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EVALUATION OF CRITICAL FACTORS AFFECTING MAINTENANCE TASKS: A CASE STUDY

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Abstract:-

The objective of this paper is to identify and analyse the factors affecting the probability of human performance in maintenance tasks. It is well known fact that there are number of parameters and factors which directly or indirectly result in a decline in human performance, causing errors in maintenance. This research work investigates the factors affecting human performance when performing maintenance tasks. The objective is to understand the interaction of the various factors and to identify driving and dependent factors. The factors are identified through a survey of the literature and ranked using a Likert scale. The reliability of measures is pretested by applying Cronbach's alpha coefficient to responses to the questionnaire given to maintenance personnel. 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. 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 performance in maintenance and help management devise policies and guidelines for maintenance related tasks.

1. INTRODUCTION

The concept of maintenance is very old but very less attention is given for proper care to the machines. Maintenance Engineering is a collective measure taken up by the industry in order to keep the equipment or machine in trouble free environment. In other words Maintenance can be defined as set of activities required to keep a system in good condition. Although it is nearly impossible to eradicate all maintenance errors, it can be minimised through good maintenance management and an understanding of the issues that affect maintenance errors. The goal of maintainability from a human factor perspective is to minimize human error, preventing failure and restoring failed systems effectively with minimum risk of accident. The reasons of maintenance errors for these include lack of training, interrupted flow of information, poorly written maintenance manuals, inadequate lighting, poor equipment design, high noise levels, inadequate work layout, improper tools etc. The consequence results in making incorrect decisions, incorrect actions, incorrect checks, etc. Therefore, it becomes very essential to investigate the factors affecting human performance in maintenance tasks and creating opportunities for human errors. In this research work work proper investigation of factors influencing maintenance tasks will be done. It has been observed from literature that, until now, less work has considered the interrelation of factors affecting the probability of failure of human operators in maintenance tasks using ISM-based analysis. "The development of new technologies in transit systems has benefited customers and transit companies but has led to difficulties upgrading the skills of the workforce maintaining the new technology" (Rail Vehicles Maintenance Training Standards, 2010). With effective training and certification, a technician can carry out tasks involving an extensive range of skilled applications. It is crucial to evaluate training as an independent factor affecting human failure. In the present scenario, the inadequacy of trained and certified maintenance personnel may affect the safe and efficient operation of systems (Rail Vehicles Maintenance Training Standards, 2010). However, complex tasks can enhance 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 plays a vital role in effective execution of maintenance tasks by supporting maintenance personnel in achieving their operational objectives. In this research work the factors causing decline in human performance resulting errors have been derived from group discussion among technicians, supervisors and academic experts. These group discussions were named as brain storming sessions. After this brainstorming session, we developed cause categories (subject factors, organizational factors, workplace design and environmental factors, maintenance task factors). From these, we constructed a cause and effect diagram (CAED) to link all possible causes with the appropriate action (Figure 1) and fault tree. In 1950, K. Ishikawa (Mears, 1995) established the cause and effect diagram (CAED) method. It is also called the "fishbone diagram" because of its resemblance to the skeleton of a fish. The right-hand side of the diagram represents the effect, such as a technician making an error; the left hand-side represents all possible causes, such as stress, time pressure, role of management etc.

