An Evaluation Method for Signalling System
Based on Concept of Availability

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Abstract

In a railway signalling system, various safety technologies based on fail-safe concept have been developed and applied. They are having contributed to improve or enhance safety of railway traffic. In Japan, an importance of systematic approach to realise safety has been pointed out since 1970's, and in recent years, a safety analysis which is based on FTA, FMEA and so on is performed commonly in a development process. On the other hand, requirement for high level of availability which consists of reliability and maintainability as well as safety is growing.

Publication of RAMS standard (IEC 62278) is one example of such trend. In Japan, social concern about stability of railway transport is growing, and favourable balance between safety and availability is important for current signalling system. However, a method to evaluate availability has not been established, and there are few practical examples. Therefore, we propose quantitative evaluation method for signalling system based on a concept of availability. In the proposed method, an impact on a train operation caused by a failure of equipment (e.g., point machine, track circuit, interlocking device) in a station is expressed by a cost indicator.

In first step, the number of trains which cannot run through the station during failure is evaluated. However, considering behaviour of trains under equipment's failure is difficult in many cases. Therefore, we developed train traffic simulator to evaluate the impact. In next step, the expected value of loss in a year is got from multiplication of the number of un-operated trains which is obtained from the simulation, average freight revenues and a failure rate of equipment. These processes are performed to every component. In final step, expected loss of total system is derived from summation of the each loss.

This method enables to evaluate signalling system architecture quantitatively from the view point of availability. For example, we can select appropriate system architecture adapting to line conditions such as a high density line or secondary line, and can evaluate the impact according to rearrangement of system architecture or change of equipment's performance such as failure rate (Reliability) or repair time (Maintainability). Conversely, it will be possible to clarify requirements of RAM performance for each component. Consequently, the proposed method will be useful to support efficient designing and selection of appropriate system which realises required availability, and will be able to contribute to effective system investment. In this paper, a detail of the method and results of case studies that we applied the method to model architectures will be described.

1. Introduction

A railway signalling system has been contributing to ensure safety of railway transport for long years. However, conventional systems were developed gradually by bottom-up or experience-based approaches. In 2002, IEC 62278 (RAMS standard) of which a basic concept is to realise excellent performance by a systematic approach. Furthermore, various new train control systems based on information technology are under active development. Considering these situations, it is required to establish an evaluation method which is applicable to design the signalling system, which has an excellent RAMS performance and appropriate functional architecture adapting to a given circumstance.

2. Railway Signalling System and RAMS Indicators

There are several types of conventional signalling systems, according to characteristics such as the grade of the line. When a railway company introduces a new signalling system, experts comprehensively consider the grade of the line, the amount of transport, the track layout in the station, the initial cost and so on, and decide on system architecture. A signalling system based on information technology will be introduced more actively in the future. Therefore, a systematic method of evaluating a signalling system will be more important in the development phase.

The relationship between Reliability, Availability, Maintainability and Safety are described in the
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RAMS standard. According to the definition, an availability and safety are the main indicators. As for safety, various technologies have been developed and applied, and signalling systems have an excellent safety record. In recent years, safety analysis is generally carried out by some systematic methods (e.g., FTA and FMEA), with appropriate measures being applied to reduce risks. On the other hand, there is no established concrete method applicable to comprehensive evaluation of the signalling system concerning availability. Furthermore, there is a growing attention to the stability of railway transport.

Therefore, we assume that any system based on proven safety technologies and safety analysis achieves a sufficient level of safety, and have focused on availability, which consists of reliability and maintainability.

3. Evaluation Method

3.1 Basic Concepts

There are several measures to express an availability. For example, it is expressed as the ratio of Mean Time Between Failure (MTBF) to sum of MTBF and Mean Time To Repair (MTTR). Although this definition expresses a performance of each component, the relationship between equipment failures and their impact on railway traffic service is not clear. Therefore, we propose a method to evaluate system availability based on the following concepts.

1. Estimating the impact on train operation caused by a failure of component.
2. Converting the impact to a loss expressed by a cost.

The proposed method will be useful to support decisions on the system architecture adapting to conditions of a line or station, making it possible to evaluate the system’s life cycle cost by adding the loss to the initial and maintenance costs.

Among those three costs, initial and maintenance costs can be estimated if the system architecture is defined. However, the loss caused by failures should be derived considering the track layout in the station, train schedule and other conditions. The method to estimate the loss is described in the following section.

3.2 Method to Estimate the Loss Caused by Failures

The basic process is illustrated in Figure 1. We consider the signalling system in a single station. When equipment (e.g., signal, track circuit, point machine and interlocking device) fails, there are various types of impacts. In some cases, the train cannot run at all, while in other cases the train can run through the station via an alternative route. In the latter case, although a train headway may be longer than usual, service suspension can be prevented. These types of impact can be defined for each failure case in advance.

