Risk Assessment for JR East

Ken KUSUKAMI

Director

East Japan Railway Company

1. INTRODUCTION

East Japan Railway Company (JR East) has organized numerous trains to transport nearly 17 million customers each day. From a risk assessment perspective, accidents might occur due to the company's providing a large number of train services. Since its establishment in 1987, JR East has reduced the occurrence of operational railway accidents by approximately one-third (see Figure 1). However, it must increase its efforts to respond to demands of customers to promote safety on railway.

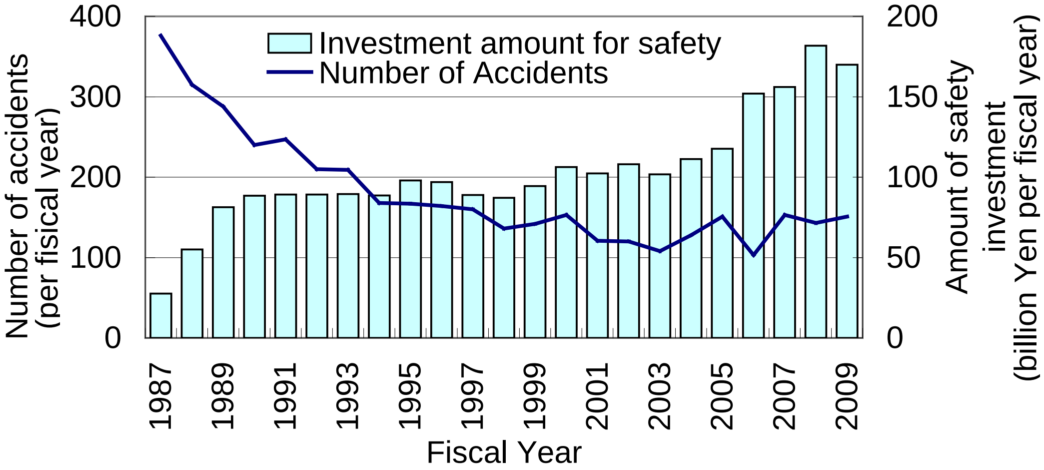

Figure 1: Change in the number of accidents and the amount of safety investment

One of the best ways for JR East to maximize its commitment to rail safety is to apply risk assessment processes when creating safety programs. The company needs to gain an understanding of the state of safety on the railway and perspective on improving safety. Thus, researchers at the Safety Research Laboratory of JR East have been investigating how to apply risk assessment methods to the company's railway service to effectively improve safety. The purpose of this paper is to present the results of the study of the risk assessment for JR East and to obtain comments to improve customer safety from experts.

2. The Risk Assessment Processes of JR East

2-1 Requirements

JR East is a railway company that has 1,689 stations, approximately 7,000 level crossings, and 7,513 km of passenger line networks. It serves approximately 17 million passengers per day. To obtain useful findings from results, calculations must be performed using small sections as much as possible. However, the smaller the sections we run in calculations, the more time and effort we spend. To do a calculation with a balance of both sides, it is important to define the requirements to implement a risk assessment method and direct efforts toward the realization of the following requirements:

- Targeting the safety risks related to train operations
- Recalculating risk easily to estimate the results of the safety measure
- Managing data feasibly

- Completing comparative estimations with weighted risks based on social values

2-2 Risk definition

In this paper, risk is defined as fatalities and injuries on the railway operations of JR East. The target of risk calculation was defined as the accidents that might involve fatalities and injuries on railway operations, excluding cases in which the train company has no responsibility for the accident, such as when a person ventures onto the track, despite being fully aware of the risks involved. Calculated results for risk are shown in fatalities and weighted injuries (FWI). We assumed that the severity of 100 injuries was equal to the severity of one fatality (see Table 1), according to the past record of the payment of insurance claim.

