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Research of Reliability, Availability and Maintainability on the All-electronic Computer Interlocking System

He Tao*[1], Ren Jianxin [2]
The Key Lab of Opto-Technology and Intelligent Control, Lanzhou Jiao tong University
An Ning district west road No.88, Lanzhou, Gansu, China.Telephone No.:86+0931-4956369
Corresponding author, email: hetao@mail.lzjtu.cn[1], 824359519@qq.com[2]

Abstract
High levels of reliability and high security are the basic characteristics and requirements of railway signal systems. So, reliability, availability and maintainability (RAM) are necessarily analyzed before the computer interlocking system will be adopted. The All-electronic Computer Interlocking System, which is a new kind of interlocking system, still needs to analyze its RAM before being put to use. In this paper, the reliability methods and Markov model are adopted to analyze the RAM indexes of the All-electronic Computer Interlocking System when its execution layer equipped with the single configuration or the dual-redundant configuration, the paper also compares the indexes with that of the traditional computer-based interlocking system. Finally, the paper will briefly include suggestions on how the All-electronic Computer Interlocking System's RAM indexes may be increased and also, how the system may be used practically.

***Keywords**: Railway signaling; Computer interlocking; All-electronic; Reliability: Availability; Maintainability*

1. Introduction

The interlocking system is mainly used to ensure the safe operation of running trains. Therefore it owns the qualities of high-accurate performance and vital responsibility. High-reliability and high-safety levels are the two most common characteristics and requirements of the system. Consequently, it is of great importance that the system's RAM be analyzed before putting to use. Scientists and researchers around the world have spent a significantly large amount of time researching the railway signaling system' RAM [1]. The All- electronic Interlocking System has obviously increased signaling system's efficiency and intelligence, lowered the entire cost, simplified the maintenance and prolonged the life cycle of signaling system. While, the system's safety has been previously discussed in other papers [2], so this paper is geared towards analyze the reliability, availability and maintainability (RAM) of the All-electronic Interlocking System.

2. Analysis of RAM of the traditional computer interlocking system.

There are a considerable number of papers and technical documents that have analyzed and calculated the RAM index of traditional computer interlocking system in details, while these analyses are only about the interlocking system's logic part; they are not relevant to the relay implementation part [3-5]. Take for example, an interlocking system existing in a railway station that has 120 railway switches, so the traditional computer interlocking chart in Figure 1 displays the system's reliability after the relay execution part of the system has been considered.

2.1 Calculating the reliability of traditional computer interlocking system.

Let's assume that the single safety relay's reliability index is 10^7h, so the whole relay combination's reliability index of the traditional computer interlocking system will be 10^6h [6]. Consequently, the Mean Time to Failures of the system $MTTF_S$ should be calculated using the following Formula:

$$MTTF_S = \frac{1}{\lambda_S} = \frac{1}{\sum_{i=1}^{n} \lambda_i} = 2.898 \times 10^3 \, \text{h} \approx 0.33 \ \ \text{year} \qquad (1)$$

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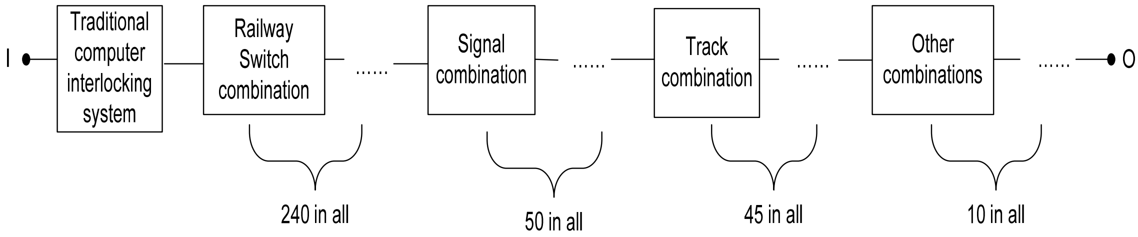


Figure 1. The reliability block diagram of traditional computer interlocking system

2.2 Calculating the maintainability and availability of the traditional computer interlocking system.

According to the previous experience and technical parameters provided by manufacturers, the maintainability index of the traditional system is about 30 minutes that includes the system's relay execution part, so the availability of the system is determined by the following Formula:

$$A_S = \frac{MTBF_S}{MTBF_S + MTTR_S} = 99.983\% \qquad (2)$$

Here, the $MTTR_S$ is set as 0.5 hour, $MTBF_S \approx MTTR_S$.

