Proceedings of the World Congress on Engineering 2014 Vol II,
WCE 2014, July 2 - 4, 2014, London, U.K.

Human Error Quantification of Railway Maintenance Tasks of Disc Brake Unit

S. Singh, R. Kumar, A. Barabadi, S. Kumar

***Abstract*- This paper investigates the probability of human error and examines technicians performing maintenance on the disc brake assembly unit of Bogie M84S (ASEA) under various error producing conditions in a railway maintenance workshop in Luleå. It implements Human Error Assessment and Reduction Technique (HEART) to determine the probability of human error occurring during each maintenance task, and applies fault tree analysis. The probability of the technician committing an error during maintenance of the disc brake assembly is found to be 0.2093. Time pressures, ability to detect and perceive problems, over-riding information, the need to make decisions and mismatch between the operator and designer's model turn out to be major contributors to human error. These findings can help maintenance management understand conditions and serve as an input to modify policies and guidelines for railway maintenance tasks.**

***Index Terms* - human error, maintenance, error probability, HEART, fault tree**

I. INTRODUCTION

The railway sector is key to the continuing expansion of industrialized nations, but the sector's working conditions and human performance requirements are qualitatively different from other industries. Human error in railway maintenance is a subject which in the past has not been given the amount of attention that it deserves. Human error contributes to the majority of incidents within complex systems, including the railway system. To cite only a few examples, from 1970 to 1998, 62% of the 13 railway accidents in Norway were the result of human error [1]. During the same period, on four British railway lines, 141 accidents were caused by human error [1, 2], with several persons killed at Clapham Junction.

Manuscript received March 14, 2014, reviewed March 25, 2014.This research work is conducted as an on-going cooperation between Luleå University of Technology, Luleå and Luleå Railway Research Centre. Luleå Railway Research Centre (Järnvägstekniskt centrum) has provided financial support.

S. Singh is Post Doc Researcher at Division of Operation and Maintenance Engineering, Luleå University of Technology, Sweden (0046920492812; sarbjeet.singh@ltu.se)

R. Kumar is Assistant Professor at Division of Operation and Maintenance, Luleå University of Technology, Sweden (rupesh.kumar@ltu.se)

A. Barabadi is working as Associate Professor in the Departmnent of Engineering and safety at University of Tromsø, Tromsø, Norway. Abbas.b.abadi@uit.no

S. Kumar is Professor at Department of Mechanical Engineering, National Institute of Technology, Hamirpur, India (sunandkumar_gupta@yahoo.com)

As reported by the Rail Accident Investigation Branch [3], 2007, a train travelling from London to Glasgow derailed when a fault in the stretcher bar of the points caused the left and right switch rails to become disconnected. In 1998, an eccentric wheel led to wheel tyre failure on a German ICE at Eschede, causing several deaths. In 1999, human error and outdated equipment caused a train collision in south-western Ontario, Canada [4]. In Thailand, about 200 people were injured due to a human error in a subway train crash at Thailand Cultural Centre Station, and in Pakistan, a three-train collision killed 133 people [5] and in the United States, a total of 4,623 deaths have resulted from train accidents [6].

A. Maintenance and Human factors

Maintenance can be defined as set of activities required to keep a system in "as-built" condition with its original productive capacity [7] and it hinges on human activity. Although it is nearly impossible to eradicate human error, it can be minimised through good maintenance management and an understanding of the issues that affect errors [7]. A maintenance technician plays an important role in the reliability of equipment but a huge proportion of human errors occur during maintenance. 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. Human error, in general, can be defined as the failure to perform a specific task that could lead to disruption of scheduled operation or result in damage to property and equipment [8]. Dhillon [9] has claimed that maintenance error is linked to incorrect repair; further, the occurrence of maintenance errors rises with increased maintenance frequency. Maintenance errors risk lives and resources and have an adverse effect on business, and are especially problematic in hazardous technologies [10]. Human errors in railway maintenance include disassembly errors, inspection errors, maintenance errors, assembly errors and installation errors. The reasons 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 of human errors in maintenance results in making incorrect decisions, incorrect actions, incorrect checks, or, conversely, correct checks on the wrong object. Railway personnel have a number of tasks that are prone to serious human errors, and a little negligence in maintenance can result in unavoidable disastrous failures and subsequent loss of lives. Since error is endemic to mankind, understanding the root causes of errors and attempting to minimise them are necessary.

