A Study on Development of Railway Accident Scenarios for Railway Workers

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The objective of this study is to develop fatality accident scenarios for railway workers and assess the risk for each scenario. In this research, we develop accident scenarios using the Quality Function Deployment (QFD) method to analyze systematically and evaluate quantitatively fatality accident scenarios for railway workers. This approach was inspired by the Quality Function Deployment (QFD) method, which is conventionally used in quality management and is used at the systematic accident scenario analysis (SASA) for the design of safer products. In this study, QFD provides a formal and systematic schema to devise accident scenarios while maintaining the objectivity. The accident scenario analysis method first identifies the hazardous events and explains the hazardous conditions that surround the accident and cause railway accidents. This method includes a feasibility test, a clustering process and a pattering process for a clearer understanding of the accident situation. Since this method enables an accident scenario analysis to be performed systematically as well as objectively, this method is useful in building better accident prevention strategies. Therefore, this study could serve to reduce railway accidents and could be an effective tool for a hazard analysis.

Key words: Railroad Safety, Preliminary Hazard Analysis (PHA), Quality Function Deployment (QFD), Accident Scenario Analysis, System Safety Management

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1. INTRODUCTION

The railway system safety procedure generally consists of three major steps; (1) identification of the hazards, (2) evaluation of the hazard levels, (3) elimination or control of the hazards. The first step includes identifying hazardous characteristics of a railway system and potential threats from railway accidents. The preliminary hazard analysis (PHA) is widely used for this task, which is based on analysis of various accident-related reports and information.

The PHA for understanding how hazardous events and hazardous conditions contribute to a railway accident examines the etiology of railway accidents and analyzes the detailed sequence of events that caused the railway accident. This can be accomplished by applying the accident analysis method. This method is the process of understanding, analyzing, and describing the accident and the behavior patterns of hazardous conditions through the use of published sources, focus groups, questionnaires, and personal interviews. The approaches most frequently used are failure modes and effects analysis (FMEA) and fault tree analysis (FTA). These approaches have several limitations, however. FMEA is limited in that it does very little to analyze problems arising from human errors or adverse environments. FTA has limitations; this approach analyses only those problems related to a central subject and excludes any intangible problems that could arise from human errors. With regard to these problems, most of these approaches only take into account technical failures [3].

On the other hand, the accident analysis method using an accident scenario analysis is often useful in that this method examines patterns of accidents and provides clues to building better prevention strategies for each pattern of accident. Drury and Brill [2] devised a limited number of accident scenarios with descriptions of the actors (victims), the props (products), the scene (environments), and the action (task). These scenarios were used to structure 'intelligent' accident investigation questionnaires for several products such as chain saws, riding toys, ranges and ovens, swimming pools.

The accident scenario analysis can be used to provide a clear picture of accidents that arise from hazardous events and hazardous conditions. Although much work has been done to apply scenario analysis to accident, there is still no systematic and formal methodology which identifies generates, analyzes, and verifies accident scenarios, in our view. The absence of such a methodology raises questions regarding accuracy and objectivity; i.e. the systematic reflection of the interaction between hazardous events and hazardous conditions is not employed. Since the validity of the accident scenario can be subjective because of its dependence on the analysts' personal experiences, this method is not widely used in accident analyses. Therefore, a new method which is more systematic as well as objective is needed to better identify and give a clearer picture of the accidents arising from the interaction between hazardous events and hazardous conditions.

Motivated by this fact, in this study, we develop fatality accident scenarios for railway workers and assess the risk for each scenario. In this research, we develop accident scenarios using the Quality Function Deployment (QFD) method to analyze systematically and evaluate quantitatively fatality accident scenarios for railway workers. The QFD method has been conventionally used in quality management and was used at the systematic accident scenario analysis (SASA) for the design of safer products [3]. In this study, the QFD provides a formal and systematic schema to devise accident scenarios while maintaining the objectivity. The accident scenario analysis method first identifies the hazardous events and explains the hazardous conditions that surround the accident and cause railway accidents. This method includes a feasibility test, a clustering process and a pattering process for a clearer understanding of the accident situation. Since this method enables an accident scenario analysis to be performed systematically as well as objectively, this method is useful in building better railway accident prevention strategies. Therefore, this study could serve to reduce railway accidents and could be an effective tool for a hazard analysis.

The rest of the paper is organized as follows: Section 2 will show the overview of the PHA and the QFD method. Section 3 will explain the framework of the used accident scenario analysis method step by step. Finally, conclusions are given in section 4.

