Estimating of Reliability in Railway Signaling and Communication Redundant Systems

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Abstract
The modern railway signaling systems currently used today are intelligent and automatic high-performance systems, for which the high level of reliability is required. However, there are many factors including those uncertainties that affect system reliability performance. In this paper, parallel system is further developed to increase the reliability performance of the system. Parallel system is a system in which components are connected in parallel and the system does not fail, even one component is in good working condition i.e. the system fails only when all components have failed. This paper provides a basic background into the types of redundancy that can be built into a system and explains how to calculate the effect of redundancy on system reliability. In modern railway signaling systems the controllers provide the flexibility to create a variety of redundant architectures. For a design guide and reference architecture on how to build a redundant system. By using the proposed methodology, the results of reliability analysis indicate that the reliability of a signaling system can be assessed effectively and efficiently.

Keywords
railway safety, railway signaling and communication, reliability and redundancy, safety and reliability

1. Introduction

Railway signaling systems are typical example of large complex systems made of multiple hierarchical layers. A signaling system is a safety-critical part of railways. Most of the railway signaling systems currently used today are intelligent and automatic high-performance systems, for which the high level of reliability is required. There are many factors including those uncertainties that affect system reliability performance.

Signaling systems are important infrastructure ensuring safe and stable transport, and the principle of securing safety assumes that the systems are fail-safe. Conventional systems have been composed mainly of electric circuits using signaling relays that are fail-safe on their own. However, as the systems become larger, issues come up such as the number of relays and volume of wiring become huge, making it easy for human error to occur, and much time and effort being required for design and construction. On the other hand, since the establishment of fail-safe technology in computer control systems, computerization of various signaling systems such as electronic interlocking equipment has advanced. With this, complex electronic circuits were replaced by software, functions were standardized, and wiring was reduced, thereby reducing human error and contributing greatly to improving safety, stability, and ease of construction.

The function of railway signaling is to guarantee the safe and fluid transportation of passengers and/or goods, while maximizing the capacity and efficiency of the railway network. To do this effectively, you need a communication network infrastructure that uses the most advanced technologies, both on the ground and on-board.

In the future we will see the introduction of ever greater dynamic signaling systems. These will require increasingly faster responses, real-time communication and a growing availability of wireless and wired technologies. To increase the operational efficiency of the infrastructure, the communications network needs to develop more capacity and systems need to become faster, embracing an Ethernet and IP architecture able to replace old networking technologies. This network must meet the requirements of reliability, bandwidth capacity, and resistance to unkind environments and extreme temperatures.

It can also be used for the operation of systems related to signaling such as SCADA controls, security and maintenance systems. Train operational frequencies can be increased to accommodate high rail travel levels, as seen in countries with high rail infrastructure utilization such as France and Japan.

Due considerable penetration of electric trains / vehicles the study included creating scenarios for transport, using the virtual environment. Railway signaling and communication networks have to be capable of handling increasing bandwidth requirements while meeting uncompromising safety and reliability standards.

2. Railway Signaling and Communication Integrated System

Systems for Railway Signaling and Communication integrates technologies is interfaced with the fields of control engineering, track, architecture and electric power. This system ensures rapidness, correctness and safety of train operation by interconnecting the technologies of system engineering and reliability systematically.

The signaling systems must enables train to be operated safely by detecting the location and measure the speed of train. Researchers must develop new equipment to transmit and receive information as an alternative of using conventional track and wire cable. The modern railway, signaling and communication network systems are achieved by replacing and upgrading existing signaling and communication networks, while at the same time installing new networks with increasingly sophisticated systems [1].

Signaling system is divided into on-board and wayside, automatic train stop equipment currently being used in manual operation is the main result of development in on-board. The wayside has switching equipment, track circuit equipment and centralized train control system.

Modern systems are defined as the systems using continuous bi-directional data link of wayside and onboard equipment.

Data link is the system to decide the location of train and control the location speed and direction without conventional physical track circuit by using pattern belt, leakage coaxial cable, inductive loop or radio frequency, and etc. Researches for the development of optimal system through systematic analysis and buildup of technologies necessary for constructing the system for driverless operation are in progress.