Type of Damage	Weighted Coefficient
Fatality	1.0
Injury	0.01

Table 1: Weighted coefficients for type of damage

2-3 Calculation sections

The definition of the calculation sections influences the number of the calculation and utility of the results. In order to obtain useful findings from the results, calculation needs to be carried out in small sections as much as possible. However, the smaller the sections for which we calculate, the more time and effort we spend on data maintenance. After trial and error, we concluded that it would be reasonable to define a calculation section as a section in which the passenger line networks of JR East were divided into stations, as some important data on calculation was constant in the sections between stations. For example, the number of passengers in a train was constant in the sections between stations because passengers got on and off a train at a station. Moreover, the number of trains was also constant in the sections between stations. On the other hand, the number of accidents related to level crossings represented approximately one-third of the accidents at JR East, so we needed to focus on each level crossing to improve safety. Eventually, we set approximately 9,100 sections: 2,100 sections between stations and 7,000 level crossings (see Figure 2).

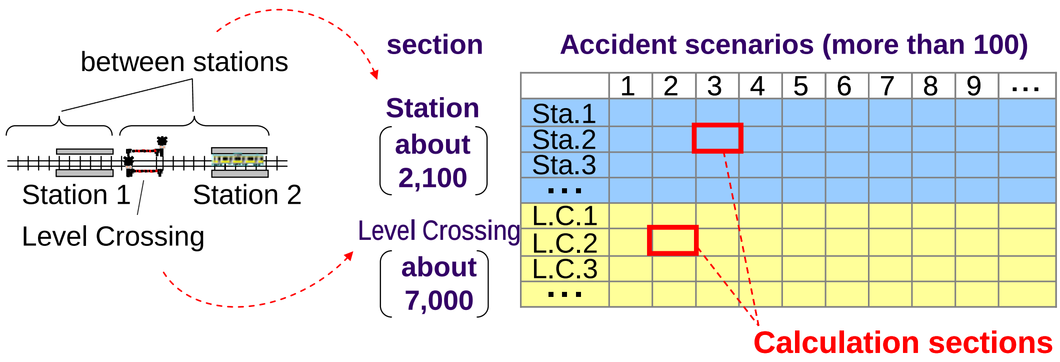

Figure 2: Calculation sections

2-4 Risk estimation

In general, risk can be calculated by combining the frequency and the consequence of an event. There are approximately 9,100 sections needed to estimate the risk. Further, we had to run multiple calculations to understand the effects of safety investments. In order to run these calculations for 9,100 sections, we made functions that generated the FWI from two inputs: an accident scenario and a specific section of the 9,100 sections. Once the functions obtained the two inputs, they gathered data based on the section information, performed calculations based on the procedures of the accident scenario, and generated FWI based on the expected fatalities and injuries.

(1) Frequency analysis

Given an accident scenario and a section to calculate, this section shows how to estimate the frequency of the scenario. As shown in Figure 3, we assumed that the number of accidents could be calculated in the three steps based on a fault tree analysis (FTA).