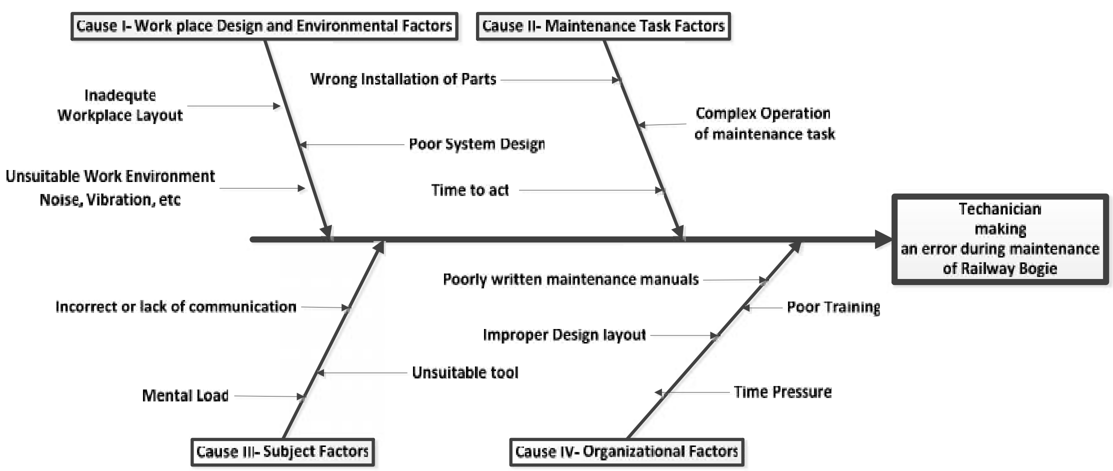

Figure 1

In the present work, nine factors affecting the probability of the failure of human operators in maintenance tasks were identified through a comprehensive literature review and discussions with experts from industry and academia. The factors include; Role of Management (F1), Complexity of task (F2), Training and certification (F3), Tool availability (F4), Time pressure (F5), Available time to diagnose (F6), Workstation design (F7), Stress (F8) and Maintenance Manuals (F9). 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.

2. METHODOLOGY

The existent maintenance practises in the maintenance workshop are not considering various factors and their effects on each other. It has been observed from literature review that research has used structural factors to measure maintenance performance, human errors, and performance shaping factors but very less work has considered the interrelation of factors affecting the human performance in maintenance tasks using ISM-based analysis. Therefore the objective drawn from the literature 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. Therefore, an attempt will be made to identify various factors affecting human performance in maintenance tasks. Moreover, the present research work investigates the association between various factors influencing maintenance tasks and creating opportunities for human errors. In the beginning of research work, a questionnaire-based survey was used to rank the factors affecting human performance in maintenance tasks and to develop an ISM approach. In this research work a questionnaire was designed keeping the opinions of experts from academia and industry. In the questionnaire, maintenance personnel were asked to designate the significance of eight identified factors on a five -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 maintenance workshops. Cronbach´s alpha coefficients were applied to the responses to determine reliability. In this case, the value of Cronbach´s alpha coefficients falls within the range of 0.6-0.8, ensuring acceptable reliability (Nunnaly 1987). In total, 60 questionnaires were distributed and 52 completed questionnaires were received, giving a fairly good response rate (Malhotra and Grover 1998). The questionnaire based survey was further processed with the help of Minitab software version 16.

Interpretive Structural Modelling

The concept of Interpretive Structural Modelling (ISM) was first proposed to analyse complex socioeconomic systems by Warfield in 1974, but it has a long history of use (Harary et al. 1965). It uses expert knowledge and experience to decompose a complex system into several subsystems and construct a multilevel structural model to identify and summarise relationships among specific items (Warfield 1974; saga 1977). ISM provides a means to impose an order on complex items in a carefully designed pattern (Raj et al. 2008; 2009; Mudgal et al. 2010; Singh et al. 2003; Ravi and Shankar 2005; Borade et al. 2011). ISM generally has the following steps (Ravi and Shankar, 2005; Warfield, 1974; Sage 1977); Step 1: Factors identification affecting the system; Step 2: Contextual relationship among the factors; Step 3: SSIM (Structural Self-Interaction Matrix) for factors based on pairwise comparison of factors;Step 4: Reachability matrix from SSIM and verification of its transitivity; Step 5: Partition of reachability matrix into levels Step 6: Drawing of diagraph based on contextual relationship; removal of transitivity links; Step 7: Creation of ISM. 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. Furthermore, the coefficient of correlation among factors appears in Table 2. The table shows that "Available time to diagnose" have the maximum value of correlation.

