THE RISK MANAGEMENT METHODOLOGY USED IN RAILWAY SYSTEMS - A CASE STUDY OF ALISHAN FOREST RAILWAY

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Abstract

To effectively manage assets, geographic information system had been introduced into railway systems. A lot of spatial data had also been applied to forecast potential problems. However, a pre-analysis plan is rare to be implemented to clarify what kinds of information needed by the stakeholders. A goal-oriented concept should be adopted before the construction of Spatial Data Infrastructure.

The Alishan Forest Railway is a traditional railway system in Taiwan, and it has been operated for more than 100 years since its establishment. In recent years, the railway had been damaged by typhoons and earthquakes many times, and it is possible to cause serious accidents if the operator cannot react to disasters immediately. So, the operator want to build up an smart alarm system to prevent serious accidents. In the project, to clarify what kinds of data needed is the first step. This study followed the risk management methodologies in EN 50126 to reconsider the impact of natural disasters. The result demonstrates that the possible safety hazards caused by natural disasters, and preliminarily clarify what data should be collected in priority. The results also help operators to find out the weakness of the system, and the appropriate mitigating measures are identified both before and after the natural disasters.

Keywords: Railway, Risk Management, Natural Disasters

1. INTRODUCTION

1.1. The Background of Alishan Forest Railway

Alishan Forest Railway (AFR) is a traditional railway system, and it is famous for its beautiful high mountain railway and Z-shaped switchback lines. Tab. 1 is the operating features of AFR, and Fig. 1 shows its line map. AFR were damaged by typhoons and earthquakes in recent years, and parts of the railroads have not been restored. Unfortunately, these natural disasters also led to many fatalities and injuries shown as Tab. 2.

Table 1: The Operating Conditions of Alishan Forest Railway

Operating Features	Description
Length (in operation)	Main Line: 45.8 km Branch Line: 7.95 km
Operating Speed	Level Area: 45 km/hr Mountain Area: 20km/hr
Maximun Slope	6.25 %
Minimun Radius	40 m
Height above sea level	30 m ~ 2216 m
Operation Mode	Single track, bi-directional
Passenger	About 5000 persons per day

Figure 1: Line Map of Alishan Forest Railway

Source: Alishan Forest Railway Website: http://www.railway.gov.tw/Alishan-en/

Table 2: Accidents Caused by Natural Disaster in Recent Years

Date	Description	Result
2009/8/8	Landslides caused by typhoon	Operation suspended
2011/4/27	Train turnover caused by falling tree	5 fatalities, more than 100 injuries
2014/7/23	Landslides caused by typhoon	Operation suspended
2015/9/28	Landslides caused by typhoon	Operation suspended

To avoid possible derailments and train turnovers, AFR will suspend the service, whenever the hourly rainfall is over 50 mm, the daily one is over 200 mm, or the earthquake magnitude is higher than 3 Richter scale. After the disasters, the service will be resumed till a overall inspection is completed. For the reason that real-time information is necessary for emergency responses, AFR would like to introduce Spatial Data Infrastructure (SDI) into its system.

1.2. SDI in Railway

The application of Geographic Information System (GIS) is the beginning of SDI in railway domain. Because GIS could be effectively deployed in a broad array of railway functions, including: (Environmental Systems Research Institute, 2005)

- Infrastructure management and maintenance planning
- Real assets management
- Rolling stock management
- Safety and security
- Design and construction
- Supply chain analysis
- Passenger information systems
- Intermodal management

Safety is the most popular reason for the government and operators to introduce GIS into the management. For example, Federal Railroad Administration (FAA) had adopted GIS to record the information of accidents and trespassers (Raquel, 2012). However, it is best to get leading indicators instead of lagging ones such as accidents and trespassers. Therefore, the data detected by sensors is combined with GIS to provide more information to forecast the potential hazards (Barbara, 2013).

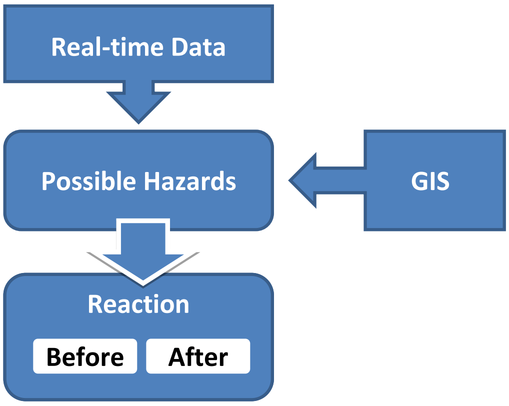
On the other hand, SDI is also applied to the asset management, especially for the maintenance. It is more convenience for railway operators to control the available resource (Kobayashi, 2006), and identify the possible failure according to the other supporting information (Shr & Liu, 2016).