Reliability is the key to running a successful railway. If the equipment, especially the rolling stock, is not reliable, the railway is not workable. Good railway management will keep track of performance, especially failures, to ensure problems are eliminated before they become endemic. On the rolling stock, the maintenance of brakes and wheels is crucial. These important safety systems must meet strict safety rules, in terms of stopping distance associated with a maximum average deceleration, in all sorts of environmental conditions. In the case study used here, a brainstorming session identified the possible causes of error. The cause and effect diagram (CAED) method was established in 1950 by K. Ishikawa [11]. It is helpful in the analysis of human reliability and error. 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).

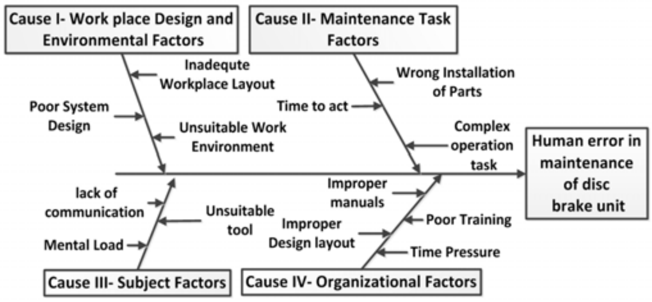

Fig. 1 Cause and Effect diagram

The right-hand side of the diagram represents the effect, such as a railway technician making an error; the left hand-side represents all possible causes, such as time to act, poorly written manual, mental load, poor training etc. This paper investigates human error probability (HEP) in maintenance of disc brake unit of railway bogie M84S (ASEA) in a workshop in Luleå, Sweden. It considers human error probability (HEP) in the performance of maintenance tasks for the disc brake unit in various error producing conditions.

B. *Disc Brake Unit Maintenance*

The disc brake assembly unit on the M84S bogie has four brake packages. Each brake package includes a braking motion and a brake unit (Figure 2). The brake unit consists of a brake actuator integrated with a brake controller. For a pair of wheels, two brake packages are mounted on special cross beams in the bogie. On the cross member, mounts keep the plates and brake pads in the correct position against the brake disc. The wheel set has two brake discs; each is associated with a specific lever in the brake unit. The brake force from the brake unit is amplified and transferred to the brake pads and brake disc. Careful and regular maintenance is required to ensure even distribution of forces to all wheels. Badly set up rigging will cause wheel flats or lead to inadequate brake force. If brakes on the wheels of one axle are not equal, the wheel on which braking pressures are higher has the tendency to roll less, causing an angular run during braking. Brain-storming sessions in railway maintenance workshops have also revealed that poorly executed maintenance tasks on the disc brake assembly unit, such as improper lubrication of the brake disc, undersize fitting of the brake block, tapping screws and cylindrical bolts can cause serious errors.

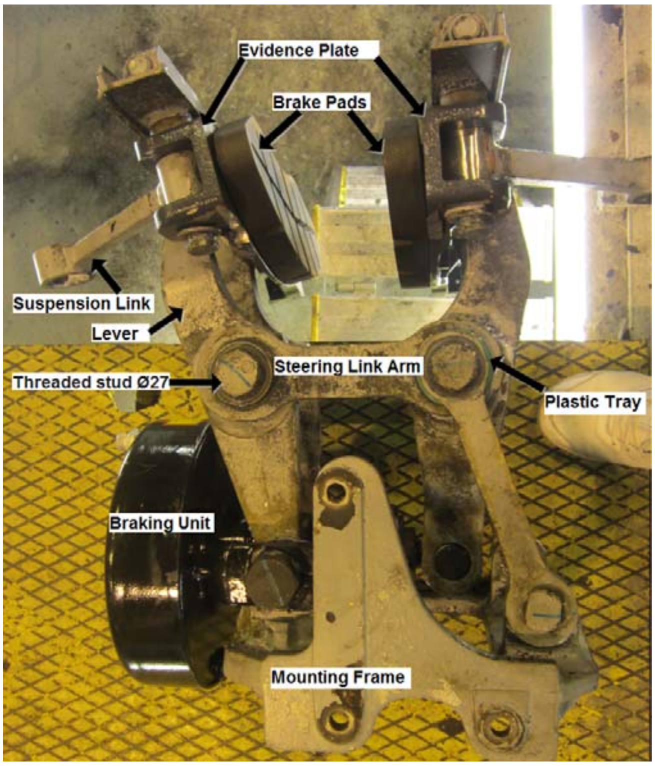

Fig. 2 Disc Brake Assembly Unit

Moreover, incorrect measurement of brake movement results in a delay in brake lever movement, thereby reducing brake performance. This affects the distribution of braking forces from a brake cylinder to the wheels on the vehicle.