Factors affecting operators' performance	**Mean Score**	**Std. Deviation**	**Variance**	**Rank**
Role of Management (F1)	3.732	1.074	1.154	III
Complexity of task (F2)	3.611	0.698	0.487	IV
Training and certification (F3)	3.611	0.916	0.840	IV
Tool availability (F4)	3.056	1.056	1.114	VI
Time pressure (F5)	2.833	1.043	1.088	VII
Available time to diagnose (F6)	4.222	1.003	1.007	I
Workstation design (F7)	3.389	0.850	0.722	V
Stress (F8)	3.889	0.758	0.575	II
Maintenance Manuals (F9).	3.611	1.092	1.193	IV

Table 1 Statistical data analysis

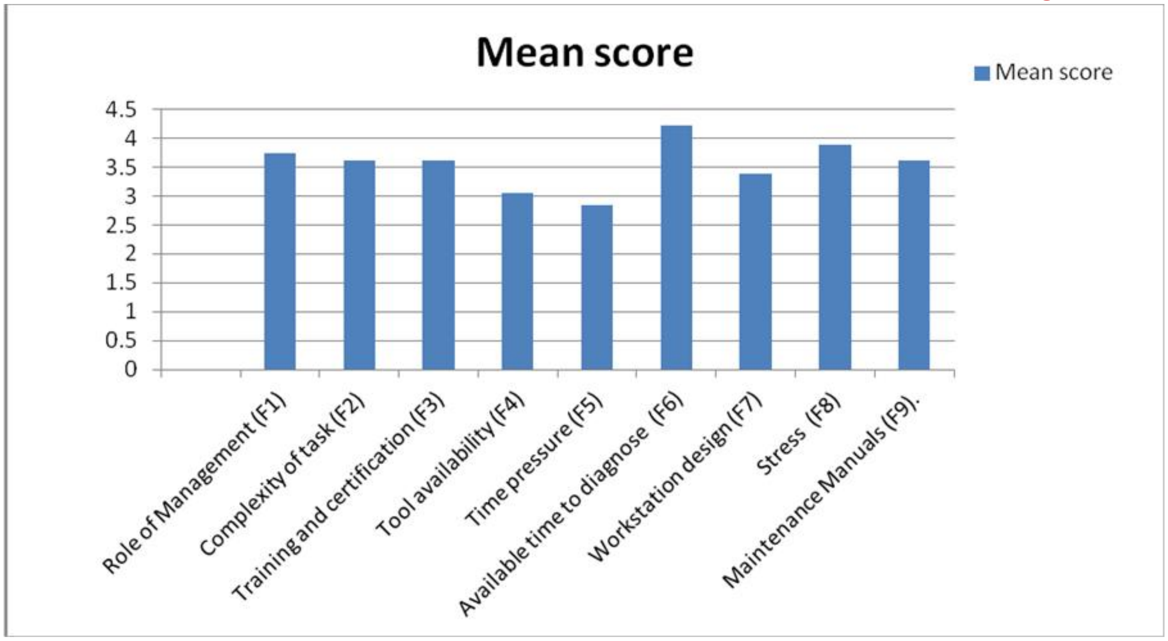

Figure 2

The correlation coefficient of factors was classified according to the strength of the correlation coefficient (Hair et al. 2003). "Training and certification" and "stress" are strongly correlated. Furthermore, "Role of Management" and "Complexity of task" and "Time pressure" and "Workstation design" and "stress" are moderately correlated (Table 3).

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	1	-0.310	0.123	0.378	0.481	-0.049	0.319	0.177	0.053
2	-0.310	1	0.393	0.271	0.067	-0.205	0.270	0.469	0.253
3	0.123	0.393	1	0.328	0.359	-0.284	0.055	0.696	0.134
4	0.378	0.271	0.328	1	0.329	0.154	0.237	0.302	0.020
5	0.481	0.067	0.359	0.329	1	0.206	0.343	0.347	0.353
6	-0.049	-0.205	-0.284	0.154	0.206	1	0.307	-0.198	-0.078
7	0.319	0.270	0.055	0.237	0.343	0.307	1	0.436	0.426
8	0.177	0.469	0.696	0.302	0.347	-0.198	0.436	1	0.371
9	0.053	0.253	0.134	0.020	0.353	-0.078	0.426	0.371	1

Table 2 Coefficient of correlation of factors

In this research, the contextual relationship among the factors affecting the probability of failure of human operators in 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. The Structural self-interactive matrix (SSIM) has been developed using the symbols (V, A, X, O) to denote the direction of the relationship between two factors (i and j). 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 4).