2.1. Subjects to be considered in construction of new railway signaling and communication systems

The followings themes should be considered in construction of rail communication system:

1) Minimize the burden of handover between wayside stations according to the movement of onboard station and correspond to high speed running of train effectively by constructing whole communication network as a single subnet network including wireless network.
2) Improve the reliability of communication by securing redundancy in communication path among automated train supervision system (ATS), ground equipment and onboard equipment.
3) Recovery of path in occurrence of error in transmission path should be fast.

Types of communication system are divided into control network and data network, and data network is divided again into wireless LAN between ground and train and cable LAN where track side, control station and central station.

At this time, interface standard applied to each network should apply following opened standard, to make integration and extension of network easy.

1) Control network IEEE1473-L standard, which has small data transmission quantity as control network for train control but high reliability and high real time performance capacity, is suggested.
2) Data network among railway track side, control station and central station IEEE802.3 standard standardized as IP based Ethernet cable LAN interface is suggested.

It is a network to connection between ground systems, and to connect information according to wireless communication with cable LAN through backbone network. Backbone network can be constructed by using cable or radio; however, it is desirable to construct cable communication network considering stability and reliability of the system.

2.2. Net response time of mixed link

It means the time for connection from wireless network to cable network as the net data link time excluding information processing time of equipment, and in the wireless network also includes the time

required in-line communication connected to router and channel service unit (CSU) or optical transmission equipment and wireless equipment and off-line communication between ground radio equipment and on-board radio equipment.

Considering that target performance of total communication system is no more than max. 1 sec, and delay time of communication between wayside and train including information processing time in required lower than 0.5sec, net communication response time between communication systems for train control should not exceed max. 0.2 sec.

2.3. Communication Based Train Control

Communication Based Train Control is an automated control system that ensures safe operation of rail vehicles using data communication between ground radio equipment and on-board radio equipment.

All signaling systems perform the same essential functions, such as interlocking and signal control, even if their system configurations are different.

Railway networks need to operate in intolerant environments. Modern IP technology and devices offer improved reliability and performance. This requires special performance and a high degree of flexibility, the need for redundancy, reliability, data security.

A network comprising devices designed for the restrain rail environment will resolves the various issues of designing the data transmission network, and ensures the overall reliability and efficiency of systems serving critical infrastructure.

Whole train control network configuration is largely divided into control facility and interconnecting equipment of station, signaling facility, wayside access point and on-board radio facility, transmission method between wayside access point and on-board radio facility.

The on-board network provides the connection for all the signaling equipment on the train. The train transmits its exact position and direction to the control center and receives movement authority, together with permissible speed and route data, processed by the on-board computer and transferred to the driver's HMI screen.

The control center is the point where all field data is collected and managed. Operators at the center are given information relating to the situation on the track and can control train traffic adherence to schedules, routes and speeds – all in real time. Other data is monitored, such as electric traction substation information, SCADA systems, passenger information system (PIS) and security systems.

But, with more connectivity comes more complexity. The safety and reliability are absolutely crucial, for the actual railway line. A system integrator must be certain for critical needs, every time.

A dedicated Ethernet-based infrastructure not only meets the requirements of critical assets such as signaling and modern train stations, it also helps to increase capacity, reliability and safety. Thanks to the innovative products, railway operators can improve system efficiency, while driving down costs with industry-leading reliability.

3. Redundancy Techniques in Non-Repairable System Design

System reliability can be increased by additional means by applying redundancy at various levels [2]. Redundancy is the provision of alternative means or parallel paths in a system for accomplishing a given task such that all means must fail before causing a system failure. The different approaches of introducing redundancy in the system are:

1. A duplicate path is provided for the entire system itself which is known as *system or unit redundancy.*
2. A redundant path is provided for each component individually which is called *component redundancy.*
3. In the third approach, the weak components should be identified and strengthened for reliability.
4. In the last approach, a mix of the above techniques is used depending upon the reliability requirements and configuration of the system which is known as *mixed redundancy*.