II. METHODOLGY

There are several methods to analyse and predict the probability of human error. H.L. Williams first suggested that realistic system reliability analysis must embrace the human aspect [12, 13]. A. Shapero and colleagues pointed out that human error is responsible for 20–50% of equipment failures [14]. Human reliability analysis performs probabilistic safety assessments. It considers all possible accident scenarios in order to probabilistically evaluate overall system safety [15]. The railway maintenance workshop of our case study in Luleå, Sweden, uses both R1 (smaller) and R4 (detailed) types of maintenance audit programs for bogie M84S (ASEA). R1 is a smaller maintenance audit and is carried out after a maximum 1200000 km, whereas R4 is more detailed and done after 3600000 km. The R1 maintenance audits for bogie M84S (ASEA) corresponds to detection, monitoring and repair of disc brake unit assembly, wheel sets and bogie frames. The participants in our study were certified technicians, aged 52-55 years, with a height of 178-190 cm and a weight of 75-85 kg; all had 25-30 years of work experience. None had a history of chronic or acute illness, hypertension or any other major health issues, and none took any prescribed medication. The workers were monitored while doing maintenance and questioned during and after the task.

A. Human Reliability Analysis

Human reliability analysis techniques have been used in a wide range of industries, including the healthcare, engineering, nuclear, transportation and business sectors. The purpose of human reliability analysis is to identify, quantify and reduce error. The objective is to take measures to reduce the likelihood of errors occurring within a system and, thus, to improve the overall levels of safety. The process of assessing human reliability in the maintenance disc brake unit of bogie M84S is shown in Figure 3.

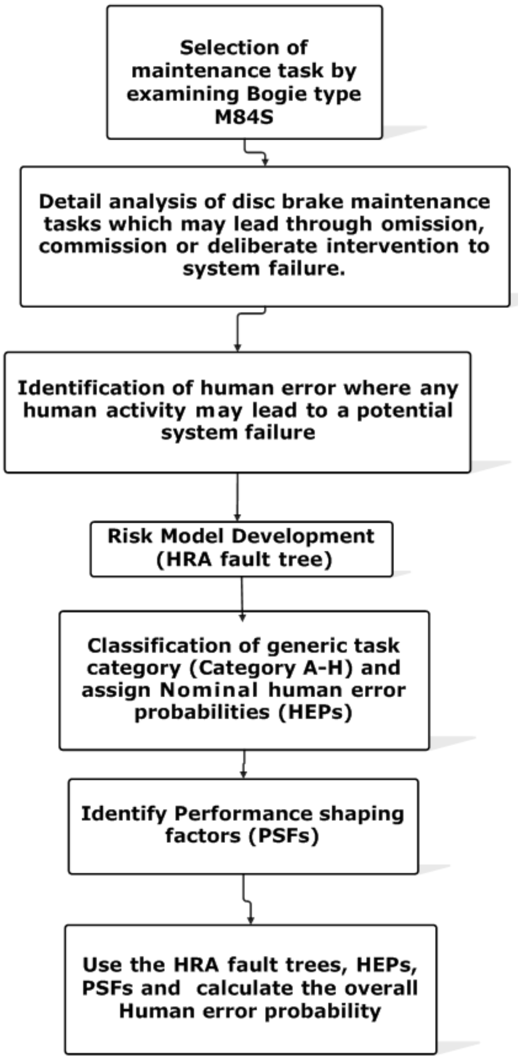

Fig. 3 Human Reliability Assessment Process, adapted from Kirwan [18]