3 Analysis of RAM of the All-electronic Interlocking System based on the single configuration.

As for computer interlocking system, the interlocking console is responsible for the interlocking operation of the whole railway station signaling system, if one tiny problem arises from the interlocking console, the whole system will be paralyzed. Therefore, we have to adopt a redundant approach to improve the system's availability, however, the sudden failure on the execution layer will impact some parts of the system such as a single railway switch. With the inspiration of the traditional computer interlocking system, the system's execution layer can be designed as the single configuration.

According to the reliability engineering theories, the system's reliability is decided by each single unit and its own structure. As for this system, the reliability block diagram is shown as Figure 2 with regard to the single configuration system.

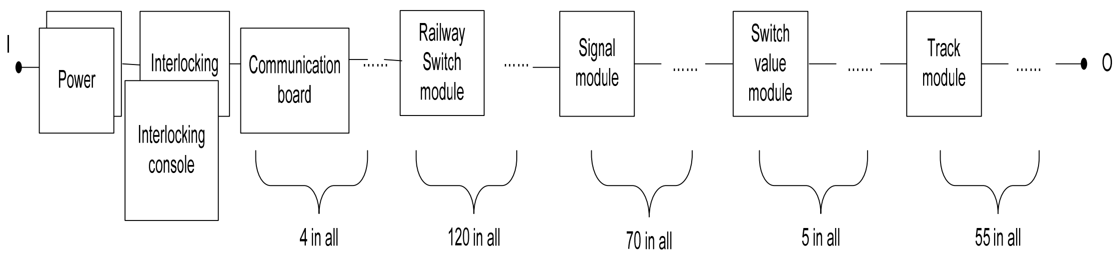


Figure 2 The reliability block diagram of All-electronic interlocking system on single configuration

The reliability indexes in Figure 2 are the predictions using its complexity, shown as following Table 1.

Table 1. The reliability index of each assembly part（10^{-6}/h）

Assembly Part	Failure Rate	Fail Rate on condition of Warm Stand-by
Power	8	——
Interlocking console	4	——
Communication board	3	——
Railway Switch module	9	7
Signal module	8	7
Switch value module	5	——
Track module	7	6.5

3.1 Calculating the reliability of the All-electronic computer interlocking system based on single configuration.

Let's assume that each unit in Fig.2 is mutually independent, the failure rate of each unit is a constant, namely, the unit module obeys exponential distribution, so the Mean Time to Failures of the system ($MTTF_S$) is:

$$MTTF_S = \frac{1}{\lambda_S} = \frac{1}{\sum_{i=1}^{n} \lambda_i} = 493\text{h} \tag{3}$$

3.2 Calculating the maintainability of the All-electronic computer interlocking system based on single configuration.

The entire maintaining time of the system can be divided into four steps: the "approaching step", the "diagnosing step", the "changing step" and the "affirming step". As for maintenance prediction, we usually analyze it from the system's bottom to its top, for example, the railway switch unit module, which is shown in Table 2. Its "approaching step" means the time that serviceman spends in getting to the railway station spot; the "diagnosing step" is the time that serviceman spends in determining the position of the failure through system's indication of lamps and maintaining machine; the "Changing step" is the amount time taken to replace the failure unit; the "affirming step" is the time used to recover to normal operation after failure unit module has been successfully replaced.

Table 2. The Maintainability Prediction of Track Switch Module

Failure Mode	Failure Rate (10^{-6}/h)	Maintaining time（h）				$MTTR_i$	Failure Rate×MTTR
		approaching	diagnosing	changing	affirming		
Measurable Failure	8.66	0.1	0.02	0.05	0.1	0.27	2.3382
Immeasurable Failure but Failure location Clear	0.123	0.1	0.2	0.05	0.1	0.45	0.05535
Immeasurable Failure and Failure location unclear	0.013	0.1	1	0.3	0.3	1.7	0.0221
In all	8.796			——			2.41565

So, the Mean Time to Repair of the unit module ($MTTR$) according to above Table 2 is:

$$MTTR = \frac{\sum f_i MTTR_i}{\sum f_i} = \frac{2.41565}{8.796} = 0.27463h = 16.5 \text{ minutes} \qquad (4)$$

Because the structure of the railway switch unit module is much more sophisticated than any other modules, it can be assumed that the other unit module's maintainability index is the same as the railway switch even under the worst condition, so the Mean Time to Repair of the system ($MTTR_s$) is:

$$MTTR_S = \frac{\sum_{i=1}^{n} \lambda_i MTTR_i}{\lambda_S} = MTTR_i = 0.27463h \qquad (5)$$

So, r=1/ $MTTR_s$ =3.64

3.3 Calculating availability of the All-electronic computer interlocking system based on single configuration.

The system's availability can be calculated by the following Formula:

$$A_S = \frac{MTBF_S}{MTBF_S + MTTR_S} = 99.945\% \qquad (6)$$

Here, the $MTTR_s$ is 0.27463 hour, $MTBF_s \approx MTTF_s$.

