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Human Error Control in Railways

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Abstract

Humans are the weakest link in any embedded system. Failure rates for humans as system components are several orders of magnitude higher than other parts of the system. Railway operation system requires involvement of a large number of persons. This results in more human errors and hence disastrous consequences. The paper presents general theory of human errors; and stresses the need to adopt optimization in railway operations to the maximum possible extent; and to develop a continuous monitoring system for physical and psychological status of the workers.

Keywords: Human error, Railways, Railway Operational System, Attention Subsystem, Automatic Subsystem, Schemata, Absolute Block System.

1. Introduction

All systems have a human component. Even the most highly automated systems are designed, installed, and maintained by people. To err is human. Human error plays a part in most accidents, if not all.

In critical systems like transport systems, safety measures against human errors play a substantial role. Human error can be committed in different phases of life cycle, namely, during system specification and development; and in the longest phase of the life-cycle during operation. In railway operation, several safety-critical tasks are assigned to the operators and are not controlled by signaling and interlocking systems. Many tasks are necessary in situations occurring very rarely. Since these situations are unfamiliar to the operators and demand of good interaction is high, pre-training is necessary to provide information and practice to solve these situations [1].

The European standards concerning railway safety - leading with EN50126, about the specification and demonstration of railway reliability, availability, safety and maintainability - forces the efforts of training and retraining of operational personnel. The main equipment for training of railway signaling personnel has become computer-based interlocking, signaling, and traffic simulation systems [2-3]. It is desirable that operators and the maintenance personnel possess necessary knowledge of equipment from the first moment of its operation. This is indispensable to an untroubled, smooth, and safe traffic operation. In case of extraordinary and troubled situations, rapid recognition and solution of the given problem is required to avoid accidents. Computer-based simulation systems are capable to help in the above-mentioned tasks.

A scenario, which represents a sequence of actions/operations, can involve human agents (H) and machine agents (M). A human agent may communicate with another human agent, and a machine may pass information to another machine in a distributed system. The minimum set of interactions between H and M are: H, M, HM, HH, and MM. Each interaction pattern, in this set, can lead to an inappropriate or undesired system performance. Based on this set of possible interactions, five types of errors may be identified; (i) human error, (ii) machine error, (iii) error resulted from human-machine interaction, (iv) errors related to machine-machine communication, and (v) errors attributable to human-human communication. Apart from these five types, a sixth type may be identified and included, i.e. organizational errors, which are caused by organizational structure or social conditions [4].

A human agent, as an integral component in the social environment of a system, takes decisions, performs actions, etc. During these interactions, deviation of normal behavior of a human agent may result in inappropriate system performances. The causes of deviations in the actions or behaviors of human agent are called human errors. Human errors may occur because of inadequate knowledge, memory lapses, incorrect mental model, etc.

Design errors, or non-adherence to user interface guidelines, etc. may give rise to situations where a human agent is unable to make a decision or to diagnose a problem when interacting with machines.This results in an undesirable system performance. Such errors are labeled as human- machine interaction mismatches. These may arise due to usability problems, poor feedback mechanisms, or inadequate error- recovery mechanisms [5]. When a

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human agent is not able to communicate appropriately, or as desired, to another human agent via any media; and which may cause an unacceptable system performance, then such factors are called human-human communication errors. Errors due to human-human communication may be linked to communication mismatch between fellow workmen as a result of ambiguous task allocation or lack of co-ordination at management level. A situation may arise when a machine is unable to communicate correctly to another machine in a network or a distributed system. This may be caused by machine- machine miscommunication [6].

The occurrence of one error may give rise to another and hence triggering a chain of non-normative events leading to an undesirable or inappropriate system performance. An attempt has been made to illustrate these causal relations of problem errors leading to an unplanned behavior through the following example.

Consider the case when an operator of a control system is not able to optimally control certain parameters (human errors) like when an operator does not have the access rights for some function/information of the machine, or is not trained enough to perform an allocated responsibility. This actually reflects on structure and planning of the organization (organization error). The human error caused by the cumulative effect of human and organization errors may lead to malfunctioning of the control system (machine errors) and ultimately result in a system breakdown.