![Figure 1 Basis of Evaluation Process](image)

In the first step, the number of trains which cannot be operated during a failure is estimated for each component based on pre-defined conditions. Duration of the failure is one of the conditions, and corresponds to an indicator of maintainability. The loss of fare revenue caused by failure is estimated from the difference between planned and actual operated number of trains. The outline of estimating
the loss of each case is shown in Figure 2.

![Figure 2 Concept of Estimating the Loss](image)

Loss = 4 \times \text{the number of passenger} \times \text{average fare}

In order to obtain the loss, we need to estimate the movement of trains under various status of a train operation. The status during a failure depends on which equipment fails and the train routes related to the failed equipment. Several examples are described in section 4.1. Since it will be difficult to estimate the movement only by a desk study, we use the train traffic simulator to perform detailed estimation. This simulator is based on the programme which was developed for evaluating a signalling regarding a minimum headway, recovery performance from delay and so on. The original programme simulates movements of trains in reflection of train control and interlocking function. In the new simulator, a downtime and impact on a route control (e.g., all trains should stop, train runs through alternative route) can be set for each component. The number of trains which can be operated during the failure is obtained from the simulation.

In the next step, the expected loss is derived by a product of the loss of fare revenue obtained in the first step and the failure rate of each component. The failure rate corresponds to an indicator of reliability.

The expected loss of the whole system is obtained by summing the expected loss for each component. The resulting loss reflects factors of maintainability and reliability, and expresses the risk level of a train operation service. Therefore, it is a kind of availability indicator.

### 4. Case Study of Applying the Method

#### 4.1 Preconditions
We assume three types of model stations, as indicated in Figure 3 and Table 1. Station A and Station B are common models of high density lines, and Station C is a model of suburban lines.

![Figure 3 Model Stations](image)

**Table 1 Characteristics of Each Model**

<table>
<thead>
<tr>
<th>Stations type</th>
<th>Train headway</th>
<th>Dwell time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station A</td>
<td>120 seconds</td>
<td>* Main track and side track are used alternatively.</td>
</tr>
<tr>
<td>Station B</td>
<td>120 seconds</td>
<td>60 seconds</td>
</tr>
<tr>
<td>Station C</td>
<td>300 seconds</td>
<td>30 seconds</td>
</tr>
</tbody>
</table>

We have assumed two types of signalling systems for the case study. The model systems are outlined in Figure 4. The first one is a conventional system consisting of track circuits, wayside signals, etc.

Another one is a future system based on a new concept. Main feature of the system is that interlocking function is not centralised. This system performs a function of conventional interlocking...
device by data communications between field equipment capable of autonomous action. In a conventional system, all train operation will be stopped if an interlocking device fails. However, in this system, impact of a failure may be restricted in many cases because the interlocking function is not performed by centralised unit. We performed basic experiment on the new system and have confirmed its feasibility. This decentralised system is outlined in Figure 5, 6 and 7 have the following features.

(a) Field equipment (track circuits, point machines and on-board control unit existing in a station area) have radio transmission interfaces and are connected by radio link each other.
(b) Interlocking function is performed based on radio communications between the equipment, and is not performed by a centralised device.
(c) Track circuits and point machines manage their status and requests from the train which are related to on-board control unit ID.
(d) The train transmits route setting requests to track circuits and point machines.
(e) The point machine controls itself based on the request if safety is confirmed, and transmits the answer to the train.
(f) The track circuit transmits movement authority to the train based on the status of train existence and point machine within its area.

**Figure 4** System models

**Figure 5** Outline of Decentralised System

**Figure 6** Train Interval Control Function
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We have estimated the loss at Station 13 (Line A, Line B) and Station 7 (Line C). The train operation status under failure is defined in advance. Two examples are given in Figure 8.

The failure rates and down times of each equipment are assumed as listed in Table 2 and Table 3. The values in Table 2 are estimated from times of suspended train operation due to failures of signalling systems for about five years, which are recorded in the Railway Safety Database managed by our institute. However, the decentralised system does not have actual records. As shown in Table 3, the values for a point machine and track circuit are assumed same as conventional system. The value for the radio terminal is assumed considering that it does not have an interlocking function of a whole of a station and its hardware may not be as complex as the ground control of radio based system. The down time of the radio terminal two kinds of values are assumed.

