An ISM-based Analysis for Modelling Factors in Railway Maintenance task

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Abstract:
The objective of this paper is to understand the interaction of the various factors and to identify driving and dependent factors. An interpretive structural model (ISM) is presented, and factors are classified using matrice d'impacts croises-multiplication appliqué à un classement (MICMAC). The research may help maintenance management understand the interaction of factors affecting human failure probability in railway maintenance and help management devise policies and guidelines for railway maintenance related tasks.

Key words: maintenance, human probability, modelling, factors

1. Introduction

Railway system has different working conditions, and human performance requirements compared to industries (Donald and Thomas (2007). Maintenance includes a variety of technical fields, work tasks, and personnel interacting with complex technologies (Oedewald and Reiman (2003). Maintenance in railways includes such activities as shunting, cleaning, graffiti removal, overhauls, effective management of spare parts and reprocessing of components such as traction motors, wheels and bogies etc. Maintenance is more or less a human activity; it is nearly impossible to entirely eradicate human error but can be minimized through good maintenance management and an understanding of the issues that affect error (HSE, 2000). . Human factor specialists are attempting to create a suitable framework for the analysis of the human factor in systems reliability. The primary emphasis is on the quantification of human error, which generally reflects a negative attribution but covers diverse situations and events, including management decision errors, design and maintenance errors, and operator errors (Watson and Oakes 1988). In railway maintenance tasks, there can be many reasons for human errors but some are more salient than others. Researchers (Singh et al. 2015; Singh et al. 2014; Dhillon 1986; Meister 1962; Rigby 1970) define the most probable causes of human error as poor training, poor equipment design, complex tasks, poor work and design layout, poorly written maintenance manuals, inadequate work tools, poor verbal communication, poor management etc. As per (HSE 1999), three factor categories, job and organizational factors, affect the performance of any work activity, including maintenance. until now, research has been conducted to measure maintenance performance (Kumar et al. 2011), human errors during operation and maintenance, and performance shaping factors by structural factors (Yoshino 1996). The research has been conducted in two railway maintenance workshops in Luleå, Sweden. It considers individual factors (stress, fatigue, work station design, maintenance manuals, complexity of tasks, available time to diagnose problems. The main objective of is to prioritize the identified factors, classify them as dependent, linkage, or driving factors, and evaluate the contextual relationship among them using ISM-based analysis. Seven factors affecting the probability of the failure of human operators in railway maintenance tasks were identified through a comprehensive literature review and discussions with experts from industry and academia. The factors include: experience, stress, fatigue, complexity of task, work station design, maintenance manual, available time to act and available time to diagnose. Experience is an important factor in maintenance. An individual gains knowledge and skill through increasing involvement in or exposure to a particular task over time. With fewer years of experience, an individual may not have the knowledge required to perform the necessary task. With more experience less time is required for actions and decisions; it is a better predictor of performance than age (Bruce et al. 1990). Many researchers have noted the relationship between human performance and stress. There are four types of occupational stressors (Hagen 1976; Dhillon 2007): change-related, frustration-related, workload-related, and miscellaneous stressors. Hagen (1976) and Beech (1982) demonstrated the relationship between stress and human performance as a curve. Interestingly, maximum human performance effectiveness occurs at moderate levels of stress and not at low stress. Beyond moderate stress levels, fear, anxiety and other types of psychological stress result in a decline in performance, resulting in errors in maintenance tasks (Dhillon, 2007). Fatigue can affect almost all maintenance tasks, as it causes memory lapses, reduced judgment, difficulty focusing, reduced motivation, and other performance effects (Hobbs et al. 2011). Much has been written on fatigue in the transportation industry and there is a close association between fatigue and human-error related accidents (Dinges 1995; Mitler 1988). Maintenance quality relies on the performance of maintenance staff. Even though high-quality maintenance is extremely important, the increasing complexity of maintenance tasks on today’s railway system makes it difficult for operators to fully understand the system's functions, escalating the risk that maintenance is carried out incorrectly (HSE, 2000). Effective maintenance execution in railways will reduce maintenance time at minimum cost with inventive, unified and effective solutions. However, complex tasks can increase the time required to diagnose and act. Therefore, it is essential to evaluate the complexity of tasks when determining their effect on the probability of human failure. In maintenance related tasks, workstation design and layout considers workers’ needs, competences, anthropometry, and viewing angles and distances. Poor design can result in risk of damage to users’ muscles and joints, (Health and Safety Guidance, 1998), can cause significant forces on lower back (Singh & Kumar 2012a). It is therefore suggested that the workplace should be designed for negligible twisting and moderate lifting frequency (Singh and kumar 2012b) for negligible human failure. A good workstation design and layout supports maintenance personnel in achieving their operational objectives. Generally, there are three goals to consider in human-centred design: augment maintenance personnel abilities, overcome human limitations, and encourage user acceptance. Well-developed procedures and clear instructions are a prerequisite to achieving maintenance objectives. A machine that requires its operator to follow a complicated user manual is a source of risk in itself (HSG245 2004**).** Maintenance manuals/procedures are judged by the speed with which information can be found. A complex or poorly written maintenance manual (procedures) increases the risk that reaction times are longer and maintenance tasks are carried out incorrectly.