Factor	[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	1,2,4,5,6,10,11	3
8	8	3	2,7	4,5,9	1,6,10,11
9	9		7	2,5,8	1,3,4,5,8,9

Table 3 Classification of factors based on significance of correlation

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

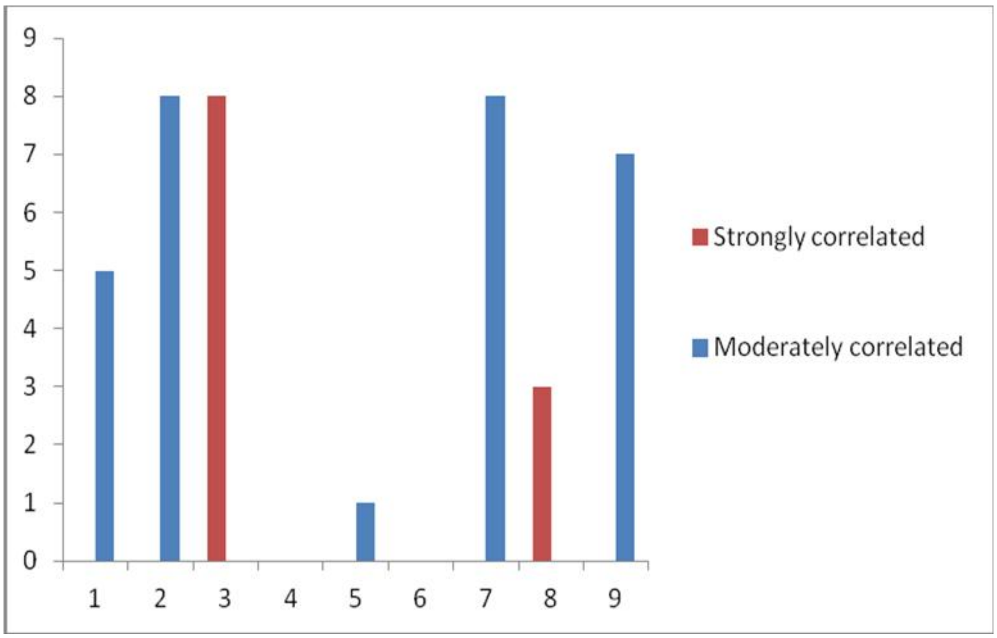

Figure 3

The reachability matrix (Table 5) 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 final reachability matrix indicates the driving power and dependence of each factor (Table 6). Dependence is the total number of variables (including it) which may be impacting a factor. The driving power for each variable is the total number of variables (including itself), which it may impact. However, the reachability and antecedent set (Warfield 1974) for each factor have been obtained from final reachability matrix.

	9	8	7	6	5	4	3	2
1	O	V	V	O	O	V	O	V
2	V	V	V	A	A	X	X	
3	A	V	V	A	A	X		
4	O	X	V	A	A			
5	O	V	V	O				
6	O	V	V					
7	A	X						
8	A							

Table 4 : Structural self-interactive matrix (SSIM)

	1	2	3	4	5	6	7	8	9
1	1	1	0	1	0	0	1	1	0
2	0	1	1	1	0	0	1	1	1
3	0	1	1	1	0	0	1	1	0
4	0	1	1	1	0	0	1	1	0
5	0	1	1	1	1	0	1	1	0
6	0	1	1	1	0	1	1	1	0
7	0	0	0	0	0	0	1	1	0
8	0	0	0	1	0	0	1	1	0
9	0	0	1	0	0	0	1	1	1

