groth [Groth 2009] using Bayesian Belief Network (BBN). De Ambroggi, M. Trucco, P. in their article [De Ambroggi 2011] describe a model for quantification of PSFs effects on HEP (weights) based on ANP (Analytic Network Process). Chang, Y.H.J. and Mosleh, A. [Chang 2007] present the IDAC model (information, decision, and action crew in context) where they identify 50 PSFs, divided into 11 groups. Factors in each group do not overlap with each other; nevertheless there may be dependencies between PIFs within different groups.

This article will describe another possibility of analyzing the relationships between performance shaping factors; namely using the method of qualitative modelling [Vicha 2008].

2 METHODS

2.1 Qualitative models

The following qualitative analysis is based on four values only:

Values:	Positive	Zero	Negative	Anything	(1)
	+	0	-	*	
Derivatives:	Increasing	Constant	Decreasing	Any trend	

A qualitative model, as used in this paper, is a union of qualitative equations and equation less relations based on n variables:

Model (X_1,X_2,……,X_n) (2)

Specific computer programs are available to solve qualitative models. It is not the goal of this paper to study this problem.

A set of m qualitative n-dimensional scenarios is a solution of the model (2). It is described by the following set of triplets:

[(X_1,DX_1,DDX_1),(X_2,DX_2,DDX_2),…..(X_n,DX_n,DDX_n)]j, j=1,2,….,m. (3)

where Xi is the i-th variable (2) and DXi and DDXi are the first qualitative and second qualitative derivations with respect to time t. It makes no sense to incorporate higher derivatives. They are usually unknown if problems realted to sustainability are studied.

There are two typical qualitative knowledge items that are usually elements of the model (2):

- Pairwise equation less relations, see e.g. Fig. 1.
- Equations with unknown numerical constants.

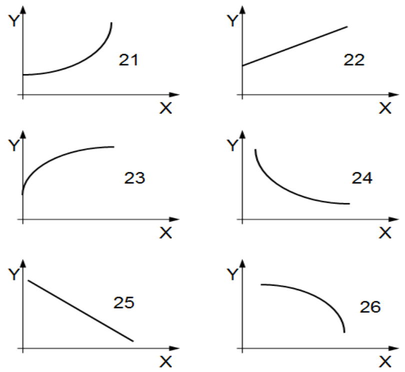

Figure 1. Pairwise equation-less relations and their identification numbers

All pairwise relations X, Y in Fig. 1 are qualitative relations. This means that nothing is quantified. For example, the relation No. 23 indicates that:

- The relation is increasing, the first derivative dY/dX is positive
- There is a "saturated'' relationship between Y and X, the second derivative is therefore negative; there is an upper Y limit, its numerical value is not known

- If X = 0 then Y is positive (4)

A subset C of variables X can be controlled by a decision maker; the remaining variables are lottery variables L as they are outside any control:

X=CUL
C=(C_1……….C_v)=(X_1……….X_v)
L=(L_1……….L_w)=(X_(v+1)……….X_n) (5)
n=v+w

2.2 *Qualitative transitions*

An unsteady state behaviour can be described by a time sequence of scenarios (3). Different points of view can be taken into consideration while developing algorithms used to generate feasible sequences. For example, sets of scenarios are based on the first and second derivatives (3). However, the ignored / unknown third derivatives can be a driving force of a transition between two scenarios if the following triplet (+ + +) is studied. E.g. if the third derivative is negative, then the following transition takes place:

(+ + +) → (+ + 0) (6)

see the first line of Tab. 1. If the third derivative is positive or zero then there is no transition and the status quo is maintained:

(+ + +) → (+ + +) (7)

Tab. 1 contains some shortcuts as well; for example, the following transition (see line No. 14, Tab. 1)

(0 0 0) → (+ + +) (8)

can be replaced by the following sequence of transitions which are mathematically feasible if the third derivative is positive during the following sequence of transitions:

(0 0 0) → (0 0 +) → (0 + +) → (+ + +) (9)

The first transition (0 0 0) → (0 0 +) is caused by the positive value of the third derivative. This transition is not given in Tab. 1. The second step (0 0 +) → (0 + +) is caused by the positive value of the second derivative. The last step (0 + +) → (+ + +) is caused by the positive value of the first derivative.
A complete set of all one-dimensional transitions between two triplets used in this paper is given in Tab. 1.
Tab. 1 is not dogma. It may be modified on an ad hoc basis. The only requirement is that the transitions must fit the user's reasoning. For example, it is possible to remove all / some shortcuts, see e.g. (7), ignore all such transitions which are caused by uncertainties related to unknown third derivatives, remove a pre specified set of transitions which are considered by a user as unacceptable / undesirable / uninterested.
Fig. 2 gives a qualitative description of an oscillation using the one-dimensional triplets n = 1 (3).
The qualitative description, see Fig. 2, describes different quantitative oscillations. For example, the oscillation's amplitudes are not constant. The only limit is the time sequence of the triplets, e.g.
(+ + -) → (+ 0 -) → (+ - -) etc., see Fig. 2
The triplet (+ 0 -) represents the following three qualitative equations (3):