2. Preliminary Hazard Analysis (PHA) and Quality Function Deployment (QFD)

2.1. Risk Analysis Process

In many cases, railway system changes are associated with risk change, that is potentially harmful to people. The risk level associated with a change can vary from negligible to totally unacceptable. Risk could generally be reduced, although usually at a cost. Risk assessment entails a systematic analysis of the potential losses associated with the change and of the measures for reducing the likelihood or severity of the losses. It enables losses to be aggregated and compared against the cost of measures. Risk assessment is tightly coupled with hazard identification and risk reduction. The hazards of a system have to be identified for an accurate assessment of risk. Risk assessment provides, throughout the lifecycle of a system or equipment, both input to risk reduction and feedback on its success [4]. The seven-stage process of risk assessment is depicted in Figure 1 [4].

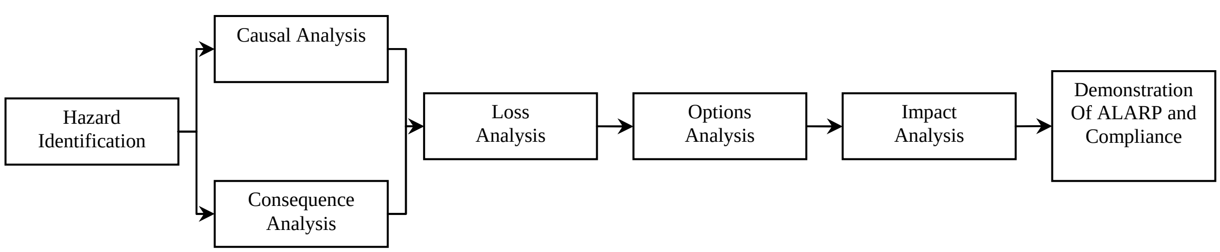

Figure 1: Risk assessment stages

The PHA, often called hazard identification, is used in the early life cycle state to identify critical system functions and system hazard factors. The PHA for understanding how hazard factors contribute to railway accidents can provide a clear picture of the accidents by understanding, analyzing, and describing the accident process through the use of published sources. This can be accomplished by applying the accident analysis method given in following sections.

2.2. Preliminary Hazard Analysis (PHA)

A PHA is used in the early stage of life cycle for the identification of critical system functions and system hazard factors. The identified hazard factors are often assessed and prioritized, and safety criteria and requirements may be identified. A PHA is performed so that safety considerations are included in the risk reduction measures. Because a PHA is performed at the early stage of risk assessment, little detail is available and assessments of hazard and risk levels are qualitative and limited [6]. The PHA process is depicted in Figure 2.

Input Data for Analysis	· Hazardous event lists generally considered for railway system · Hazard analysis scope · Definition of severity and frequency levels for hazardous conditions · System Description - Functional flow diagram - Product Breakdown Structure (PBS)

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Preliminary Hazard Analysis	· Selection of a hazardous event from hazardous event lists · Evaluation of the frequency and the severity for the hazardous event · Definition of hazardous conditions to initiate the hazardous event · Description of hazardous conditions · Analysis of influence on the hazardous event for each hazardous condition · Evaluation of hazard levels for each hazardous condition · Definition of control measures for each hazardous condition - Corrective or preventive measures, possible safeguard, and recommended action · Verifying that control measures effectively control hazardous conditions

⇩

Expected Output	· Severity and frequency levels of hazardous conditions related to a hazardous event · Potential hazard factors · Risk reduction alternatives

Figure 2: Preliminary Hazard Analysis Process

In PHA, severity, frequencies, and restraint conditions are involved so that hazardous conditions can be identified and evaluated, and corrective or preventive measures are involved to control hazardous conditions for hazardous events.

2.3. Quality Function Deployment (QFD)

The QFD method provides a way to incorporate customer needs into product development and production. In QFD, the relationship between customer needs and the quality requirements necessary to produce those needs are charted, as are the component characteristics, process planning, and production planning. This process may help reduce product development time and give the product a competitive advantage. It could also maximize customer satisfaction by reflecting customers' needs in the final products [3].

The QFD method contains one or more matrices called 'House of Quality' [1], termed QFD matrix for convenience. It displays the customers' needs along the left column and the development team's quality requirements in the top row. The QFD matrix consists of several sub-matrices joined together in various ways- e.g. relationship matrix, market evaluation matrix, and roof matrix (see Figure 3).