Table 5 : Initial Reachability matrix

Factors	1	2	3	4	5	6	7	8	9	Driver Power	Driver Rank
1	1	1	1*	1	0	0	1	1	1*	**7**	**I**
2	0	1	1	1	0	0	1	1	1	**6**	**II**
3	0	1	1	1	0	0	1	1	1*	**6**	**II**
4	0	1	1	1	0	0	1	1	1*	**6**	**II**
5	0	1	1	1	1	0	1	1	1*	**7**	**I**
6	0	1	1	1	0	1	1	1	1*	**7**	**I**
7	0	0	0	1*	0	0	1	1	0	**3**	**IV**
8	0	1*	1*	1	0	0	1	1	0	**5**	**III**
9	0	1*	1	1*	0	0	1	1	1	**6**	**II**
Dependence	**1**	**9**	**9**	**9**	**1**	**1**	**9**	**9**	**7**		
Dependence Rank	**III**	**I**	**I**	**I**	**III**	**III**	**I**	**I**	**II**		

Table 6 : Final reachability matrix

1* entries are included to incorporate transitivity

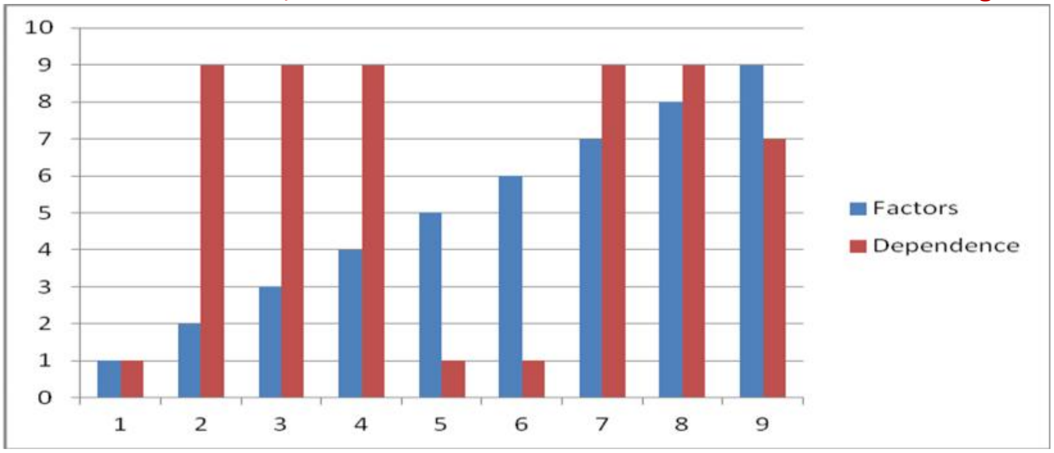

Figure 4

Factors	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,	2,3,4,8,9	
3	2,3,4,7,8,9	1,2,3,4,5,6,8,9,	2,3,4,8,9	
4	2,3,4,7,8,9	1,2,3,4,5,6,7,8,9,	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,	4,7,8	**I**
8	2,3,4,7,8	1,2,3,4,5,6,7,8,9,	2,3,4,7,8	**I**
9	2,3,4,7,8,9	1,2,3,4,5,6,9,	2,3,4,9	

Table 7 Iteration I

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

Table 8 Iteration II

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

Table 9 Iteration III

3. MICMAC ANALYSIS

Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) analysis involves the development of a graph to classify factors as driving or dependent (Duperrin 1973).
The main objective of MICMAC analysis is to analyse the drive and dependent enablers. Its main function is to identify the enablers that drive the system. In this case, the factors affecting the human performance in 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).