The example is not to demonstrate a generic path for causal relations errors causing the problem, but to illustrate the occurrence of interaction between different types of errors responsible for the problem. The example has two important messages: First, if error is known, the requirements engineer can explore its effect(s) on the system behavior by exploiting these causal relations to simulate the causal chain of events in the normal task-flow. on the other hand, if consequences are known from any previous histories of undesirable system behavior, the requirements engineer can start from the consequences to determine the cause(s) or errors by following the causal path of events. These techniques of forward and backward searches can be integrated in the method of scenario analysis. This approach of causal analysis is very similar to hazard analysis techniques, for instance, HAZOP in safety engineering.

2. Human Error

It has been estimated that up to 90 % of all workplace accidents exhibit human errors as a cause [7]. Human error was a factor in almost all the highly publicized accidents in recent memory including the Bhopal pesticide plant explosion, Hillsborough football stadium disaster, Paddington and Southall rail crashes, capsizing of Herald of Free Enterprise, and Challenger Shuttle disaster.

In order to address human factors in workplace safety settings, peoples' capabilities and limitations must first be understood. The human characteristics that can lead to difficulties interacting with the working environment are the following:

2.1. Attention

The modern workplace can 'overload' human attention with enormous amount of information, besides of that encountered in the natural world. The way in which we learn information can help reduce demands on our attention, but can sometimes create further problems.

The Automatic Warning System installed on all passenger trains in U.K is an example of a system that is designed without considering limitations of human attention in mind. It is a device fitted in the train cab and based on the current obsolete mechanical system of signaling which is used to signal either STOP or PROCEED. It sounds a bell when a clear (green) signal is passed and a buzzer when caution or danger is signaled. If the buzzer is not acknowledged by the press button, then the train begins to stop automatically. In commuter traffic, most signals are at the 'caution' aspect, and given the frequency of signals (spaced 1 km apart), most drivers will face two signals per minute. Given the tendency for the attention system to automate highly repetitive behavior, many drivers lose focus on the reasons for carrying out this repetitive task, and act in reflex whenever the buzzer sounds.

The ultimate result is that drivers often hear the buzzer and press the button reflexively without actively thinking about the train speed and location.

2.2. Perception

In order to interact safely with the world, we must correctly perceive it and recognize the dangers it holds. Work environments often challenge human perception systems and information can also be misinterpreted.

2.3. Memory

Our capacity for remembering things and imposing methods upon ourselves to access information often put excessive pressure on us. Increasing knowledge about a subject or process allows us to retain more information relating to it.

2.4. Logical Reasoning

Failures in reasoning and decision-making can have severe implications for complex systems such as railway operations, chemical plants, and for tasks like maintenance and planning.

Under optimum field conditions and with the best of intentions, a human being is likely to commit error now and again. Human operators are one of the biggest sources of errors in any complex system. Human errors are dependent on many factors [10] as indicated in Table 1.

To reduce the extent and consequences of human errors in railway operation, automation is quite helpful. A well-designed human-computer interface (HCI) is an essential requirement of automation [8]. However, human beings are often needed to be the fail-safe in other automated system. Even the most highly trained and alert operators have a tendency to monotony when they are usually not needed for normal operation. They panic when an unusual situation occurs, and stress levels are raised, and lives are at stake. The HCI must give appropriate feedback to the operator to allow him/her to make well-informed decisions based on the latest information of the state of the system.

High false alarm rates will make the operator ignore a real alarm conditions. Automated systems are extremely good at repetitive tasks. However, if an unusual situation occurs and corrective action must be taken, the system usually cannot respond well.In this situation, a human operator is needed to handle an emergency.

Humans are much better than machines at handling novel occurrences, but cannot perform repetitive tasks well. Thus, an operator is left to passively monitor the system when there is no problem; and is only a fail-safe in an emergency.

Table 1: Human errors factors

CATEGORY	SOURCES OF ERRORS
Physiological	(1) Work Environment- Noise, lighting, work timings, shift arrangements, temperature, ventilation, etc. (2) Stress- Reaction to stress. (3) Attention capacity- over attention or inattention, perceptual confusion. (4) Adoption-reaction to changes in system and environment. (5) Mental Load-tired, stressful.
Anatomical	Physical Health-disability, age, sick or injured, poor physical co-ordination.
Social & Personal	Distress to family member(s). Strained relationship between Two/more family members. Social disharmony /distressful situation.