1.3. Key Issues

After the brief review of the SDI implication in railway systems, Fig. 2 shows the conceptual SDI framework applied in AFR, and it leads to the following questions.

1. What kinds of real-time data are needed?
2. What kinds of GIS information are needed?
3. How does the operator identify the possible hazards?
4. What are the reactions to mitigate the impact before and after the disasters?

Figure 2: The Framwork of SDI used in Alishan Forest Railway



This paper has been organized as follows. The risk management methods are illustrated first in Section 2, and the results and findings of the analysis are organized in Section 3. Finally, the contributions and future works are summarized in Section 4.

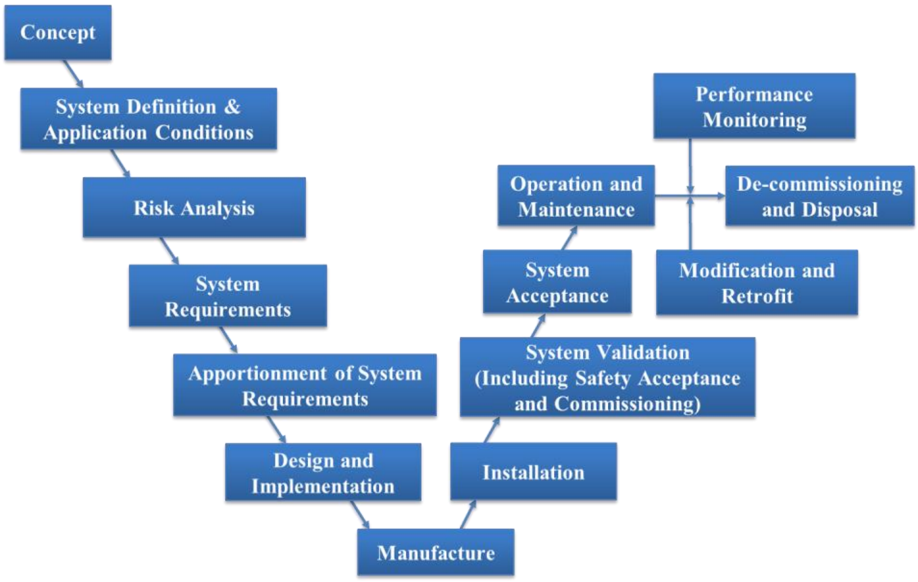
2. METHODOLOGY

Two popular risk management methods are used in this study, one is Preliminary Hazard Analysis (PHA) and the other is Hazard and Operational Analysis (HAZOP). First of all, this section introduces the general concepts of risk management in railway system, and then illustrates these two methods.

2.1. Risk Management in Railway Systems

Regarding risk management in railway systems, a series of methodologies in the European standard EN 50126 are well defined and applied in many railway systems. Fig. 3 shows that the purpose of EN 50126 is to manage hazards throughout the entire V-typed lifecycle, including design, construction, operation, and all the way to decommissioning. The causes, mitigations, and residual risk class of hazards are updated accordingly during the entire life cycle.