Results and Conclusions

The objective of this paper is to identify and analyse the factors affecting the probability of human performance in maintenance tasks. In the research work, the coefficient of correlation among factors (Table 2) shows that “stress” and “training and certification” have the maximum value of correlation. The correlation coefficient of factors was classified according to the strength of the correlation coefficient (Hair et al. 2003). “Stress”, “training and certification” are strongly correlated. However, “Role of Management”, “Complexity of task” and “Time pressure” and “Workstation design” and “stress” is moderately correlated.In this research work “Workstation design” comes out to be a dependent factor. These have weak driving power but strong dependence power. “Complexity of task”, “Training and certification”, “Tool availability”, “stress” and “maintenance manuals” 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 has been reflected in Figure 1 that “Role of Management”, “time pressure”, and “available time to diagnose” 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 human performance in maintenance task.

Driving Power										
	9			Driving Factors				Linkage Factors		
	8									
	7	F1,F5,F6								
	6							F9		F2,F3,F4
	5									F8
	4			Autonomous Factors					Dependent Factors	
	3									F7
	2									
	1									
		1	2	3	4	5	6	7	8	9
		Dependent Power								

Figure 5 Clusters of factors affecting human performance in maintenance tasks

This research work investigates the factors affecting human performance when performing maintenance tasks. The objective is to understand the interaction of the various factors and to identify driving and dependent factors. The factors are identified through a survey of the literature and ranked using a Likert scale. The reliability of measures is pretested by applying Cronbach’s alpha coefficient to responses to the questionnaire given to maintenance personnel. An ISM-based model (Figure 2) 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.

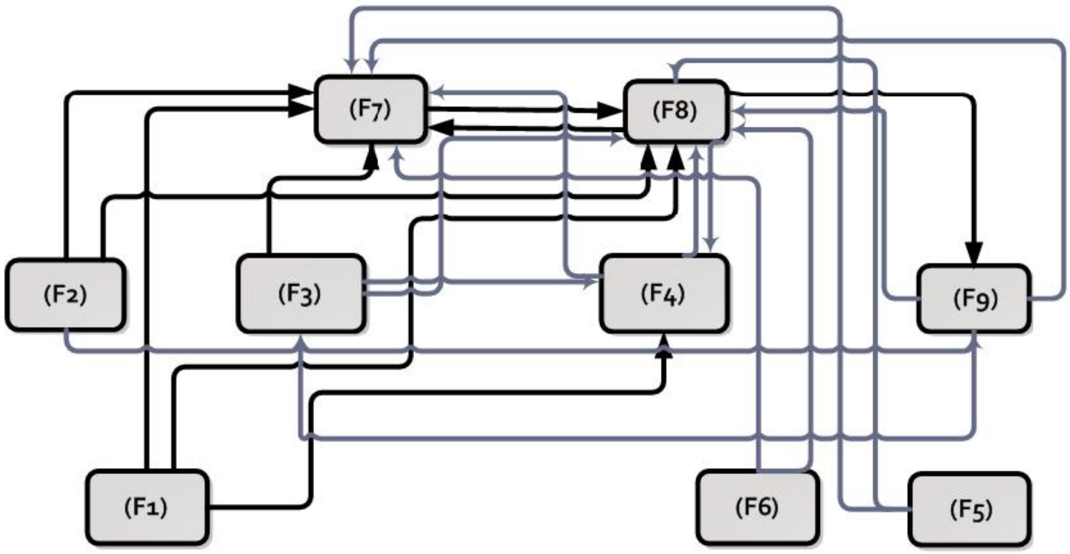

Figure 6 Proposed ISM showing factors affecting human performance in maintenance tasks

CONCLUSIONS

In this research work An interpretive structural model (ISM) is proposed and factors are classified using matrice d'impacts croises-multiplication appliqué à un classement (MICMAC). The proposed model can help in improving the quality of maintenance by identifying those factors that most adversely affect the performance of maintenance staff. The proposed ISM-based model provides a very useful explanation of the relationships among the factors. The model can be statistically tested using structural equation modelling (SEM); this can test the validity of the model.Further, this study has provided practical advice for the formulation of guidelines to improve the quality of maintenance activities. It is believed that the results can assist maintenance management understand the interaction of factors affecting human performance in maintenance and help management devise policies and guidelines for maintenance related tasks.

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