The application of a particular technique depends upon many factors, for example the weight, size, initial cost and operating characteristics of components or systems. Particularly in electrical and electronic systems redundancy use at the component level introduces certain deviation in operating characteristics of the main systems. Particular attention should be given to such systems.

Redundancy can either be *active* in which case all redundant elements operate simultaneously in performing the same function or *standby* in which the duplicate element is switched into service when a primary element falls.

3.1. Standby redundancy

The standby redundancy model represents the more common ones used in industry. Standby redundancy is made when an identical secondary unit to back up the primary unit. The secondary unit normally does not monitor the system, but is there just as an auxiliary. The standby unit is not usually kept in synchronization with the primary unit, so it must reconcile its input and output signals on takeover of the device under control. The secondary unit may send control signals to the device under control that are not in synchronization with the last control signals that came from the primary unit.

There is a third party to be the watchdog, which monitors the system to decide when a switchover condition is met and command the system to switch control to the standby unit and a logical component that decides when to switch over and which unit is given control of the device under control.

As described earlier, the reliability of a system can be greatly improved by making it redundant. The redundant pair can be operated either as an active/backup pair or as an active/active system. A second system is added. In a dually redundant system the probability that both systems will fail simultaneously is less than the probability that either system will fail at that time. The peak probability that both systems will fail occurs at the peak probability of each failure probability distribution. The availability of the redundant system can be significantly improved by appalling the starting times. The probability of failure of one system is high; the probability of failure of the other system is low, thus minimizing the chance that there will be a dual system failure.

The availability of a pair of redundant systems can be significantly enhanced via a simple expedient. Simply collapse their starting times. In this way, the time corresponding to the peak probability of failure of one system will not align with the time corresponding to the peak probability of failure of the other system. When one system is likely to fail, the other system is likely to survive.

3.2. Redundancy improves reliability

Reliability is defined as the probability of not failing in a particular environment for a particular mission time. The environment is determined by the nature of the application itself. Cannot normally change the time of mission. Therefore, one can best influence the reliability of the system through careful part selection and design practices [3]. Reliability is a statistical probability and there are no absolute guarantees. The goal is to increase the probability of success as much as one can.

The probability equation most commonly used in industry to calculate reliability is the following equation [4].

$$R(t) = e^{-\lambda t}, \tag{1}$$

where $R(t)$ is the probability of success;

t is the mission time, or the time the system must execute without interruption;

λ is the constant failure rate over time (N failures/hour);

$1/\lambda$ is the Mean Time To Failure (MTTF).

Usually, the only factor that can have an impact on is the failure rate (λ). This equation assumes to have a constant failure rate (λ).

3.3. Mean Time to Failure (MTTF)

Based on mathematical set theory, all applications are either successful or a failure. Thus the sum of the the probability of success, R and the probability of failure, F is unity [5].

Therefore one state that: R + F = 1. Because most companies tend to track failures more than successes, one can turn the equation around to calculate reliability: $R = 1 - F$.

When the system is new, it is unlikely to fail. As it ages, the probability that it will fail increases. At some point, the probability that it will fail will begin to decrease because it likely already has failed. The probability that the system will fail at some time t_i during a small time interval Δt is probability distribution, $p_i \cdot \Delta t$.

The MTTF for the system is the average of these failure probabilities:

$$\text{MTTF} = t_i \cdot p_i \cdot \Delta t\,. \tag{2}$$

The MTTF should be a function of time. As time goes on, MTTF should become shorter for realistic systems. It is more likely that the system will fail as time progresses.

For a continuous function, this becomes [6]:

$$\text{MTTF}=\int_0^\infty tf(t)dt=\int_0^\infty R(t)dt \tag{3}$$

The MTTF is a standard industry value which provides the average time to failure of n*on-repairable items* such as light bulb and diodes or unserviceable systems such as encapsulate blocks used in the field of signaling and communication. For items with long life expectancies, it is often a more useful to report MTTF in years rather than hours. MTTF can be used to determine the impact on the availability of various redundant system configurations.