This is a major problem in HCI design because when the user is not routinely involved in the control of the system, they will tend to become bored and be lulled into complacence (9). This is known as operator drop-out. Since the user's responsiveness is dulled, in a real emergency situation, he or she may not be able to recover as quickly; and will tend to make more mistakes.

Stress is also a major factor to human error. Stressful situations include unfamiliar or exceptional occurrences, incidents that may cause a high loss of money, data, life, and time critical tasks. Human performance tends to decline when stress levels are raised. Intensive training can reduce this affect by turning unusual situations into familiar scenarios via drills. However, cases where human beings must perform at their best to avoid hazards are often the cases of most extreme stress and worst error rates. The failure rate can be as high as thirty percent. Unfortunately, the human operator is our only option, since a computer system usually cannot correct unique situations and emergencies.

3. Classification of Human Errors

Better training or supervision can prevent errors but most effective action can be taken to reduce opportunities for error, or minimize their effects, by changing designs or methods of work. Human errors are committed due to different reasons and it requires different actions to prevent or reduce the different sorts of errors [10]. They are:

3.1. Those That Occur Because One Does Not Know What to Do.

The intention is wrong. They are usually called mistakes.Some of these errors are due to a lack of the most basic knowledge of the properties of materials or equipment handled or to lack of sophisticated knowledge and other errors may be caused by following the rules when flexibility was needed. However, many written rules cannot handle every situation that might arise and people should therefore be trained to diagnose and handle unforeseen problems. Sometimes people are given contradictory instructions or instructions with implied contradictions.

3.2. Those That Occur Because Someone Knows What to Do but Decides not to do.

They are usually called violation or non-compliance. Many accidents have occurred because operators, maintenance workers or supervisors did not carry out procedures that they considered troublesome or unnecessary. If the wrong method is easier than the correct method, people are tempted to use the wrong one.

3.3. Those That Occur Because the Task is Beyond the Physical or Mental Ability of the Operator.

They are called mismatches, few accidents occur because individuals are unsuitable for a job. More occur because people are asked to carry out tasks, which are difficult or impossible for anyone, physically or, more often, mentally.

3.4. The Errors Due to a Slip or a Momentary Lapse of Attention.

The intension is correct but it is not carried out.

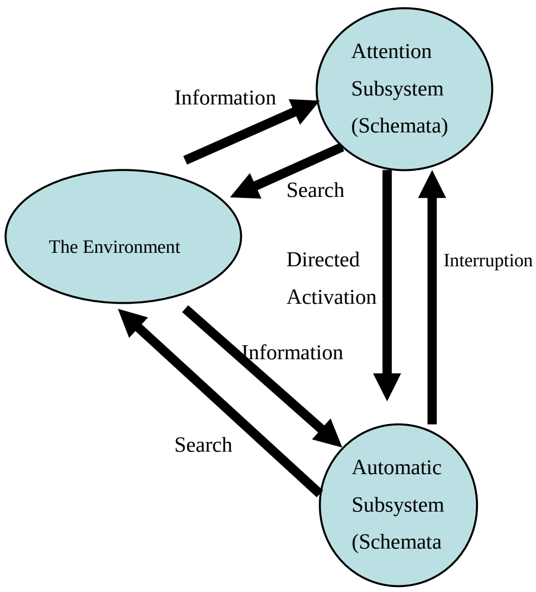

Figure 1: Three Interacting Sub-Systems.

4. General Theory of Human Error

An adequate theory of human action must account not only for correct performance, but also for the more predictable varieties of human error. Perhaps the most important convergence in human error research is responsible for the development of a partial model of human cognition. Figure 1 illustrates the basic elements of this emerging model as drawn from Reason's [11] Generic Error-Modeling System (GEMS).