X = +, DX = 0, DDX = - (10)

If the qualitative variable X is a description of a quantitative variable x then the set of equations (8) corresponds to:
X = any positive value, $dx/dt = 0$, d^2x/dt^2 = any negative value and this is an indication of a maximum, see Fig. 2.

Any quantitative one-dimensional oscillation, see e.g. Fig. 2, can be represented by a simple oriented graph, see Fig. 3. The transition from the triplet (+ + +) to the triplet (+ + 0), see Fig. 2, is based on the first row of Tab. 1, see the first and only possible transition.

Table 1. A complete set of one-dimensional transitions

				a	b	c	d	E	f
	From		To	Or	Or	Or	Or	Or	Or
1	+++	→	++0						
2	++0	→	+++	++-					
3	++-	→	++0	+0-	+00				
4	+0+	→	+++						
5	+00	→	+++	+--					
6	+0-	→	+--						
7	+-+	→	+-0	+0+	+00	0-+	00+	000	0-0
8	+-0	→	+-+	+--	0-0				
9	+--	→	+-0	0--	0-0				
10	0++	→	++0	++-	+++				
11	0+0	→	++0	++-	+++				
12	0+-	→	++-						
13	00+	→	+++						
14	000	→	+++	---					
15	00-	→	---						
16	0-+	→	--+						
17	0-0	→	--0	--+	---				
18	0--	→	--0	--+	---				
19	-++	→	-+0	0++	0+0				
20	-+0	→	-+-	-++	0+0				
21	-+-	→	-+0	-0-	-00	0+-	00-	000	0+0
22	-0+	→	-++						
23	-00	→	-++	---					
24	-0-	→	---						
25	--+	→	--0	-0+	-00				
26	--0	→	---	--+					
27	---	→	--0						

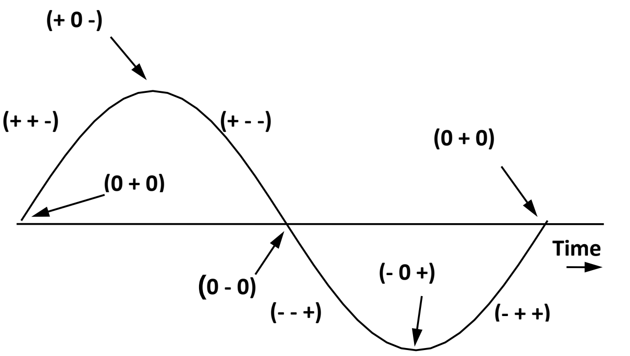

Figure 2. A qualitative description of an oscillation using a sequence of one-dimensional scenarios

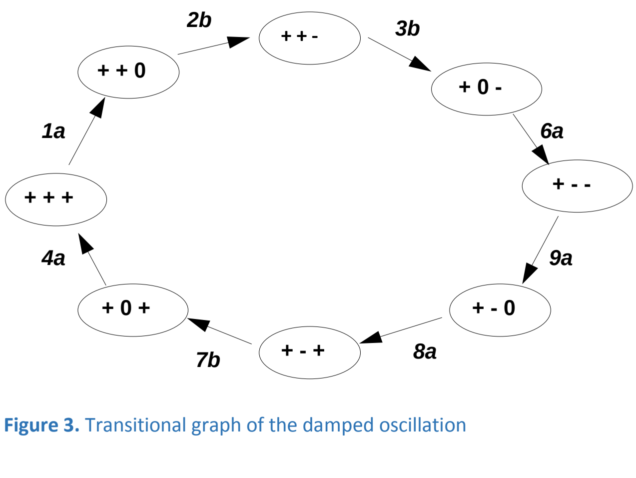

Figure 3. Transitional graph of the damped oscillation

Any set of scenarios (3) is a finite set because of the finite set of the qualitative values (1). Let the set S(m, n) of m qualitative n-dimensional scenarios (3):

$$S\ (m,\ n) \qquad (11)$$

be a solution of a qualitative n dimensional model M (2)