Figure 3: V-typed Lifecycle

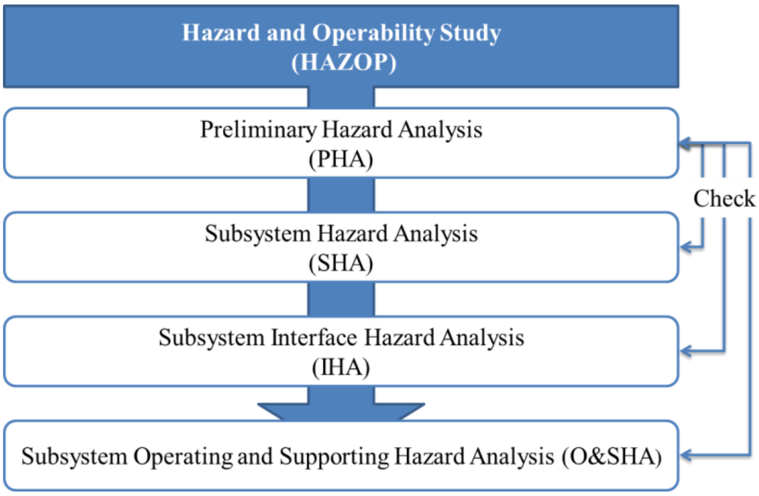


Source: EN50126

In common railway practices, risk management will be implemented at the beginning of planning and design stage, and the hazard data will be handed over to the operator after the construction. The operator could keep updating the data based on the operating observations, such as adding mitigations for unexpected accidents/incidents, or new hazards caused by new equipment or procedures. However, the old railway system may not have this kind of hazard data, because the concept of EN 50126 had not been applied till 1990. Therefore, the first step in this study is to build up the specific hazard data for AFR.

Fig. 4 is the general procedure for analysing safety hazards in a railway project. The process reveals that HAZOP is a systematic brainstorming to identify potential hazards, and it is usually applied in Preliminary Hazard Analysis (PHA), Subsystem Hazard Analysis (SHA), Subsystem Interface Hazard Analysis (IHA), and Subsystem Operating and Supporting Hazard Analysis (O&SHA). Here we illustrate HAZOP and PHA model as below.

Figure 4: Safety Hazard Analysis Procedure for Railway System



2.2. Preliminary Hazard Analysis

PHA is usually implemented at the early stage in a railway project. It could preliminary identify the possible hazards, causes, impact, and required mitigations. SHA, IHA, and O&SHA are the subsequent analyses, and more detailed information will be built up. The results of these subsequent analyses should be confirmed with PHA to ensure whole hazards are covered.

Since it is a time consuming work to complete SHA, IHA, and O&SHA for a railway system, this study only implemented PHA to preliminarily clarify the whole picture of hazards in AFR. Tab. 3 shows the template used in PHA, and the explanation of each column is described as follows:

Table 3: The Template of PHA

No	Hazard Description	Hazard Cause	Possible Accidents	Present Mitigation	Initial Risk	Reduction Measures	Expected Risk

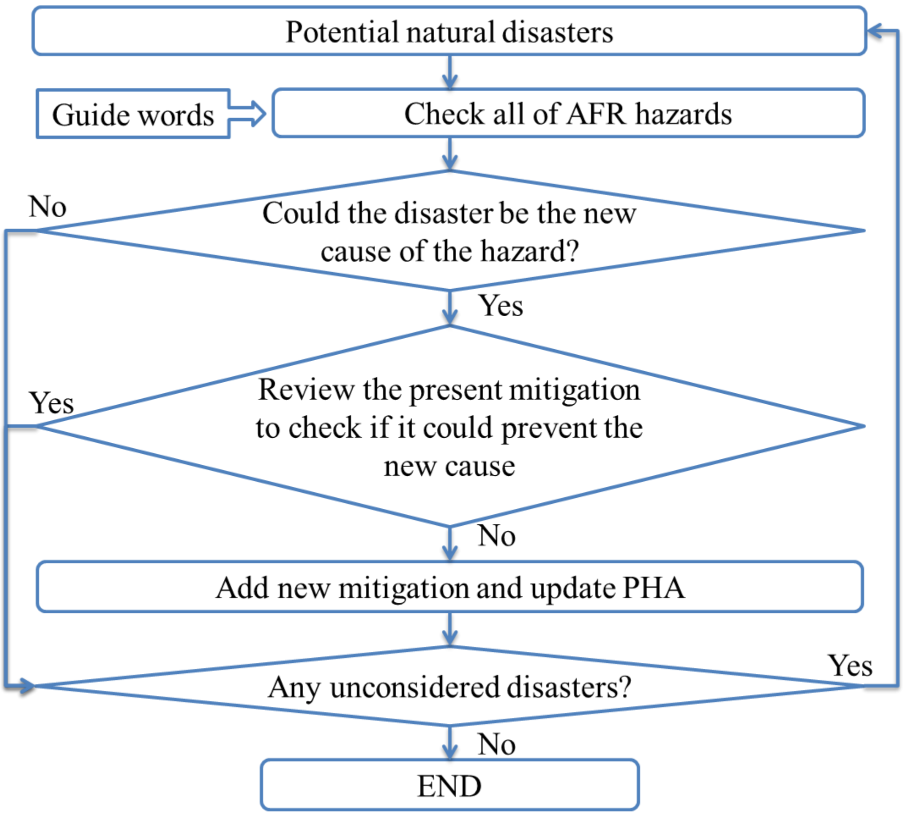
- No: the serial number of the hazard
- Hazard Description: the detailed description of the hazard
- Cause: the possible cause leading to the hazard
- Possible Accidents: the possible accident caused by the hazard
- Present Mitigation: the present mitigation to avoid the hazard
- Initial Risk: the present risk of the hazard
- Reduction Measures: the additional measures suggested to mitigate the risk