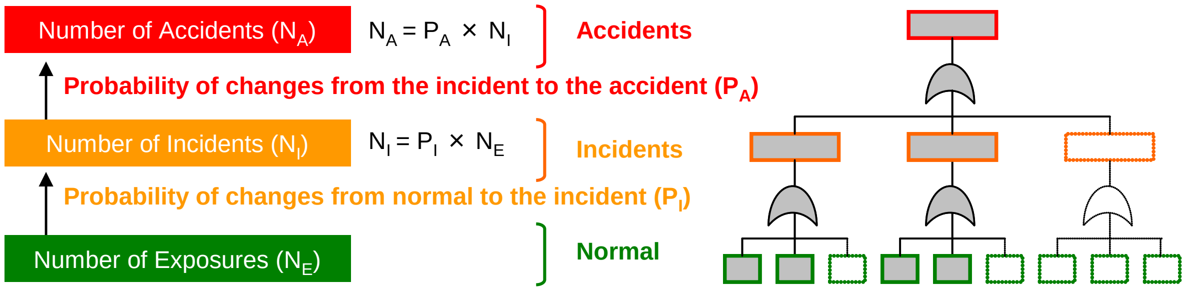

Figure 3: Framework of frequency analysis

When ordering the calculation procedure in this way, the accident frequency can be estimated based on the number of exposures (N_E), probability of changes from normal to the incident (P_I), and probability of changes from the incident to the accident (P_A). We estimated the number of incidents (N_I) and accidents (N_A) for a section by defining the three elements in advance. This allowed us to estimate the extent to which the safety program decreased the number of accidents by predicting the change in those three elements. In this situation, how we defined those three elements was important.

JR East has gathered a significant amount of accident/Incident data since it was established in 1987. It was reasonable for us to use these data when we defined the aforementioned three elements. We focused on the processes of each incident and accident, classified the processes, and defined the above three elements. A simple example is shown below.

Assume that there is an accident in which a train collides with a motorcar, which becomes stuck in a class 1 level crossing that is equipped with a crossing bar and a device to warn cars and pedestrians of an oncoming train (see Figure 4). To prevent this type of accident, JR East has been introducing a flashing light signal device to warn an approaching train of an emergency. The device has two types of triggers: automatic and manual. The automatic trigger device acts when it automatically detects an obstruction at the level crossing, whereas the manual trigger device acts when someone who notices the emergency pushes the button. Because we had real data about N_I and N_A, we could calculate P_I and P_A using the equation below, assuming that N_E was a combination of N_C and N_T. Table 2 shows the result of the calculation for P_I and P_A for three types of class 1 level crossings: flashing light signal devices with an automatic trigger, flashing light signal devices with a manual trigger, and no flashing light signal devices.

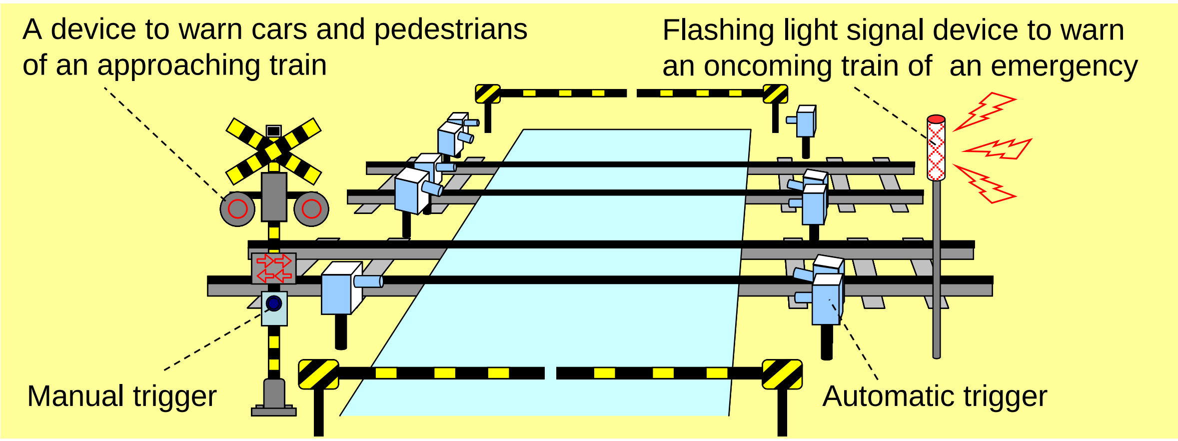

Figure 4: Example of class 1 level crossings

$$P_I = \frac{\sum N_I}{\sum N_E}, \quad P_A = \frac{\sum N_A}{\sum N_I} \qquad (1)$$

The most important point in this definition of the processes of the accident scenario is to solve for N_E. In this case, we defined the equation of N_E as "$(N_C \times N_T)^{0.5}$" after trying several combinations.