$$M\ (r,n) \qquad (12)$$

where r is the number of its equations/relations, see e.g. Fig. 1. A transitional graph G is an oriented graph. Its nodes are the set of scenarios S (9) and oriented arcs are the transitions T:

$$G\ (S,\ T) \qquad (13)$$

However, the set of transitions T can be easily generated by the corresponding set of scenarios S using Tab. 1:

$$G(S,\ T(S)) \qquad (14)$$

3 RESULTS

Realistic sustainability models with more than ten variables, n > 10, (2), often have several hundred scenarios, m > 100, (3), and several thousand transitions T (11). The results are therefore not publishable. Based on a literature review, from 60 PSF were selected 10 factors for qualitative model. Each factor was characterised by 10 variables (see Tab. 2).

Table 2 Selected factors for qualitative model

No.	Variable	The name of factor	Subset (C or L) (5)
1	REL	Human reliability	L
2	SAT	Staff satisfaction	L
3	SAL	Staff costs	C
4	INT	Intelligence	C
5	AGE	Age	C
6	EDU	Education	C
7	EXP	Experience	C
8	TIM	Available time	L
9	ENV	Environment	C
10	STR	Stress	L

Interdependencies between variables are based on research published in literature sources [Gardner 2002], [Ganzach 1998], [Clark 1996], [Wickens 2013], etc. For each pair of factors, relevant qualitative relations (mutual bonds) were selected (see Fig. 1). Factors without interdependencies were marked "X" (see Tab. 3).

Table 3. Interdependencies between variables

	REL	SAT	SAL	INT	AGE	EDU	EXP	TIM	ENV	STR
REL	-									
SAT	23	-								
SAL	23	22	-							
INT	23	22	21	-						
AGE	26	23	22	23	-					
EDU	23	22	21	22	22	-				
EXP	23	21	21	X	22	X	-			
TIM	23	23	23	X	X	X	X	-		
ENV	23	23	21	23	X	23	X	22	-	
STR	26	22	25	25	21	22	25	25	25	-

All the relations listed in Tab. 2 were added to the following input model (see Tab. 4). The first column is the serial number, the second is a kind of graph, the third and fourth refer to the interacting variables, and the last column indicates what the Y variable will be like (negative, zero, positive) when the X variable is equal to zero .

Table 4. Input model

1 23 SAT REL 0	10 21 EXP SAT 0	19 22 EDU INT 0
2 23 SAL REL 0	11 23 TIM SAT 0	20 23 ENV INT 0
3 23 INT REL 0	12 23 ENV SAT 0	21 25 STR INT 0
4 26 AGE REL 0	13 21 INT SAL 0	22 21 STR AGE 0
5 23 EDU REL 0	14 21 EDU SAL 0	23 23 ENV EDU 0
6 26 STR REL 0	15 21 EXP SAL 0	24 25 STR EXP 0
7 22 SAL SAT 0	16 23 TIM SAL 0	25 22 ENV TIM 0
8 22 INT SAT 0	17 21 ENV SAL 0	26 25 STR TIM 0
9 22 EDU SAT 0	18 25 STR SAL 0	27 25 STR ENV 0

The results of simulation are scenarios shown in the following Tab. 5. Scenario number corresponds to the number of row into the table.

Table 5. Results of simulation

REL	SAT	SAL	INT	AGE	EDU	EXP	TIM	ENV	STR
+++	+++	+++	+++	+--	+++	+++	+++	+++	+--
++0	+++	+++	+++	+--	+++	+++	+++	+++	+--
++-	+++	+++	+++	+-+	+++	+++	+++	+++	+--
++-	+++	+++	+++	+-0	+++	+++	+++	+++	+--
++-	+++	+++	+++	+--	+++	+++	+++	+++	+--
++-	++-	++-	++-	+-+	++-	++-	++-	++-	+-+
+0+	+0+	+0+	+0+	+0-	+0+	+0+	+0+	+0+	+0-
+00	+00	+00	+00	+00	+00	+00	+00	+00	+00
+0-	+0-	+0-	+0-	+0+	+0-	+0-	+0-	+0-	+0+
+-+	+-+	+-+	+-+	++-	+-+	+-+	+-+	+-+	++-
+-0	+-+	+-+	+-+	++-	+-+	+-+	+-+	+-+	++-
+--	+-+	+-+	+-+	+++	+-+	+-+	+-+	+-+	++-
+--	+-+	+-+	+-+	++0	+-+	+-+	+-+	+-+	++-
+--	+-+	+-+	+-+	++-	+-+	+-+	+-+	+-+	++-
+--	+--	+--	+--	+++	+--	+--	+--	+--	+++