In our case study, brainstorming sessions with technicians and workshop managers allowed us to identify human activities leading to a potential system failure. We then built a fault tree to determine the interactions leading to failure. Once a task description was constructed, we derived nominal human error probabilities for task from tables [16]. The error producing conditions (EPC) were considered and applied to each task by an expert panel. We implemented Human Error Assessment and Reduction Technique (HEART) to evaluate the probability of a human error occurring throughout the completion of a specific task. HEART is highly flexible and applicable in a wide range of areas which makes it a popular choice [17]. We selected HEART because it is a task-based analysis [18] not a de-compositional approach focusing on types of error.The method is based upon the principle that every time a task is performed on the maintenance of a disc brake, wheel or frame, there is a likelihood of failure and the probability of this is affected by one or more error producing condition, for instance, shortage of time, over-riding information, inexperience etc. Moreover, HEART incorporates the most widely used estimates of error rates of generic tasks. There are 9 Generic Task Types (GTTs) described in HEART, each with an associated nominal human error probability (HEP), and 38 Error Producing Conditions (EPCs) that may affect task reliability, each with a maximum amount by which the nominal HEP can be multiplied. In our research we selected Generic Task F (F= 0.003, restore or shift a system to original or new state following procedures, with some checking). The tasks related to the maintenance of the disc brake unit were identified and examined in detail and the information reviewed from the perspective of risk analysis of the system. These tasks were then grouped into disassembly tasks, inspection tasks, maintenance tasks, assembly tasks and installation and testing tasks. Each was further divided into subtasks, such as D1, D2, D3, D4 (for disassembly), M1, M2, M3, M4, M5 (for inspection and so on; see Table 1). Based on the HEART table [16] nominal human reliability values were assigned to each task. Human error probability was evaluated by applying error producing conditions [16] and engineer's proportion of affect (EPOA). EPOA ranging from 0-1 was assigned to each task by an industry expert. In certain cases, more than one error producing item was selected and applied in the formula to calculate final human error probability:

$$(HEP) = \text{GTT x A1 x A2 x} \ldots \text{ An}$$

Where GTT is human error probability associated with each generic task.

$$\text{A1} = \text{Assessed effect} = ((\text{Total Heart effect} - 1) \text{ x EPOA}) + 1$$

B. Fault Tree Analysis

Fault tree analysis (FTA) was developed in the early 1960s at the Bell Telephone Laboratories to perform safety analysis [19]. It is broadly used to perform reliability analysis of engineering systems and is a logical representation of the relationship of fault events that may cause an adverse event, called the top event, to occur. The events that result in the occurrence of the top event are connected and generated by logic gates AND and OR. The OR gate provides a true output (i.e., fault) when one or more of its inputs are True (fault). In this study, fault tree analysis (FTA) was used to perform human error analysis in the railway maintenance of disc brake unit of bogie M84S (ASEA). After analyzing maintenance tasks, the top fault event "D" (technician making an error while doing maintenance on the Disc brake unit) and possible causes or basic fault events (brake disassembly error, brake inspection error, brake maintenance error, brake installation and testing error) that cause the top event to occur were identified using OR gate. A fault tree was then developed down to the lowest level. The occurrence probability of the technician making an error (top event) was calculated using the probabilities of occurrence of basic fault events (disassembly error, brake inspection error, brake maintenance error etc; see Figure 4).