Trigger	N_L	N_E	P_I	P_A
No flashing light signal devices	2,444	$(N_C \times N_T)^{0.5}$	4.38×10^{-7}	0.1882
Flashing light signal devices with a manual trigger	1,346		1.78×10^{-6}	0.0656
Flashing light signal devices with an automatic trigger	2,639		1.04×10^{-6}	0.0063

Note. N_L: the number of level crossings, N_C: the number of traffic of motorcars, N_T: the number of trains

Table 2: Example of definitions of the processes of the accident scenario

We could then estimate N_I and N_A for any level crossing using the equation and the coefficients in Table 2. Figures 5 and 6 show the results of comparing real data and estimated values after we computed N_I and N_A for all of the class 1 level crossings and arranged every branch office.

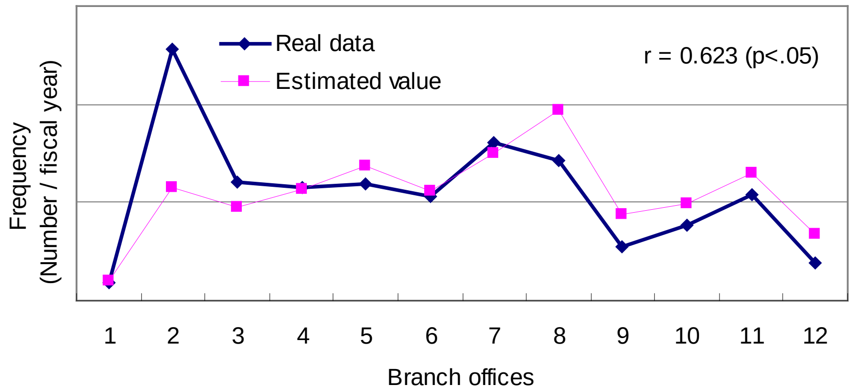

Figure 5: Comparison of estimated values and real data of incidents

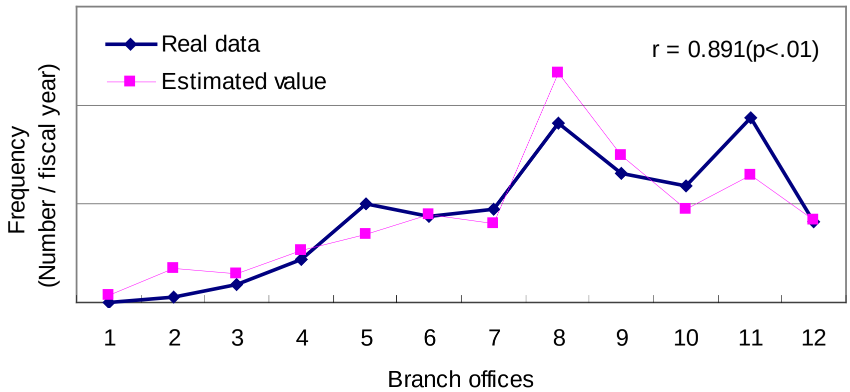

Figure 6: Comparison of estimated values and real data of accidents

The effect of the safety measures could also be estimated. For example, $P_I \times P_A$ for the manual trigger device was 1.17×10^{-7} and $P_I \times P_A$ for the automatic trigger device was 6.55×10^{-9}. When introducing the automatic trigger device into the level crossing with the manual trigger device, it was possible to estimate that N_A would decrease to 1/18. The effect of the safety measures was proportional to N_E.

Table 3 shows the estimation of a manual trigger device and an automatic trigger device. As this table shows, we could estimate the effectiveness of the safety measure when using P_I and P_A in Table 2. If we introduced an automatic trigger device into the level crossing equipped with a manual trigger device and if it the traffic volume at the level crossing was 1000 motorcars a day (N_C) and 100 trains a day (N_T), we could expect to decrease the number of accidents by 3.48×10^{-5}. The larger the exposure was, the greater the effectiveness to introduce an automatic trigger device was.