- Expected Risk: the expected risk if all reduction measures are implemented

2.3. HAZOP

Regarding the hazard analysis, it is usually implemented through the brainstorming. However, the performance of brainstorming depends on the professional ability of the attendances, and some rare conditions may be neglected in the discussion. Therefore, a well-defined process and supporting tools is needed to guarantee the performance of the brainstorming. HAZOP is one of systematic methods used in railway domain to identify potential hazards. The method considers the possible deviations of functions or activities, and some guild words are applied to support the brainstorming. This study modified it to identify the possible impact caused by the disasters, and the flowchart is shown as Fig. 5.

Figure 5: HAZOP Flowchart in This Study



The guide word list is the main tool to remind the attendances to consider possible impacts caused by the deviations. Tab. 4 is the guide word list used in this study, and the results of HAZOP are shown in Section 3.

Table 4: Guide Words in HAZOP Method

Guide Word	Explanation
No	None of the required intent
Part of	Part of the required intent
Reverse	Opposite of the required intent
More/Higher	Quantitative/qualitative increase of the parameters
Less/Lower	Quantitative/qualitative decrease of the parameters
As well as	Additional activities occur
Late	Late activities
Early	Early activities
Other than	Another activity takes place

3. RESULTS AND FINDINGS

3.1. Hazards identified through PHA and HAZOP

In this study, 8 major categories of railway safety hazards are identified, and there are more than 350 hazards in the PHA totally. All of these hazards are reviewed in HAZOP to identify the possible impacts caused by natural disasters. Tab. 5 shows the results, and 10 kinds of disasters are considered in HAZOP, including earthquake, landslide, heavy rain, etc.. The number in column “Hazard” represents the category of the hazard, for example, 1.2 means the major category is ‘1’, and the sub-category is ‘2’. “Guide Words” and “Deviations” are the main results contributed by the brainstorming in the HAZOP. The “Required Spatial Data” describes the available spatial information to mitigate the risk of the hazard.

Table 5: Results of HAZOP for AFR

Disaster	Hazard	Possible Accidents	Related functions/ activities	Guide Words	Deviation (Hazard Cause)	Required Spatial Data
Earthquake	1.1 Train leaves guideway	Derailment, turnover	The rail should guild the train	No	Rail broken	The layout, maintenance records, and real-time status of rail
				Part of	Part of rail fastenings loose	
	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment, turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The sites and status of danger trees and slopes aside the rail
					Building structure falls into train envelope	The sites of buildings aside the rail
	4.1 Person struck by falling objects	Person injuries	The object shoud be fixed	No	The object is not fixed	-
	4.14 Person trapped in station	Person injuries	Person could be evacuated from stations	No	The roads and railways are broken	-
	7.4 Obstacles on staff walkways	Person injuries	The walking area aside the rail should be clear	No	Environmental obstacle falls on walking area	The sites and status of danger trees and slopes aside the rail
					Building structure falls on walking area	The sites of buildings aside the rail
	7.8 Staff in danger cannot escape from guideway	Person injuries	The walking area aside the rail should be clear	No	Staff trapped in collaping structure	The coverage of radio along the rail and working area
Landslide	1.1 Train leaves guideway	Derailment, turnover	The rail should guild the train	No	The ballast or subgrade loss	The layout, maintenance records, and real-time status of subgrade