2 Methodology

A questionnaire-based survey was used to rank the factors affecting human performance in railway maintenance tasks and to develop an ISM approach. The questionnaire took into account the opinions of experts from academia and industry. In the questionnaire, maintenance personnel were asked to designate the significance of 11 factors on a 5-point Likert scale. On this scale, “1” and “5” corresponded to “not at all influential” and “extremely influential” respectively. The questionnaire was administered to personnel in railway maintenance workshops at Luleå, Sweden. Cronbach´s alpha coefficients were applied to the responses to determine reliability. In this case, the value of Cronbach´s alpha coefficients is 0.71; this falls within the range of 0.7-0.8, ensuring acceptable reliability (Nunnaly 1987). The questionnaire based survey was further processed with the help of Minitab software version 16. The mean, standard deviation, variance and rank for each factor are shown in Table 1. The correlation coefficient of factors (Table 2) was classified according to the strength of the correlation coefficient (Hair et al. 2003).

Table 1 Statistical data analysis

Factors	Mean Score	Std. Deviation	Variance	Rank
Experience (F1)	3,732	1,074	1,154	III
Stress (F2)	3,611	0,698	0,487	V
Fatigue (F3)	3,611	0,916	0,840	V
Complexity of task (F4)	3,056	1,056	1,114	VII
Workstation design (F5)	2,833	1,043	1,088	IX
Maintenance Manual (Procedure) (F6)	4,222	1,003	1,007	I
Available time to diagnose (F7)	3,389	0,850	0,722	VII

Table 2 Classification of factors based on significance of correlation

Variable Numbers	[a]Very strongly correlated	[b]Strongly correlated	[c]Moderately correlated	[d]Weakly correlated	[e]Not correlated
1	1		5	4,7,11	2,3,6,8,9,10
2	2		8	3,4,7,9,10	5,6,11
3	3	8		2,4,5	1,6,7,9,10,11
4	4			1,2,3,5,7,8	6,9,10,11
5	5		1	3,4,6,7,8,9,11	2,10
6	6			5,6,10	1,2,3,4,7,8,11
7	7		8,9	1,2,4,5,6,10,11	3

[a]correlation coefficient between 0.801-1.000; [b]correlation coefficient between 0.601 -0.800; [c]correlation coefficient between 0.401-0.600; [d] correlation coefficient between 0.201-0.400; [e]correlation coefficient less than or equal to 0.200.

3. Interpretive Structural Modelling

Interpretive Structural Modelling (ISM) has a long history of use (Harary et al. 1965), but was first proposed to analyse complex socioeconomic systems by Warfield in 1974. The basic idea is to use expert knowledge and experience to decompose a complex system into several subsystems and construct a multilevel structural model (Warfield 1974; saga 1977). ISM provides a means to impose an order on complex items in a carefully designed pattern (Singh et al. 2003; Ravi and Shankar 2005; Borade et al. 2011). In this research, the contextual relationship among the factors affecting the probability of failure of human operators in railway maintenance tasks was developed after consulting experts from both academia and industry. A “leads to” contextual relationship was chosen to analyse the relationship among the factors. In the process of developing SSIM, the symbols (V, A, X, O) were used to denote the direction of the relationship between two factors (*i* and *j*). In Table 5, V is the relation from factor *i* to factor *j* (i.e. if factor *i* influences or reaches to factor *j*), A is the relation from factor *j* to factor *i* (i.e. if factor *j* reaches to factor *i*), X is used for both direction relations (i.e. if factors *i* and *j* reach to each other), and O indicates no relation between two factors (i.e. if factors *i* and *j* are unrelated). Based on these contextual relationships the SSIM is developed (Table 3).