	Flashing light signal device with a manual trigger	Flashing light signal device with an automatic trigger	Effectiveness
Number of motorcars (N_C)	1000	1000	-
Number of trains (N_T)	100	100	-
Exposure (N_E) per day	$(1000\times100)^{0.5}$	$(1000\times100)^{0.5}$	-
Number of incidents (N_I) per year	5.63×10^{-4}	3.29×10^{-4}	2.34×10^{-4}
Number of accidents (N_A) per year	3.69×10^{-5}	2.07×10^{-6}	3.48×10^{-5}

Table 3: Estimation of the two trigger devices

In this way, when given an accident scenario and a section to calculate, we could estimate the frequency of accidents for the section using the section's data and the defined processes of the accident scenario (see Table 2). As a result, we could estimate the frequency of every accident scenario and section.

(2) Consequence analysis

When given an accident scenario and a section to calculate, this section shows how to estimate the consequence of the accident. The explanation focused on severe accident scenarios, such as collisions and derailments. For the other accident scenarios, the consequence of the accident conducted average value of the past accidents due to minor consequences.

The estimation for severe accident scenarios involves making the probability distribution of the consequences. The consequence of a previous accident is based on its occurrence condition. If the accident occurs at a different time or a different radius of curve, the consequence must be different. In the accident in which a train collided with a motorcar at a level crossing, the consequence was different based on the weight of the motorcar. Therefore, for severe accidents, it might not be appropriate to estimate the consequences using an average of the consequences of past accidents due to the low frequency and wide range of the consequences. For this reason, we estimated the probability distribution of the consequences. In order to obtain a consequence distribution, we followed two steps: event tree analysis and consequence estimation. The framework of this analysis is shown in Figure 7.

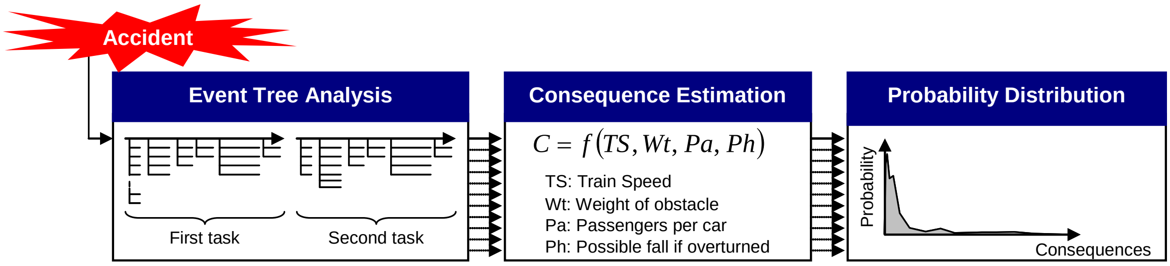

Figure 7: Framework of consequence analysis

Event tree analysis is divided into two tasks. The first task involves creating combinations using the elements (see Table 4). At the same time, the way in which the branch probabilities are set is important. The number of assumed combinations for each element is shown near the element. The branch probabilities that are used with the combination are set based on the section's data that are selected to calculate. For example, for "time of day", there are 48 categories. Further, the branch probabilities can be defined as the ratio based on the 48 categories that are distributed in the number of trains for "time of day", such as in the case of the accident scenario in which exposure was explained as the number of trains in the frequency analysis. For "radius of curve", there are five categories. Moreover, the branch probabilities can be defined as the ratio based on the five categories that are distributed in the radius of the curve for the section. For "weight of obstacle", there are five categories. In addition, the branch probabilities can be defined as the ratio based on the five categories that are distributed in the number of different weights of passing motorcars for "weight of obstacle", such as in the case of the accident scenario in which a train collides with a motorcar at a level crossing.

Time of day (48), passengers (48), number of trains (48), number of cars on the train (48), train speed (5), weight of obstacle (5), possible fall if overturned (5), radius of curve (5), type of line (3: single, double, quadruple track), and maximum speed (1).