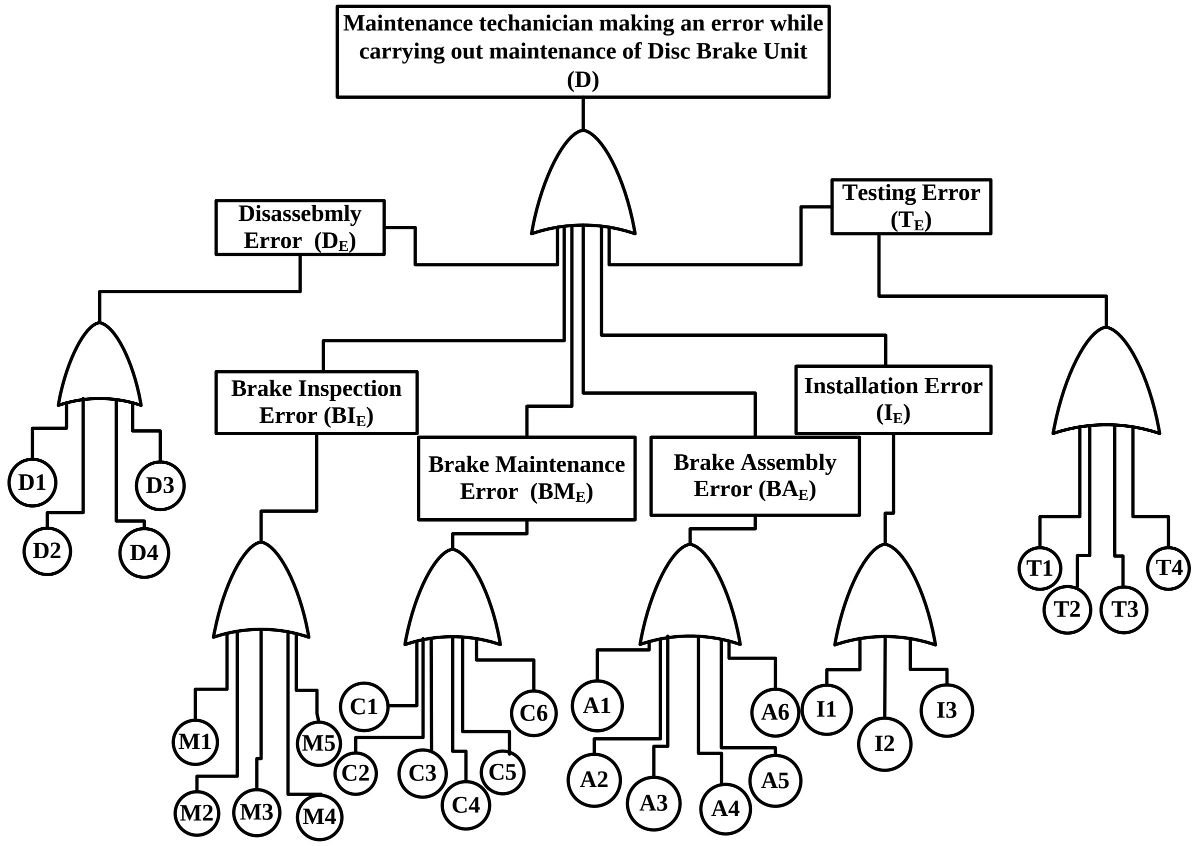

Fig. 4 Fault tree for technician making error during maintenance of Disc Brake Unit

The probability of occurrence of the OR gate output fault event is given by formula [20]:

$$P(y_0) = 1 - \prod_{i=1}^{k} \{1 - P(y_i)\}$$

Where $P(y_0)$ is the probability of occurrence of the OR gate output fault event, y_0. k is the number of OR gate input fault events, and P (y_i) is the occurrence probability of OR gate input fault event y_i ; for i = 1, 2, 3, …, k.

III. RESULTS AND DISCUSSION

Human error probability (HEP) of each sub-task associated with the maintenance (Type R1) of disc brake unit was evaluated using Human Error Assessment and Reduction Technique (HEART) (Table 1). The probability of occurrence of event disassembly error ((BI_E), inspection error (BI_E), maintenance/repair error (BM_E), assembly error (BA_E), inspection error (I_E), testing error (T_E) was calculated using the below mentioned formulas:

$$P(BI_E) = 1 - [1 - P(M1)]\,[1 - P(M2)]\,[1 - P(M3)]\,[1 - P(M4)],$$
$$P(BM_E) = 1 - [1 - P(C1)]\,[1 - P(C2)]\,[1 - P(C3)]\,[1 - P(C4)]\,[1 - P(C5)],$$
$$P(BA_E) = 1 - [1 - P(A1)]\,[1 - P(A2)]\,[1 - P(A3)]\,[1 - P(A4)]\,[1 - P(A5)]\,[1 - P(A6)],$$
$$P(I_E) = 1 - [1 - P(I1)]\,[1 - P(I2)]\,[1 - P(I3)],$$
$$P(T_E) = 1 - [1 - P(T1)]\,[1 - P(T2)]\,[1 - P(T3)]\,[1 - P(T4)],$$
$$P(D_E) = 1 - [1 - P(D1)]\,[1 - P(D2)]\,[1 - P(D3)]\,[1 - P(D4)],$$