Disaster	Hazard	Possible Accidents	Related functions/ activities	Guide Words	Deviation (Hazard Cause)	Required Spatial Data
	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment, turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The sites and status of slopes aside the rail
					Building structure/equipment falls into train envelope	The sites of buildings/equipment aside the rail
	4.14 Person trapped in station	Person injuries	Person could be evacuated from stations	No	The roads and railways are broken	-
	7.4 Obstacles on staff walkways	Person injuries	The walking area aside the rail should be clear	No	Environmental obstacle falls on walking area	The sites and status of slopes aside the rail
					Building structure/equipment falls on walking area	The sites of buildings/equipment aside the rail
	7.8 Staff in danger cannot escape from guideway	Person injuries	The walking area aside the rail should be clear	No	Staff trapped in collaping structure	The coverage of radio along the rail and working area
Heavy Rain	1.1 Train leaves guideway	Derailment, turnover	The rail should guild the train	Part of	The resistance is not enough and leads to wheelspin	The real-time information of rainfall along the rail
	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment, turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The sites and status of slopes aside the rail
	1.3 Trains enter the blocked area	Collision	The train should stop before the blocking area (where another train is occupying)	Late	The train cannot brake caused by wheelspin	The real-time information of rainfall along the rail

Disaster	Hazard	Possible Accidents	Related functions/ activities	Guide Words	Deviation (Hazard Cause)	Required Spatial Data
	4.14 Person trapped in station	Person injuries	Person could be evacuated from stations	No	The roads and railways are broken	-
	5.5 Staff run over by trains	Person injuries, fatalities	The shunting area should be clear	Part of	The sight view is not clear	The real-time information of rainfall around shunting area
	7.4 Obstacles on staff walkways	Person injuries	The walking area aside the rail should be clear	No	Environmental obstacle falls on walking area	The sites and status of slopes aside the rail
					Building structure/equipment falls on walking area	The sites of buildings/equipment aside the rail
Strong Wind	1.1 Train leaves guideway	Derailment, turnover	The lateral force to train should be limited	More	Lateral force is over the limitation	The real-time information of windspeed along the rail
	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment, turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The sites and status of danger trees aside the rail
	7.4 Obstacles on staff walkways	Person injuries	The walking area aside the rail should be clear	No	Environmental obstacle falls on walking area	The sites and status of danger trees aside the rail
	7.13 Staff struck by falling objects	Person injuries	The walking area aside the rail should be clear	No	Environmental obstacle falls on walking area	-
Drought	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment, turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The sites and status of danger trees aside the rail

Disaster	Hazard	Possible Accidents	Related functions/ activities	Guide Words	Deviation (Hazard Cause)	Required Spatial Data
High temperature	1.1 Train leaves guideway	Derailment , turnover	The rail should guild the train	No	Rail broken caused by over thermal expansion of track	The layout, maintenance records, and real-time status of rail
Low temperature	1.1 Train leaves guideway	Derailment , turnover	The rail should guild the train	Part of	The resistance is not enough caused by surfacing frost of track, and leads to wheelspin	The layout, maintenance records, and real-time status of rail
Snow	1.1 Train leaves guideway	Derailment , turnover	The rail should guild the train	Part of	The resistance is not enough caused by surfacing frost of track, and leads to wheelspin	The layout, maintenance records, and real-time status of rail
	1.3 Trains enter the blocked area	Collision	The train should stop before the blocking area (where another train is occupying)	Late	The train cannot brake caused by surfacing frost of track, and leads to wheelspin	The layout, maintenance records, and real-time status of rail
Lightning	2.4 Fire	Fire	The sleepers should be fixed and support the tracks	No	The wood sleepers are on fire caused by lightning	The sections with wood sleepers or pre-stressed concrete sleepers
Flood	1.2 Obstacle/ person intrudes the clearance of train envelope	Derailment , turnover	The train envelope should be clear	No	Environmental obstacle falls into train envelope	The real-time information of rainfall along the rail and working area

3.2. Findings

According to Tab.5, the findings are described as follows:

1. The real-time status of rail is the most important data to avoid the possible hazards caused by natural disasters, including the information of tracks and the subgrade. Further, to monitor the temperature of tracks is also important to avoid the potential hazards. For example, if the temperature is overheat, it may lead to track buckling. In contrast, if the temperature is freezing cold, it may have frost on the surface of tracks. The trains may lose braking function because of the low resistance between wheels and tracks.
2. AFR has a standard operation procedure to suspend the service caused by heavy rainfall (50 mm per hour or 200 mm per day). However, a long period of rain could also lead to accidents, even the daily rainfall is not over the threshold. Further, the rainfall along the rail may be different with the data recorded by specific meteorological stations nearby. It is necessary for AFR to build its own sensors to get more real-time and accurate information.
3. The slopes (rocks) and trees are the most possible objects to be the obstacles on the rail. AFR has daily inspections to ensure no obstacle on the rails. Tab. 5 shows that the inspections should be more careful after heavy rain and strong wind, not only after typhoons and earthquakes at present. Further, the drought may increase the possibility of falling trees also.