Note. The number in ( ) shows the number of the assumed categories.

Table 4: Elements of event tree analysis

The second task involved identifying the endpoint: the train collides with something and derails or rolls down the track. The estimation of the consequence was conducted using those endpoints. For example, whether the derailed train blocked the other tracks or rolled down the track depended upon the train's speed and the radius of curve. If the train blocked the other tracks, whether the train collided with an oncoming train depended upon the train's interval. As previously described, several thousand endpoints were created to combine accident scenarios and sections.

Consequence estimation involves estimating consequences (fatalities and injuries) for the endpoint. To easily estimate consequences for many endpoints, we created the consequence equations in advance. As shown in Figure 7, we selected four elements, including the train speed, weight of obstacle, passengers per car, and possible fall if overturned. We assumed that these elements influenced the severity of the consequences and used those elements as inputs in the equation. We could use the various ideas in the consequence equation. We then developed the equation based on the idea that the larger each element was, the more severe the consequence was.

The values of the four elements were uniquely determined by the condition of the endpoint from the event tree analysis. We could estimate the FWI using the equation when obtaining the values of the four elements for each endpoint. After estimating all of the endpoints, we could make the probability distribution of the consequences. This distribution made it possible to evaluate not only the expected consequences, but also the risk of severe consequences. We could understand the risk of the accident that FWI exceeded 5, by focussing on the area that FWI exceeded 5 in the probability distribution of consequences.

In this way, when given an accident scenario and a section to calculate, we could estimate the probability distribution of consequences for the section using the section's data defined in the event tree and consequence equations in advance. Consequently, we could estimate the probability distribution of consequences for every accident scenario and section.

2.5 Social values

One major feature of the risk assessment of JR East is that the social values are included in the risk assessment processes. Social values in this report are defined as the ways in which people think about safety measures of the risk on JR East railway operations. By estimating the risk for each accident scenario using the method described in section 2.4, it was possible to rank the various risks from an engineering perspective. However, in a practical situation, we could encounter problems, as we cannot set priorities to safety measures using engineering risks that are calculated by combining the frequency and the consequence of the accident.

For example, imagine two accident scenarios that have the same magnitude of engineering risk (see Table 4). In this case, it seems that Scenario A is more serious than the Scenario B with regard to safety investments, as people might believe that the company has more responsibility in Scenario A than Scenario B. For this reason, we had to consider not only engineering risks, but also other factors when setting priorities about safety investments. This is why we thought that the engineering risk should be adjusted using social values.

Accident Scenarios		Causes
A	A running train derailed and collided with an oncoming train after an axle of the running train broke.	Internal
B	Due to heavy rain, the embankment collapsed; consequently, the train was lifted up by sediment and derailed.	External

Table 4: Comparison of risk in the different accident scenarios

In order to understand what the other factors are, we employed a group interview method. In the interview, we focused on to what people attached importance when an accident occurred. The answers could be classified into five categories as shown in Table 5.

Importance	Factor	Point
High	Causes	Could the operation company avoid the accident?
↑	Correspondences	Are the explanations, attitudes, and so on related to the accident in the company appropriate?
	Scale of damage	Should the company take responsibility for the accident, regardless of cause, if the consequence of the accident was large?
↓	Repetition	Did the company learn a lesson from past accidents?
Low	Frequency	Can the company decrease the frequency of accidents?

Table 5: Five factors to which people attach importance in an accident

Of the five factors in Table 5, we focused on causes, as it was the most important. We assumed that social values could be explained by this factor. In the calculation, we assumed that social values could be defined as one of the weighted coefficients to adjust practical consequences to the impact of the accident on society. It was possible to view the weighted coefficients as the degree of responsibility for the accident that the operation company held. To estimate the factor "causes", we administered Internet questionnaires. Specifically, we prepared 12 accident scenarios and questioned subjects about the magnitude of the accident. We analysed the data using pairwise comparison tests. The factor was classified into five categories. In addition, weighted coefficients were set for each category based on the internet questionnaires (see Table 6). In addition, Figure 8 shows the method we used to conduct the calculation with weight coefficients.