Table 3: Structural self-interactive matrix (SSIM)

	7	6	5	4	3	2
1	V	O	O	V	O	V
2	V	A	A	X	X	
3	V	A	A	X		
4	V	A	A			
5	V	O				
6	V					
7						

3.2.2 Reachability Matrix

A reachability matrix is a binary matrix (1, 0). The structural self-interactive matrix is transformed into initial reachability matrix by substituting V, A, X and O by 1 and 0. The rules for formulating this matrix are as follows:

a) In structural self-interactive matrix (SSIM), if the cell (*i*, *j*) is assigned symbol V, in the initial reachability matrix, this cell (*i*, *j*) entry becomes 1 and the cell (*j*, *i*) entry becomes 0.

b) In structural self-interactive matrix (SSIM), if the cell (*i*, *j*) is assigned symbol A, in the initial reachability matrix, this cell (*i*, *j*) entry becomes 0 and the cell (*j*, *i*) entry becomes 1.

c) In structural self-interactive matrix (SSIM), if the cell (*i*, *j*) is assigned symbol X, in the initial reachability matrix, this cell (*i*, *j*) entry becomes 1 and the cell (*j*, *i*) entry also becomes 1.

d) In structural self-interactive matrix (SSIM), if the cell (*i*, *j*) is assigned symbol O, in the initial reachability matrix, this cell (*i*, *j*) entry becomes 0 and the cell (*j*, *i*) entry becomes 0.

Following these rules, the initial reachability matrix is obtained (Table 4).

Table 4: Initial reachability matrix

	1	2	3	4	5	6	7
1	1	1	0	1	0	0	1
2	0	1	1	1	0	0	1
3	0	1	1	1	0	0	1
4	0	1	1	1	0	0	1
5	0	1	1	1	1	0	1
6	0	1	1	1	0	1	1
7	0	0	0	0	0	0	1

The concept of transitivity is to fill some of the cells of the initial reachability matrix (Table 4) by inference. The use of assumptions (Sharma et al. 1995; Watson 1978; Farris and Sage 1975) fills the gap, if any, in the experts' opinions collected during the development of the SSIM, thus helping to maintain the conceptual consistency (Raj et al. 2008). If factor A is related to B and factor B is related to C, transitivity implies that factor A is necessarily related to C. After incorporating the transitivity concept, the final reachability matrix is obtained. The final reachability matrix indicates the driving power and dependence of each factor (Table 5). Dependence is the total number of variables (including itself) which may be impacting a factor. The driving power for each variable is the total number of variables (including itself), which it may impact.

Table 5: Final reachability matrix

Factors	1	2	3	4	5	6	7	Driver Power	Driver Rank
1	1	1	1*	1	0	0	1		
2	0	1	1	1	0	0	1		
3	0	1	1	1	0	0	1		
4	0	1	1	1	0	0	1		
5	0	1	1	1	1	0	1		
6	0	1	1	1	0	1	1		
7	0	0	0	1*	0	0	1		
Dependence									
Dependence Rank									

1* entries are included to incorporate transitivity

3.1 Partitioning Factors

From the final reachability matrix, the reachability and antecedent set (Warfield 1974) for each factor are obtained. Then, the intersection of the sets is derived for all factors. The factor for which the reachability and the intersection sets are the same becomes the top-level factor in the ISM hierarchy. It is clear from Table 6 that "available time to diagnose" and "available time to act" are at level 1. Tables 7 and 8 show levels II and III. The factors at these levels are:

Table 6 Iteration 1

Variables	Reachability set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,7,8,9	1	1	
2	2,3,4,7,8,9	1,2,3,4,5,6,8,9,10,11	2,3,4,8,9	
3	2,3,4,7,8,9	1,2,3,4,5,6,8,9,10,11	2,3,4,8,9	
4	2,3,4,7,8,9	1,2,3,4,5,6,7,8,9,10,11	2,3,4,8,9	
5	2,3,4,5,7,8,9	5	5	
6	2,3,4,6,7,8,9	6	6	
7	4,7,8	1,2,3,4,5,6,7,8,9,10,11	4,7,8	I