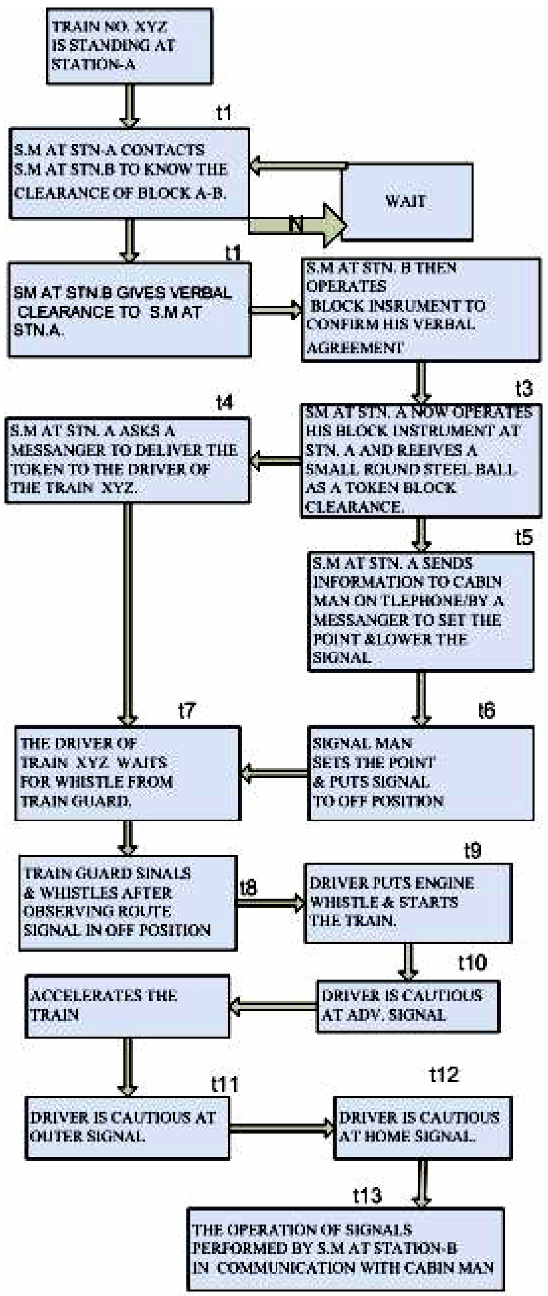

Figure 2: Flow chart for movement of trains

Figure 1 has three interacting subsystems. One is the Automatic subsystem that works below the level of consciousness. Research indicates the automatic subsystem schemata (organized collections of information) and response patterns within a person. When the proper conditions exist, a schema is activated. There are two core mechanisms for selecting schemata to be activated. The first mechanism is pattern matching and the second is frequency gambling.

The second subsystem is Attention subsystem (consciousness). The attention system has powerful logical capabilities. According to Reason [8], this mode is "limited, sequential, slow, effortful, and difficult to sustain for more than brief periods.

The automatic and Attention subsystems do not work independently. The attention subsystem holds goals. These goals influence the activation of automatic subsystem nodes. When the attention subsystem loses its goal, the entire cognitive system is likely to err. However, the limited attention resources must also be allocated to planning for future actions and dealing with unexpected conditions.

The third subsystem is the environment. Human cognition is not merely internal. It is situated in the environment surrounding it. Sellen and Norman stresses that the integration with the environment takes place continuously as we plan and execute an action. First, we form a high-level intention. When we execute it, we constantly adjust our action through feedback with environment. This adjustment takes place without burdening our limited attention system in most cases. In addition, once the adjustment begins, it takes on a life of its own. Sometimes it goes in unforeseen directions.

5. Human Involvement in Railways

With the advancement of civilization and as a result of globalization of business, travel and transport sector are still in a period of major growth. The challenge is to manage this growth with a commensurate increase in safety. As a response to this, railways are expanding throughout the world.

Many workers are required for system design, operation, and maintenance of the railways. Most of rail accidents are attributed to human error. In engineering, an error is a difference between desired and actual performance of a system or object/man. One type of error is human error, which includes cognitive bias. Human errors are predictable, and thus can be prevented by changing the design of a system. Psychologists use their knowledge of human perception, response time, and cognition to predict and prevent possible errors.

Any organization that professes to have a safety culture should treat human behavior as an important issue.

5.1. Dependencies between Human Actions

One human error may make other more likely. A mistake by an operator that results in a hazardous situation may cause them to be more stressed, impairing their thought processes and making further errors is more expected. An inadequate understanding of dependencies between human actions can lead to a significant underestimation of risk.

5.2. Indian Railways

In India, more than 90% of train movements are being controlled by "Absolute Block" system. This system requires a large number of manpower for operation control, which is evident from the flow chart shown in figure2.