4. Redundant Systems with Parallel Components

Parallel system is a system in which components are connected in parallel and the system does not fail, even one component is in good working condition i.e. the system fails only when all components have failed.

Let E_i the event that component i is in good working state. The number of components in the system be n the failure rates over time of components 1, 2, … i, n are $\lambda_1, \lambda_2, \lambda_3, \ldots \lambda_n$ respectively.

Let be $p_i(t)$ the probability that component i is functioning at time t. The system' unreliability F is done by the product of unreliability of components [7]:

$$\begin{aligned} F &= P_r(E_1 \cap E_2 \cap E_2 \cap \ldots \cap E_n) = P_r(E_1) \cdot P_r(E_2/E_1) \cdot P_r(E_3/E_2 \cdot E_1) \cdot \ldots \cdot P_r(E_m) = \\ &= P_1(t) \cdot P_2(t) \cdot P_3(t) \cdot \ldots \cdot P_n(t) = \left(1 - e^{\lambda_1 t}\right) \cdot \left(1 - e^{\lambda_2 t}\right) \cdot \ldots \cdot \left(1 - e^{\lambda_n t}\right) \end{aligned} \tag{4}$$

Unreliability of a parallel systems is done by the product of its component unreliability [7].

By adding one more unit to the existing system which is having already m units, the system reliability will increases to:

$$R_{m+1}(t) = 1 - [1 - p(t)]^{m+1} \tag{5}$$

and the increase in reliability is given by:

$$\Delta R_{m+1}(t) = 1 - [1 - p(t)]^{m+1} = p(t) \cdot [1 - p(t)]^m \tag{6}$$

Consequently the following recursive formula is available for estimating the reliability:

$$\begin{aligned} R_1(t) &= P^{(t)} \\ R_m(t) &= R_{m-1}(t) + \Delta R_{m-1}(t) \end{aligned} \tag{7}$$

If the failure rates are constant, then

$$R(t) = 1 - \left[1 - e^{-\lambda}\right]^m. \tag{8}$$

The mean time to fail (MTTF) of the system is:

$$\text{MTTF}=\int_0^\infty \left\{1-\left[1-e^{-\lambda}\right]^m\right\}dt \tag{9}$$

$$\text{MTTF} = \int_0^\infty \left(e^{-\lambda_1 t} + e^{-\lambda_2 t} + \cdots + e^{\lambda_m t}\right)dt \tag{10}$$

For higher values of m, it is observed that the enhancement in the mean life with redundancy is logarithmic. If the component reliabilities are not equal, the problem becomes complex and reliability must increase over time. Reliability growth is defined as the positive improvement in reliability parameters of new railway signaling and communication systems over a period of time due to changes in the product's design and/or the configuration systems. The term "growth" is used since it is assumed that the reliability of the system will increase over time as design changes and fixes are implemented [8].

5. Conclusions

By using the proposed methodology, the results of reliability analysis indicate that the reliability of a signaling system can be assessed effectively and efficiently. With the help of ever increasing bandwidths, both wired and wireless, railway operators can control and monitor an increasing number of systems from remote control centers.

Based on modern IP technology, one reduce maintenance and intervention costs, thus increasing the efficiency of rail network. Those are becoming an issue in complete computerization of signaling systems, so we are working on the improving of safety as has been introduced herein.

Reliability growth and repairable systems analysis provide methodologies for analyzing data/events that are associated with systems that are part of a stochastic process. Reliability growth occurs from corrective and/or preventive actions based on experience gained from failures and from analysis of the equipment, design, production and operation processes.

Reliability growth is related to factors such as the management strategy toward taking corrective actions, effectiveness of the fixes, reliability requirements, the initial reliability level, reliability funding and competitive factors. Issues to work on in the future are further improving the individual techniques, developing techniques where safety has consistency throughout the entire development process, and improvement effects in the lifecycle of Railway Signaling and Communication.

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