The principle of this case study was that every time a task is performed during maintenance, there is a likelihood of failure; this facilitated our evaluation of the probability of human error associated with each task and allowed deeper understanding of the impact of each individual task. The probability of the occurrence of causes (fault events) was evaluated using the fault tree method. The OR gate provides a true output (i.e., fault) when one or more of its inputs are True (fault). The maintenance of the disc brake unit includes disassembly, measurement and inspection, corrective maintenance, assembly, installation and testing; the probability of human error is each task was found to be 0.04, 0.04, 0.05, 0.05, 0.02 and 0.03 respectively. The probability of event D occurring (the technician committing an error while performing maintenance on the brake disc unit) was determined to be 0.2093 using the following formula:

$$P(D) = 1 - [1 - P(BI_E)]\,[1 - P(BM_E)]\,[1 - P(BA_E)]\,[1 - P(I_E)]\,[1 - P(T_E)]\,[1 - P(D_E)]$$
$$P(D) = 0.2093$$

Thus, the probability of the technician committing an error was found to be 0.2093. The fault tree of the above calculated event occurrence probability values appears in Figure 5.Technicians in railway maintenance tasks are confronted with a set of error producing conditions within strenuous railway maintenance systems, including time pressures, negligible feedback, confined work spaces, awkward body positions (bent and/or twisted backs, both arms above the shoulder etc.), poorly written procedures, lack of access to the equipment etc. These conditions, in combination with basic human tendencies, result in various forms of errors.