In the flow chart, t_1 to t_{13} are the times consumed by the persons concerned with train movement. It also depends on the I.Q., efficiency, skill, age, and health status of individuals concerned.

Moreover, physical environment will vary from individual to individual. At busy railway stations, a number of incoming and outgoing trains have to be handled simultaneously. The manual of such situations becomes quite complex, and probability of human errors is higher (12).

In addition, huge manpower is engaged in works like, track maintenance, cabin management, station administration, workshops, etc. Such a sizable involvement of manpower in railway operating system makes it prone to human errors and consequent accidents.

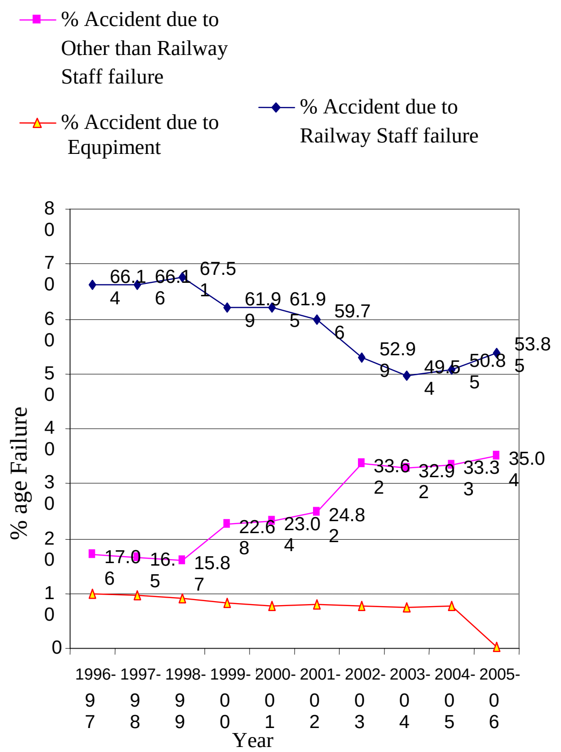

Figure 3: Responsibility wise Analysis during 1996-97 to 2005-06 on Indian Railway

Amitabh Agarwal, Ministry of Railways, Government of India, reports that in last ten years (1996- 2006), 59% of the accidents on Indian Railways have been caused by failure of Railway staff, and 25.5% have been caused by failure of other than Railway staff. Failure of equipments has contributed 6.5% and 9% by balance. From the break-up it is more than evident that human error has been the major factor in causing accidents on Indian Railways. Figure 3 represents responsibility-wise analysis during this period (13, 14, and 15).

5.3. Case Study

Head-on collision of 9112 Dn Jammu Tawi Ahmedabad Express with JMP Diesel Multiple Unit Passenger train between Bhangala and Mirthal stations of Northern Railway on fourteenth of December.2004 happened, where 38 persons lost their lives and many were injured.

The present case study was undertaken by officials of Indian Railways, Ministry of Railways, and Government of India.

5.3.1. Cause of the Accident

The two Station Masters did not exchange messages properly on VHF sets. This resulted in dispatching trains in the same block section from opposite directions on a single line section.

5.3.2. Key Observations

1. Quad cable supporting the block circuits was damaged due to construction activity in the section causing failure of Block instruments and block phones at both stations 24 hours prior to the accident.
2. Trains between Mirthal and Bhangala were being worked on paper line clear (PLC) 24 hours prior to the accident.
3. This is a saturated section handling both passengers and traffic to full capacity. It is quite demanding to operate even under normal circumstances.
4. Both Station Masters dispatched trains from their respective stations towards each other in the same block section by granting "line clear" on VHF sets exchanging private numbers and issuing PLC.
5. Poor supervisory and managerial interventions were continuing in this most unsafe and accident-prone conditions.
6. Work of locating and rectifying the fault was not undertaken on emergency basis.

5.3.3. Human Errors Involved

5.3.3.1. Human errors were manifested by vulnerable functioning after the technical failure i.e. the cutting of quad cable supporting control circuits during excavation of earth.

5.3.3.2. Both station masters adopted the least cumbersome process of granting "line clear" after failure of Block instruments and Block phones i.e. VHF communication over controller communication being easy to use. Despite VHF communication being more vulnerable to outside interference, the prescribed safeguard for ensuring that reply to the line clear inquiry is emanating from the authorized person competent to grant "line clear" was not adopted by Station Masters.