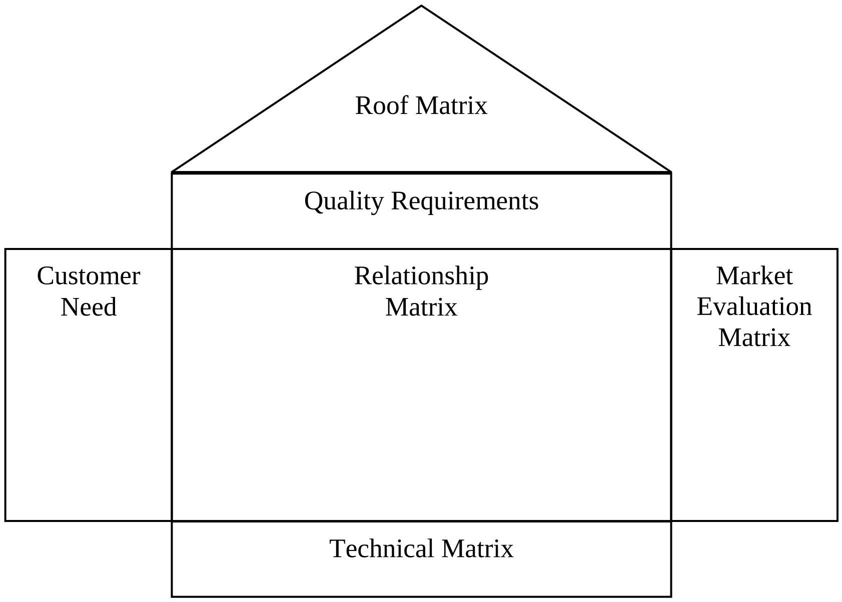

Figure 3: House of Quality (HOQ)

3. Railway Accident Scenario Development using a Quality Function Deployment

The used method was based on a modified QFD matrix. The used method replaces the customer’s needs and quality requirements on the QFD matrix with hazardous events and hazardous conditions. However, the used method keeps the meanings for the relationship matrix the same. The market evaluation matrix, technical matrix, and the roof matrix are neglected in the used method. The used method adopted the modified QFD matrix as a tool for devising accident scenarios. Figure 4 shows a complete process of the used method. There are seven key steps.

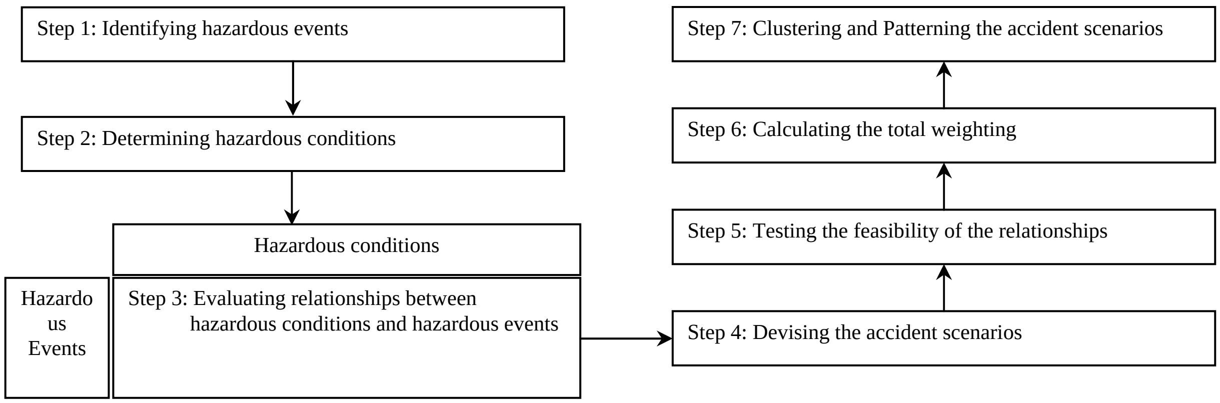

Figure 4: Railway Accident Scenario Analysis Approach

3.1. Identifying hazardous events (Step 1)

This step is probably the most important in that it can pinpoint the safety problems of a railway system; only a successful identification of the problem can lead to improved and safer railway system. Identification of the hazard factors, defined by railway accidents, is carried out mainly by gathering various accident-related reports and information to define hazardous events such as collisions, derailments, explosions, etc. A series of hazard evaluation approaches as FMEA, FTA can be also used in this step.