4 DISCUSSION

4.1 Scenarios assessment

For our case, the most interesting are scenarios where reliability and staff satisfaction are increasing with staff costs showing a decrease. This can be expressed as follows (see Tab.6):

Table 6. Goals of simulation

Variable	Goals, i.e.	desired trends
Human reliability	REL	Increase
Staff satisfaction	SAT	Increase
Staff costs	SAL	Decrease

The results of the analysis show that this scenario is not realistic (in long-term it is not possible to run the facility operated by reliable and satisfied staff with decreasing costs per worker). Should the staff be reliable and satisfied in their work, it is also necessary to increase the staff costs. Therefore, we will focus on the scenarios where reliability, satisfaction and even staff costs per individual worker increase as shown in the scenarios 1 to 6 in Tab. 5. Other scenarios refer to the cases where the reliability of staff decreases; therefore it is an undesirable situation.

4.2 Transitional graph of scenarios

To find out if it is possible to switch from the current scenario, in which the system is, to a desired scenario, it is possible to use the transition matrix which is graphically shown in fig. 4. This directed graph illustrates how the desired scenario might be achieved. The nodes represent the individual scenarios, directed flow lines - possible transitions between the scenarios.

Scenario 15 (the last row into the table 5) represents the situation where there is no path to improvement; it is the worst case where all parameters are unsatisfactory (REL and SAT decrease, AGE and STR increase). Scenario 9 enables the only path to the unsatisfactory scenario 15. Within the transition from Scenario 6 to Scenario 9, the worst state will be reached. In the opposite case, Scenario 6 will lead to Scenario 8. This scenario is a zero (critical) point, wherefrom we can get both the best or to the worst scenario. The transition from the unsatisfactory Scenario 12 to the satisfactory Scenario 1 can be achieved using several paths:

12 → 13 → 11 → 10 → 7 →1,

12 → 13 → 14 →11 → 10 → 7 →1,

12 → 13 → 11 → 10 → 8 →1,

12 → 13 → 14 →11 → 10 → 8 →1.

If we consider the first path 12 → 13 → 11 → 10 → 7 → 1, then, within the transition 12 → 13, the factor "AGE" is changed. The transition 13 → 11 is accompanied by two changes: of factors "REL" and "AGE". The key transitions are 10 → 7 and 7 → 1 where all 10 variables are changed. A subset C of variables X can be controlled by a decision maker; the remaining variables L are lottery variables as they are outside any control (see Tab.2, Subset C or L). For instance, factors "INT", "AGE", "EDU", "EXP" can be influenced by intentionally accepting a better candidate for the particular working position. Factor "ENV" is also controllable, physical conditions of the workplace and ergonomics are measurable and can be changed. Variable "SAL", or costs per worker can also be affected. Other factors such as reliability, staff satisfaction, the time available for performing the task and stress are influenced only indirectly. Scenarios 2-5 are affected only by the age of employees. This may be caused by the fact that the factor "AGE" has the most interactions in the input model.

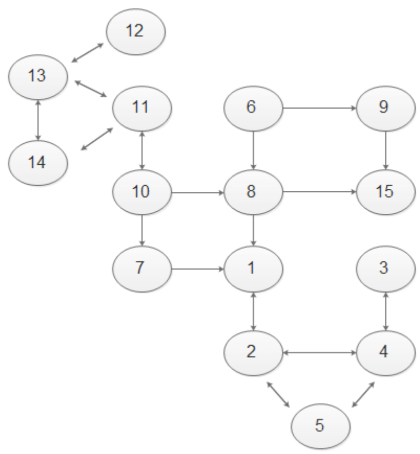

Figure 4. Transitional graph of scenarios

5 CONCLUSIONS

The paper presents a simple formalized qualitative model of performance shaping factors influencing human reliability. As input information the interdependencies between factors are used. Appropriate qualitative relations were chosen for each pair of factors, and using a specific computer program, different scenarios were created.

Using the above mentioned model, it is possible to specify how to map the situation with a subsequent increase in reliability and staff satisfaction. As can be seen from the created model the way how to achieve this goal is not through the reduction of staff costs. When choosing a suitable employee we should focus on the factors of age, intelligence, education and experience of the candidate.

A described model is not the only alternative. Further modifications and extensions are possible.This paper presents an application of qualitative modelling methodology for determining PSF bonds and demonstrates the possibilities of modelling of PSF bonds related to the operators of technical systems. This study could be specified and supplemented with the use of more factors (such as the individual effects of the working environment, organizational stressors and individual characteristics of employees) and by modelling via unidirectional independent bonds between PSFs.

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