Table 7 Iteration 2

Variables	Reachability set	Antecedent Set	Intersection Set	Level
1	1, 9	1	1	
2	9	1, 5,6, ,9,10,11	9	II
3	9	1,5,6,,9,10,11	9	II
4	9	1,5,6,9,10,11	9	II
5	5,9	5	5	
6	6,9	6	6	

Table 8 Iteration 3

Variables	Reachability set	Antecedent Set	Intersection Set	Level
1	1	1	1	III
5	5	5	5	III
6	6,	6	6	III

3.2 ISM model development

The structural model generated from a final reachability matrix is called a diagraph. In this case, the ISM model was developed after removing transitivity links and replacing the node numbers with statements (Figure 1). The model shows that the most significant factors affecting the probability of operator failure in railway maintenance are "experience", "workstation design", "maintenance manual", "training and certification" and "role of management".

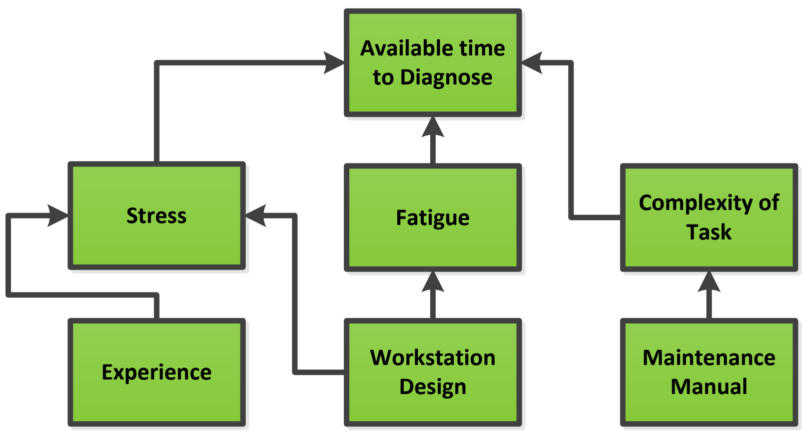

Figure 1: Proposed ISM showing factors affecting probability of operator failure in railway maintenance tasks

3.3 MICMAC Analysis

MICMAC analysis refers to *Matrice d'Impacts Croisés Multiplication Appliquée à un Classement* (Duperrin, 1973). It involves the development of a graph to classify factors as driving or dependent. In this case, the factors affecting the failure probability of human operators in railway maintenance tasks are classified as: autonomous factors (weak driving power and weak dependence), linkage factors (strong driving power as well as strong dependence), dependent factors (weak driving power but strong dependence) and independent factors (strong driving power but weak dependence power). The drive power-dependence power diagram is shown in Figure 2.

Figure 2: Clusters of factors affecting probability of human failure in railway maintenance tasks

Driving Power	7	F1, F5, F6	Driving Factors (IV)				Linkage Factors (III)	
	6							
	5						F2, F3	F4
	4		Autonomous Factors (I)				Dependent Factors (II)	
	3							F7
	2							
	1							
		1	2	3	4	5	6	7
	Dependence Power							

4. Results and Conclusions

This paper's objective is to identify and analyse the factors affecting the probability of human failure in railway maintenance tasks. An ISM-based model has been developed to analyse the interactions among the factors. The driver power-dependence matrix sheds light on the relative importance of each factor and the interdependence among the factors. Figure 2 shows that none of the factors fall into category- I (autonomous factors); in other words, all factors considered in the research significantly affect operator failure. "Available time to diagnose" is dependent factor. These have weak driving power but strong dependence power. "Stress", "fatigue", and "complexity of task" have strong driving power as well as high dependencies and are linkage factors. If these factors are accommodated, there will be a positive influence on maintenance with a reduction in human error. It Figure 2 also shows that " experience", "workstation design", and "maintenance manuals" are independent factors. In other words, they have strong driving power and weak dependency on other factors. They may be treated as the key factors affecting the probability of human failure. This study can provide valuable information for the formulation of guidelines to improve the quality of maintenance activities. The results can assist maintenance management in taking remedial actions. The proposed ISM-based model provides a very useful explanation of the relationships among the factors.

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