3.2. Determining hazardous conditions (Step 2)

Hazardous conditions are the characteristics and circumstances surrounding a railway accident. Drury and Brill [2] show that a product use accident involves the interaction between a product, a user, a task and an environment. For railway accidents, this study makes hazardous conditions composed of the four parts: (1) victim, (2) task, (2) environment, and (4) cause. For each part, detailed hazard conditions can be defined. For example, gender, age, height, weight, injured body parts, and injury types are used to describe victim characteristics.

		Hazardous Conditions											
		Victim Characteristics			Task Characteristics			Environment Characteristics			Cause Characteristics		
Hazardous Events	**Importance**	1	2	••	1	2	••	1	2	••	1	2	••
Hazardous Events **1**													
Hazardous events **2**													
.													
.													
.													
Hazardous events N													

Relationship Rating Indication

◎: Strong relationship (5)

△: Moderate relationship (3)

○: Slight or possible relationship (1)

Figure 5: Railway Accident Analysis Tableau

3.3. Evaluating relationships between hazardous conditions and hazardous events (Step 3)

In the original sense of the QFD method, the importance of each the QFD method, the importance of each customer’s needs is rated based on the results of questionnaires and the direct experience of the QFD development team [2]. Consumer’s needs are then matched with quality requirements to determine the influence of the latter on the former. The QFD team, consisting of marketing people, design engineer, and manufacturing staff, seeks a consensus on these evaluations based on expert engineering experience and results from statistical studies or controlled experiments.

On the basis of railway accident data, the used method rates the importance of a hazardous event by computing the severity of the hazardous event (e.g. equivalent fatality per year) and evaluates between the hazardous events and hazardous conditions by computing the frequency. That is, the most severe hazardous event is assigned the highest weight and the most frequent relationship between the hazardous events and hazardous conditions is assigned the highest weight.

A review of various literature shows that in the QFD method, the ratings are generally weighted with 1 to 5 or 1 to 9 scales with the larger number indicating greater importance or stronger relationship. There is no established scientific basis to determine the superior rating system [6]. In the study, the used method adopts the 1-5 rating scale, meaning a hazard factor weighted ‘1’ indicates the least important, and ‘5’ the most important. The relationship between the hazard factors and situation characteristics is weighted ‘5’ if the relationship is strong, ‘3’ if moderate, and ‘1’ if weak.

3.4. Devising the accident scenarios (Step 4)

Figure 5 shows a complete scheme for devising railway accident scenarios. The scheme, 'railway accident analysis tableau', creates scenarios from a matrix of all the possible relationships; the relationship of each hazardous event with its corresponding hazardous conditions. For example, if any hazardous event is related to four victim characteristics, two task characteristics, three environment characteristics, and one cause characteristic, the accident analysis tableau can devise a total of twenty-four accident scenarios.

3.5. Testing the feasibility of the relationships between a hazardous condition and hazardous conditions (Step 5)

The used method filters out infeasible relationships between elements of the hazardous conditions, therefore, mitigating the need to devise and analyse the accident scenarios. For example, consider the victim characteristic, 'passenger' and the task characteristic, 'train maintenances'. The victim characteristic, 'passenger' can not be related with the task characteristic, 'train maintenances'. Therefore, the railway accident scenario including these terms is classified infeasible.

3.6. Calculating the total weighting (Step 6)

After the railway accident scenarios are created, the total weight is calculated to determine the prominence of railway accident scenarios. To calculate the total weight for each railway accident scenario, the importance of the hazardous event is multiplied by each of its corresponding hazardous conditions and then added together to get the total. The railway accident scenarios for each hazardous event are prioritized by their relative rankings based on total weights. The highest ranked railway scenario describes the most hazardous case.

3.7. Clustering and Patterning the accident scenarios (Step 7)

As mentioned above in step 4, the railway accident analysis tableau devises the railway accident scenarios based on all the possible relationships between the hazard factors and situation characteristics. The process may create too many railway accident scenarios to be dealt with. In order to understand the hazardous condition thoroughly, the clustering and pattering processes are introduced. These processes make the used method an easier and simpler railway accident analysis method.

4. CONCLUSION

In this study we developed fatality accident scenarios for railway workers. This approach was inspired by the QFD method. In this study, the QFD method provides a formal and systematic schema to devise accident scenarios while maintaining the objectivity. The accident scenario analysis method first identifies the hazardous events and explains the hazardous conditions that surround the accident and cause railway accidents. This method includes a feasibility test, a clustering process and a pattering process for a clearer understanding of the accident situation. Since this method enables an accident scenario analysis to be performed systematically as well as objectively, this method is useful in building better accident prevention strategies. Therefore, this study could serve to reduce railway accidents and could be an effective tool for a hazard analysis.

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