Obviously, we are not satisfied with the RAM indexes when system adopts the single configuration. In order to achieve the high level of reliability and availability of the system, we will adopt a redundant approach.

4. Analysis of RAM of the All-electronic interlocking system based on redundant configuration.

Common redundant configurations such as the Standby Switch or Dual-machine Hot Standby are usually used in the interlocking system. In terms of the system which both has control outputs and collecting section, its standby mode tries to possibly insulate the main system to decrease the Common Mode Fault; however, the interlocking system is not equipped with load-bearing. So, precisely speaking, the system adopts the mode of "Warm Standby", both the railway switch module and signal modules are suitable for "Warm Standby". While the track module generally adopts a special redundant mode (an indirect redundant way) by getting through a matching unit and double redundant parallel computers, but switch value module employs direct double computer redundancy.

4.1 Calculating the RAM index of unit module on the warm standby mode.

(1) Reliability

The switch module should be added to the system when warm standby. Let’s take an example of the track switch module, the reliability block diagram of a single unit module after achieving standby application is shown as Figure 3.

According to reliability theories, the module A and "the opening circuit invalidity of switch module" can be considered as an integration. So, the system will have four types of states.

State 1: Module A and Module A' are both in normal operation.
State 2: Module A is in normal operation, Module A' is not.
State 3: Module A operation is failing, Module A' is in normal operation.
State 4 : Module A and Module A' both are not in normal operation.

Assume that module can be repaired or replaced when fails to operate.

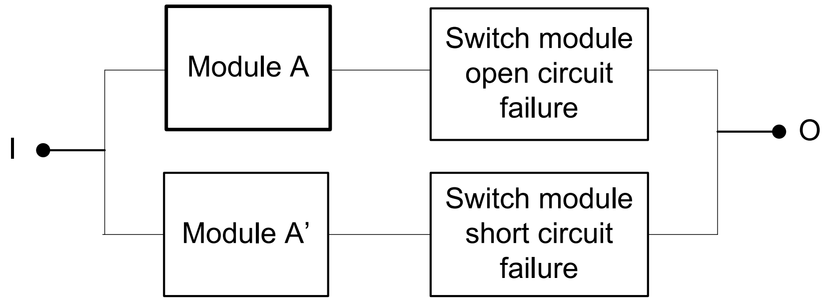


Figure 3. The reliability block diagram of unit module on warm standby.

So, according to the above assumption, the state transition diagram of unit module on the warm standby can be shown as Figure 4.

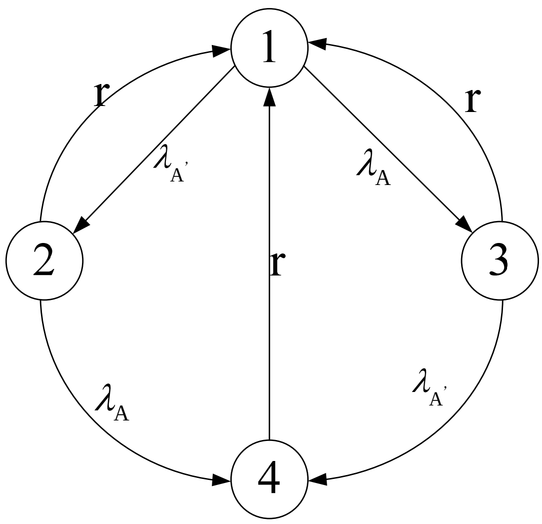
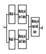
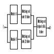
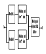
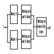
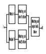


Figure 4. The state transition diagram of unit module at standby mode

The system's state transition matrix is shown below according to Figure 4.

$$A=\begin{bmatrix} -(\lambda_A+\lambda_{A'}) & r & r & r \\ \lambda_{A'} & -(\lambda_A+r) & 0 & 0 \\ \lambda_A & 0 & -(\lambda_{A'}+r) & 0 \\ 0 & \lambda_A & \lambda_{A'} & -r \end{bmatrix} \qquad (7)$$