5.3.3.3. Though the practice of granting "line clear" using VHF communication had been going on for about 24 hours for several trains in both directions. By this time abnormal working had lost its alert value in the minds of individuals and a lapse was bound to take place at the level of Station Masters.

All the above lapses manifested in the form of dreaded head-on collision with the last string of frontline action coming from the two Station Masters. Role of maintenance agencies cannot be overlooked in causing the vulnerable situation of train operation for prolonged period which ultimately was manifested into the accident.

REMARK: All the above lapses resulted in the form of dreaded head-on collision with the last string of frontline action coming from the two Station Masters. Role of maintenance agencies cannot be overlooked in causing vulnerable situation of train operation for prolonged period, which ultimately manifested into this accident.

6. Remedial Approach to Railway Operation System

The basic approach towards reducing human errors in railway operations may be listed as follows:

6.1. *Reduction In Man-Power Requirement:*

This requires adoption of automation to the maximum possible extent. A variety of software packages should be available or can be indigenously developed for Centralized Railway Traffic Control System and Automatic Railway Traffic Control System. The proper selection of structure and basic function pools achieve an optimal relation between monetary requirement and performances in the above mentioned operation systems [16].

6.2. The Basic Characteristics of the Function Pool are:

(a) Effective support of operator's supervision of routes and traffic.
(b) Train number following and corresponding support functions of passenger informing, traffic disposition, and automatic control.
(c) Effective support for automatic following of traffic running and registration.
(d) Effective support for administrative activities.
(e) Automatic programmable traffic control on train number and timetable basis with the support of alternative solution in the case of conflicting states.
(f) Automatic programmable control of shunt routes.
(g) Possibility of direct manual control of routes and interlocking equipment.
(h) Special system support of "off-line" maintenance and browsing of timetable base and automatic control programs.
(i) Flexible interfaces between interlocking equipment and CTC system.
(j) Spontaneous diagnosis and centralized information of errors and self-documentation of CTC system operation.

6.3. *Selection of Necessary Man-Power*

Even after adoption of automation in railways, a reasonable number of human-related requirements would be indispensable. This makes it essential to recruit only competent and well-qualified staff for different jobs. Consequently, carefully considered standards stating qualifications and expertise for each category of employees are to be prepared and updated frequently. These standards should be adhered to since any slight deviation may result in accidents leading to loss of human lives.

6.4. Indoctrinating new Recruits

New employees should be familiar with the new work conditions, work environment, and potential work hazards. Thus, a well-planned training program for new recruits before involvement is essential. Its high effectiveness will ensure less of human errors. Continuous modifications and updating of training programs are predicated to make the whole process effective.

6.5. Refresher Training Programs:

Refresher training programs are necessary at regular intervals for all working personnel to keep them responsive to safe working conditions and practices. Such programs also provide a platform for interaction between workers and top management.

6.6. Periodical Health Check-Ups and Psychological Fitness Tests

Human errors are also dependent on health and psychological status of the employees concerned. Hence, regular health check-up and psychological fitness camps should be organized regularly. If health and psychology of employees are not suitable for a job, they should not be allowed to continue - for humanitarian considerations.

6.7. Identifying Hazards, Assessing, and Reducing Risk

Railway organization must make a systematic and vigorous attempt at regular interval to identify any possible hazards that may result in an accident at any time. The process of human error identification should be integrated with the general process of hazards identification within the system.

7. Conclusions

1. In any complex system such as railway operation, most errors and failures in the system can be traced to human errors. Humans have higher failure rates under high stress levels. Yet, they are more flexible in recovering from emergent situations and consequent potential disasters.
2. New technology always requires new safety challenges and thus entails more intricate training and retraining of the workers periodically.
3. Human involvement can be minimized if automation in railway operation is adopted, and thus lowering the probability of human errors and its consequences.
4. A high-quality system should impose accountability. This may sound obvious, but system design is carried out in the absence of feedback from its potential users, which increases the chance that the users will not be able to interact correctly with the system.
5. Continuous monitoring for physical and psychological status of employees involved in railway operations is likely to diminish the human errors.
6. Unsuitable workers in a railway job are more likely to err; and thus must be suspended immediately as soon as they are identified.

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