Type of Damage	Weighted Coefficient
Company	8.0
Customer	2.1
Train interference	2.1
Public	1.0
Natural disaster	1.8

Table 6: Weighted coefficients for causes

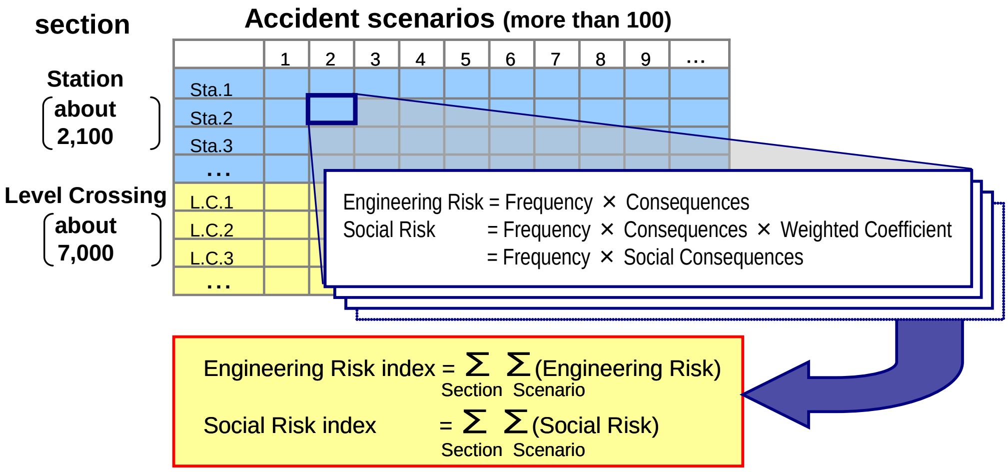

Figure 8: Framework of calculation with weighted coefficients

Table 7 shows examples of social consequences. Given that the social consequences included the operation company's responsibility for the accident, we set priorities to safety investments by comparing social risks based on the social consequences.

Accident examples		Accident Scenario A A running train derailed and collided with an oncoming train after an axle of the running train broke.	Accident Scenario B Due to heavy rain, the embankment collapsed; consequently, the train was lifted up by sediment and derailed.
Consequences	Fatalities	1	2
	Injuries	15	32
	FWI	1.15	2.32
Weighted coefficient	Causes	8.0	1.8
Social consequences		9.2	4.18

Table 7: Example of calculation for social consequences

3 CONCLUSION

The purpose of this paper was to present the results of the study of the risk assessment for JR East and to obtain comments to improve customer safety from experts. Using the method described in this paper, we could quantitatively understand where the risk was, what risk remained, how much the safety measure would improve the risk, and those priorities under the cost-effectiveness study. That is, we were able to understand the current risk of JR East and gain perspective on safety measures. It was then possible to maximize commitment to rail safety.

The risk assessment in JR East is still being investigated. There should be two further works when attempting to apply this method to the business routine. First, we need to improve arrangements of the accident scenarios and the preconditions of the calculations. As shown by ISO 31000, it is important to obtain an understanding of the evaluation results of the risk assessment from stakeholders when promoting risk management. In order to achieve this goal, it is important to refine the preconditions and the assumptions of the calculation and communicate with the stakeholders.

Second, we need to examine how this method addresses the trend of changing social values. One feature of our method is that it accounts for social values in risk assessment processes. When using this method, which assigns a weight to the risk based on social values, we can estimate the risks reflected in the needs of society and set priorities for safety measures by comparing those risks. However, social values will change with advances in technology and be influenced by the social background. As a result, we should focus on understanding changes in social values and learning how to apply them to the estimation.