![Diagram of Point Machine Control Function]

**Figure 7** Point Machine Control Function

![Diagram of Alternative Routes under Component Failure]

**Figure 8** Examples of Alternative Routes under Component Failure

(a) Station A

(b) Station B

(c) Station C
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Table 2 Failure Rates and Down Times of Conventional System

<table>
<thead>
<tr>
<th></th>
<th>Interlocking device</th>
<th>Signal</th>
<th>Track circuit</th>
<th>Point machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure rate (/h)</td>
<td>$1.5 \times 10^{-6}$</td>
<td>$1.0 \times 10^{-7}$</td>
<td>$3.2 \times 10^{-7}$</td>
<td>$5.9 \times 10^{-7}$</td>
</tr>
<tr>
<td>Down time (h)</td>
<td>3.28</td>
<td>0.78</td>
<td>1.39</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Table 3 Failure Rates and Down Times of Decentralised System

<table>
<thead>
<tr>
<th></th>
<th>Radio terminal</th>
<th>Track circuit</th>
<th>Point machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure rate (/h)</td>
<td>$7.4 \times 10^{-7}$</td>
<td>$3.2 \times 10^{-7}$</td>
<td>$5.9 \times 10^{-7}$</td>
</tr>
<tr>
<td>Down time (h)</td>
<td>2.00 (Decentralised (1))</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

4.2 Results

Figure 9 shows the results of the traffic simulation of the line B in the case where the track circuit 13T fails (Figure 8 (b)). In this case, the train headway becomes 177 seconds while the trains are operated using alternative routes. The number of trains that can run through the station depends on the down time of each model system, and is approximately from 50 to 70% of the schedule. In the case of Figure 8 (a), the train headway becomes about 140 seconds, and the rate of operated train is about from 60 to 70%.

Figure 9 Result of simulation (In case of 13T fails in Station B)
These simulations were performed for each failure case, and the expected losses for 20 years caused by component failure were estimated for the combination of the model lines and systems. The sum of the loss, initial cost and maintenance cost of each model station are summarised in Figure 10. They are expressed by relative values, with the assumption that the initial cost to introduce a conventional system into Line A is one.

These results indicate that the total costs for the decentralised system (1) (down time of radio terminal: 2 hours) is about 90% of the conventional system in Station A, about 100% in Station B and about 82% in Station C. On the other hand, the losses for the decentralised system (1) in Station A and B are grater than of the conventional system.

However, total cost for the decentralised system (2) (down time of radio terminal: 1 hour) is about 83% of the conventional system in Station A and about 90% in Station B. Furthermore, the losses of decentralised system in Station A and B are smaller than of the conventional system.

The decentralised system has no losses caused by the failure of signals and the interlocking device, because these components do not exist. Especially, the loss caused by the interlocking device is more than 50% of the total loss in the conventional system. However, the loss caused by the failure of a newly introduced radio terminals is greater than the reduction obtained by omitting the interlocking device. The supposed reason for case of decentralised system (1) that the number of terminals is comparatively large, the assumed down time in Table 3 is longer than for other equipment, and the failure rate is a little bit higher.

In contrast, the expected effect described in 4.1 is got in case of decentralised (2). In other words, it is required that the down time of the radio terminal should be about one hour in order to apply the decentralised system to high density lines.

On the other hand, the elimination of the interlocking device contributes to the reduction of the total loss in Line C because the number of equipment is comparatively small and the train headway is longer than Station A or B.

The decentralised system (3) in Figure 10 is a reference case based on assumptions that the radio terminal does not have any safety related function described in 4.1, and that function is performed by the track circuit and point machine itself. As the result, the initial cost and down time of the radio terminal will be reduced and failure rate will increase. The tentative parameters of this case are listed in Table 4.

The results are also indicated in Figure 10. In all stations, total costs are almost same as of the decentralised system (2). However, the loss in Station A and B is about 83% of the decentralised system (2) and about 78% in Station C.

Table 4 Tentative Parameters of Decentralised System (3)

<table>
<thead>
<tr>
<th></th>
<th>Radio terminal</th>
<th>Track circuit</th>
<th>Point machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure rate (1/h)</td>
<td>$1.0 \times 10^{-6}$</td>
<td>$3.2 \times 10^{-7}$</td>
<td>$5.9 \times 10^{-7}$</td>
</tr>
<tr>
<td>Down time (h)</td>
<td>0.5</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Initial cost (%)</td>
<td>40%</td>
<td>500%</td>
<td>312.5%</td>
</tr>
</tbody>
</table>

(a) Station A  (b) Station B  (c) Station C

Figure 10 Results of Estimation Total Costs

These results are examples and it may change according to the conditions such as a method to estimate the loss and failure rates of equipment. However, proposed method will contribute to evaluate the signalling systems from a RAMS viewpoint and to construct appropriate system adapting to
conditions of railways. Furthermore, it also enables to derive requirements to equipment from the conditions of train operation.

5. Conclusions

We proposed an evaluation method for railway signalling system from a RAMS point of view. It will be useful to support efficient designing and selection of an appropriate system which achieves the required availability, and will be able to contribute to effective system investment.

We are planning to study the RAMS performance of the signalling system according to various conditions (e.g., train density, failure rate and down time).