4. CONCLUSIONS AND WAY FORWARDS

4.1. Conclusions

This section summarizes the preliminary answers to the questions listed in Sec. 1.3 according to the results of the analysis:

1. What kinds of real-time data are needed?
    a. The amount of rainfall aside the rails and working area
    b. The degree of wind aside the rails
    c. The status of slops along the rails
    d. The temperature of tracks
2. What kinds of GIS information are needed?
    a. The layout of rails with maintenance records
    b. The sites of danger trees and slopes
    c. The sites of buildings/equipment along the rails
    d. The coverage of radio
    e. The sections with wood sleepers or pre-stressed concrete sleepers
3. How does the operator identify the possible hazards?
    The possible hazards and related causes are described as follows:

a. Train leaves guideway: Earthquakes, landslide, and high temperature may break the rail; low temperature and snow may decrease the resistance of tracks; strong wind may make the lateral force to trains over the limitation.
b. Obstacle/person intrudes the clearance of train envelope: Earthquakes, landslide, strong wind, heavy rain, drought, and flood may make obstacles on the rails.
c. Trains enter the blocked area (where another train is occupying): Heavy rain and snow may decrease the resistance of tracks and lead to braking problems.
d. Fire: Lightning may lead to the fire of wood sleepers.
e. Person struck by falling objects: Earthquakes may lead to falling objects in station.
f. Person trapped in station: Earthquakes, landslides, and heavy rain may break the railways and rods connected to stations, and make the persons trapped in station.
g. Staff run over by trains: Heavy rain may lead to bad sight view, and it is more possible to have human errors.
h. Obstacles on staff walkways: Earthquakes, landslide, strong wind, heavy rain, and drought may make obstacles on the walkways.
i. Staff in danger cannot escape from guideway: Earthquakes and landslide may trap staff.
j. Staff struck by falling objects: Strong wind may lead to falling objects along rails and working area.

4. What are the reactions to mitigate the impact before and after the natural disasters?
    a. Earthquake: Not only the tracks should be inspected carefully after the earthquake, but also the buildings/equipment aside the rails and the hanging objects in stations and working area.
    b. Landslide: The tracks and subgrade should be inspected carefully after the landslide.
    c. Heavy rain: The amount of rainfall should be recorded continuously to forecast the possible hazards.
    d. Strong wind: The degree of wind should be recorded in real time to provide the real-time alarms to train drivers.
    e. Drought: The drought status should be recorded continuously to forecast the possible hazards.
    f. High temperature: The temperature should be monitored continuously to forecast the possible hazards and provide real-time alarms.
    g. Low temperature: The temperature should be monitored continuously to forecast the possible hazards and provide real-time alarms.
    h. Snow: The tracks should be inspected carefully after the snow.
    i. Lightning: The train drivers should get the lightning alarm to pay attention to possible fire, especially in the sections with wood sleepers.

j. Flood: The amount of rainfall should be recorded continuously to forecast the possible hazards.

4.2. Ways forward

This study preliminary analysed the potential safety hazards caused by natural disasters in railway systems. AFR had referred to the findings to arrange the priority of improvements, including the installation of rainfall and slope inspection sensors. Furthermore, AFR also plan to build an Operation Control Centre to collect all data from sensors. Generally, the findings in this study could support AFR to define the required data to identify all possible hazards, and the methods illustrated in this study could be applicable in both railway systems and other domains. We suggest the governments to implement a preliminary analysis before the construction of the system and sensors. This analysis could filter out the useless data and clarify what kinds of data are needed by different stakeholders. Further, not only safety issues, the following issues could also be analysed to make the results more comprehensive:

1. The impacts to different stakeholders.
2. The analysis of availability, including the possible failures caused by natural disasters.
3. The impacts from external activities, such as the possible reactions made by the other organizations.

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