ISBN: 978-988-19253-5-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

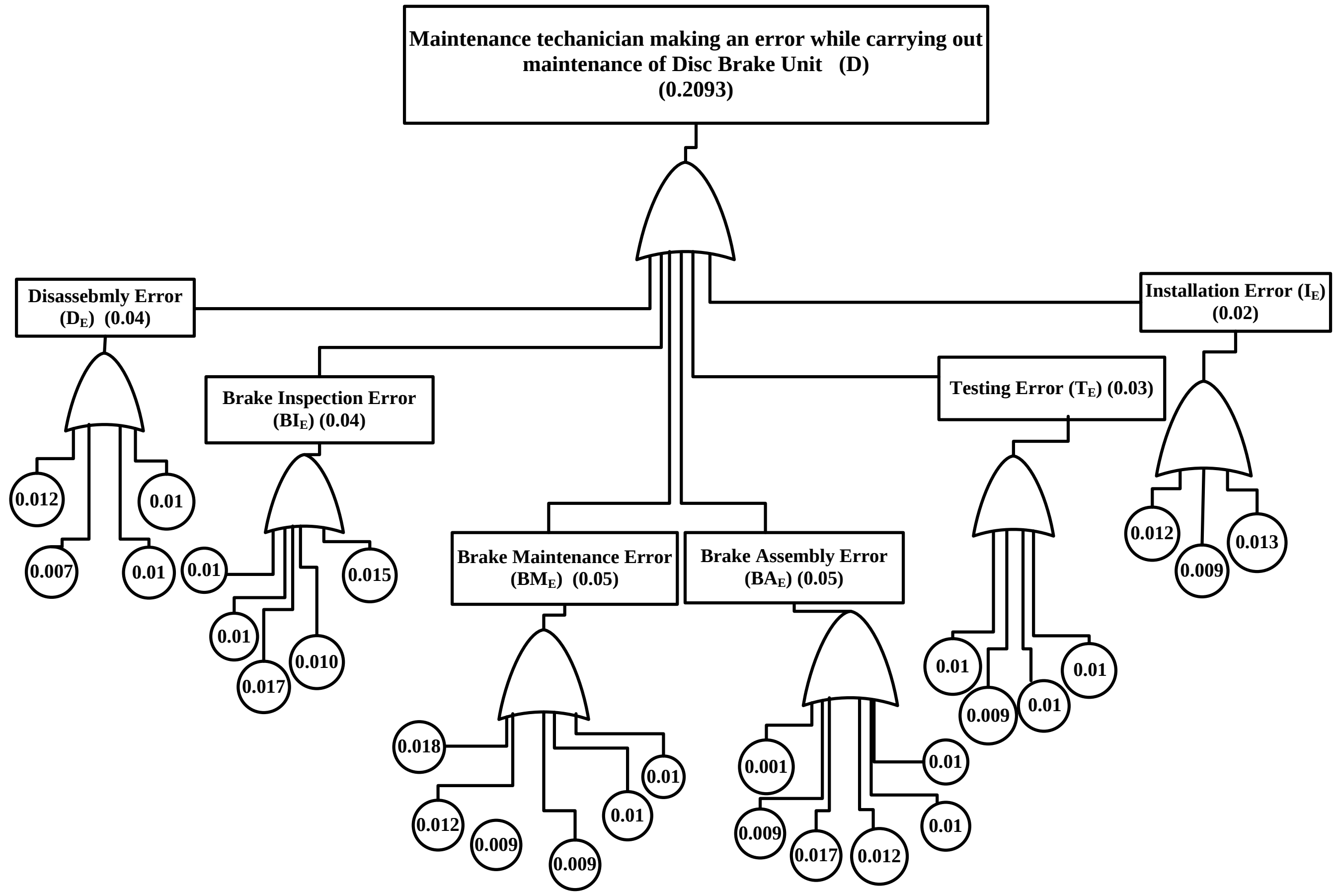

Fig. 5 Fault tree with the calculated value of top event and basic fault events (causes)

TABLE I

CALCULATED HUMAN ERROR PROBABILITY (HEP) DURING MAINTENANCE OF DISC BRAKE UNIT

Maintenance of Disc Brake Unit					
		Nominal Human Reliability			
	Disassembly Task of Disc Brake	Error producing Conditions (HEART Effect)	EPOA (0-1)	Assessed Effect	HEP
D1	Technician failed to successfully take out the brake unit from lever arms (causing sudden release of brake unit)	• Shortage of time available (X11)	0.3	((11-1)x0.3)+1=4	0.012
D2	Damage to brake pads while removing them from the evidence supports.	• Over-riding information (X9)	0.4	((9-1)x0.2)+1=2.6	0.007
D3	Technician damaged nut while removing suspension links and upper arm.	• Ability to detect and perceive (X10)	0.3	((10-1)x0.3)+1=3.7	0.01
D4	Technician omitted to press out old bushes from lever arms, steering linkages, link arms and the mounting frame.	• Over-riding information (X9)	0.3	((9-1)x0.3)+1=3.4	0.01
Corrective Maintenance tasks					
C1	Inadequate lubrication brake motion as per lubrication chart (results in reduced braking performance)	• Need for absolute judgment (X1.6) • Mismatch between an operator's model and that of designer (X8)	0.3 0.4	((3-1)x0.3)+1=1.6 ((8-1)x0.4)+1=3.8	0.018
C2	Missed replacement of bush having abnormal large gap (averaging wear more than 0.5	• Over-riding information (X9)	0.4	((9-1)x0.4)+1=4.2	0.012
…	….….…	……	…	….…	….
…	….….…	…….	…	…….	….

It is pertinent to mention that the management of human error is not the investigation of past cases but the improvement of the present situation to solve future problems in an organization [21]. This case study highlights error producing conditions which contribute to human error. Based on its findings, it proposes a maintenance decision model (Figure 6) to improve the overall quality of maintenance in the workshop. Use of this model will improve the quality of maintenance, enhance safety and lower maintenance costs; it will help management to explore and evaluate error producing conditions that adversely affect the performance of maintenance technicians.

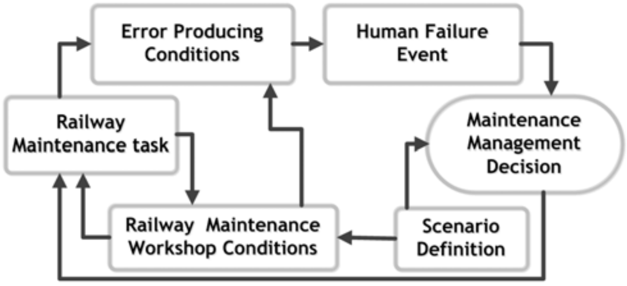

Fig. 6 Proposed maintenance decision model

IV. CONCLUSIONS

This paper notes the need for human factor interventions in maintenance tasks performed on bogie M84S (ASEA). For maximum reliability, equipment must be kept in good working condition, and for this, regular maintenance is critical. A number of factors directly or indirectly result in a decline in human performance, leading to errors in maintenance tasks. This paper presents a straightforward case study of human error probabilities in a railway maintenance system, looking specifically at disc brake unit of bogie M84S (ASEA). By looking at a number of error producing conditions and their effect, it finds the probability of human error to be 0.2093. It concludes that error producing conditions such as time pressure, ability to detect and perceive problems, the existence of over-riding information, the need to make absolute decisions, and a mismatch between the operator and the designer’s model are major contributors to human error. The proposed model can help maintenance management understand various error producing conditions and serve as an input to modify policies and develop better guidelines for railway maintenance tasks.

It can be concluded that human factor interventions on the maintenance of railway assets warrants serious attention if the railway sector is to achieve and sustain a competitive advantage. Study of the human factor is essential to ensure the continuing prosperity of railways. This calls for more research if the railway sector is to thrive and grow.

REFERENCES

[1] T. Anderson, “Human Reliability and Railway Safety,” *in Proc. 16th European Safety, Reliability and Data Association (ESREDA)*”, Seminar on Safety and Reliability in Transport, pp.12, 1999.

[2] S. Hall, Railway Accidents, Ian Allan Publishing, Shepperton, U.K, 1997.

[3] Rail Accident Investigation Branch, Progress Report: Derailment at Grayrigg, Cumbria, Department of Transport, 2007.

[4] Transportation Safety Board Investigation Report, Transportation Safety Board, Department of Transportation, Ottawa, Canada. 2001

[5] Editorial: Human Error Derails New Metro, The Nation, Newspaper, Bangkok, Thailand, 2005.

[6] Office of Safety Federal Railroad Administration, Accident/Incident Toll, Washington, D.C. 2005.

[7] J. Reason, Cognitive Engineering in Aviation Domain, Lawrence Erlbaum Associates, Mahwah, NJ, 2000.

[8] B.S. Dhillon and Y. Liu, “Human error in maintenance: A review,” *Journal of Quality in Maintenance Engineering*, Vol. 12 No. 1, pp. 21-36, 2006

[9] B.S. Dhillon, Engineering Maintenance: A Modern Approach, CRC Press, Boca Raton, FL 2000.

[10] J. Reason and A. Hobbs, *Managing Maintenance Error: A practical Guide*, Ashgate Publishing Company, Hampshire, England, 2003.

[11] P. Mears, Quality Improvement Tools and Techniques, McGraw Hill Book Company, New York, 1995.

[12] W.L. Williams, Reliability Evaluation of the Human Component in Man-Machine System, Electrical Manufacturing, pp. 78–82. 1958.

[13] B.S. Dhillon, *Human Reliability with Human Factors*, Pergamon Press, Inc., New York, 1986.

[14] A. Shapero., J.I. Cooper, M. Rappaport., K.H. Shaeffer., C.J. Bates, *Human Engineering Testing and Malfunction Data Collection in Weapon System Programs*, WADD Technical Report No. 60–36, Wright-Patterson Air Force Base, Dayton, Ohio, February, 1960.

[15] J.W. Kim, W. Jung, ”A taxonomy of performance influencing factors for human reliability analysis of emergency tasks”, *Journal of Loss Prevention in the Process Industries*, Vol. 16, no. 6, pp. 479–495. 2003.

[16] J.C. William, “A data-based method for assessing and reducing human error to improve operational performance,” *In Proc. Fourth Conference on Human Factors and Power Plants*, pp.436 – 450, 1988.

[17] P.C. Humphreys, *Human Reliability Assessor’s Guide,* Human Factors in Reliability Group, SRD Association, 1995.

[18] B. Kirwan, *A guide to practical human reliability assessment*, Taylor & Francis, 1994

[19] B.S. Dhillon and C. Singh, *Engineering Reliability: New Techniques and Applications*, John Wiley and Sons, New York, 1981.

[20] B.S. Dhillon, *Design Reliability: Fundamentals and Applications*, CRC Press, BocaRaton, Florida, 1999.

[21] M. Grozdanovic M and E. Stojilkovic, "Framework for Human Error Quantification," *Philosophy, Sociology and Psychology*, Vol. 5, No. I, pp. 131-144. 2006

ISBN: 978-988-19253-5-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)