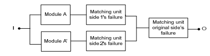
With the consideration of the system's self-repairing ability, the Transition Matrix A can be transformed as Formula 1 [7], just by replacing the redundant equation with the last line in the Transition Matrix.
At this point,  and  both contain switch module's failures,  and  are respectively predicted as the following:

 $=8.796\times10^{-6}+0.10105\times10^{-6}= 8.89705\times10^{-6}$

$\lambda_{A'}$ $=7.178\times10^{-6}+0.0672\times10^{-6} = 7.24520\times10^{-6}$

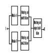
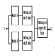
The average lifetime of the system is composed by the sum lifetime of each state, that is to say, θ=θ1+θ2+θ3. As mentioned in reference [8] Formula 4-26, θA= -Qw(0), we set the initial condition Qw(0)=(1,0,0), when the two modules are normal working at t=0.
So, the reliability index of track switch module on warm standby is :

$$MTTF= \theta = \theta_1+\theta_2+\theta_3 = 8.47\times10^{10}\,\text{h} \qquad (8)$$

And then 

=1/*MTTF*=1.181E-11

(2) Availability

The steady-state solutions of modules can be calculated by Formula 1, ,  and r. So the steady-state availability of unit module when it adopts standby mode is:

$A=P_1+P_2+P_3=0.99999999999027$.

4.2 Calculating the RAM index of unit module when dual system are indirectly but parallelly used.

The reliability block diagram of the track module when the dual system adopts indirect collateral mode is shown as Figure 5.

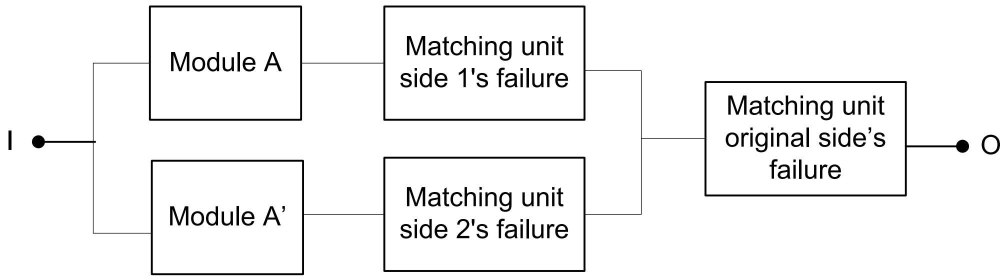
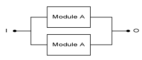


Figure 5. The reliability block diagrams of the dual system are of indirect collateral mode

The reliability index of track unit module  is 1.17E-6 calculated by the methods mentioned in 4.2.

Its steady-state availability is:

$A=P_1+P_2+P_3=0.99999987142087$.

4.3 Calculating the RAM index of unit module when dual systems are directly and parallelly used.

The switch value module, power module, interlocking board and the communication board all adopts the dual system direct and parallel mode, its reliability block diagram is shown as Figure 6.

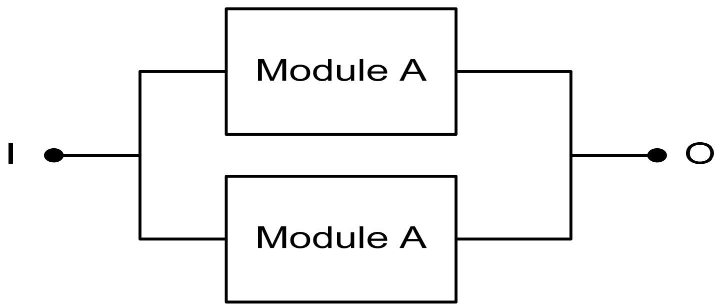


Figure 6. The reliability block diagram on direct and parallel mode

Similarly, the reliability index of switch value module is 4.579E-12 calculated by the methods mentioned in 4.2, its reliability is 0.99999999999622. The power module's reliability is 1.172E-11, the main board reliability is 2.930E-12, and the communication board reliability is 1.648E-12.

4.4 The reliability of All-electronic Interlocking System on standby mode.

According to practical situation, both the railway switch unit module and signal unit module adopt the warm standby mode, the track unit module adopts parallel redundant mode by matching unit module, the switch value unit module, power module, and interlocking module all adopt direct parallel mode. So the reliability block diagram of the whole system is shown as Figure 7.

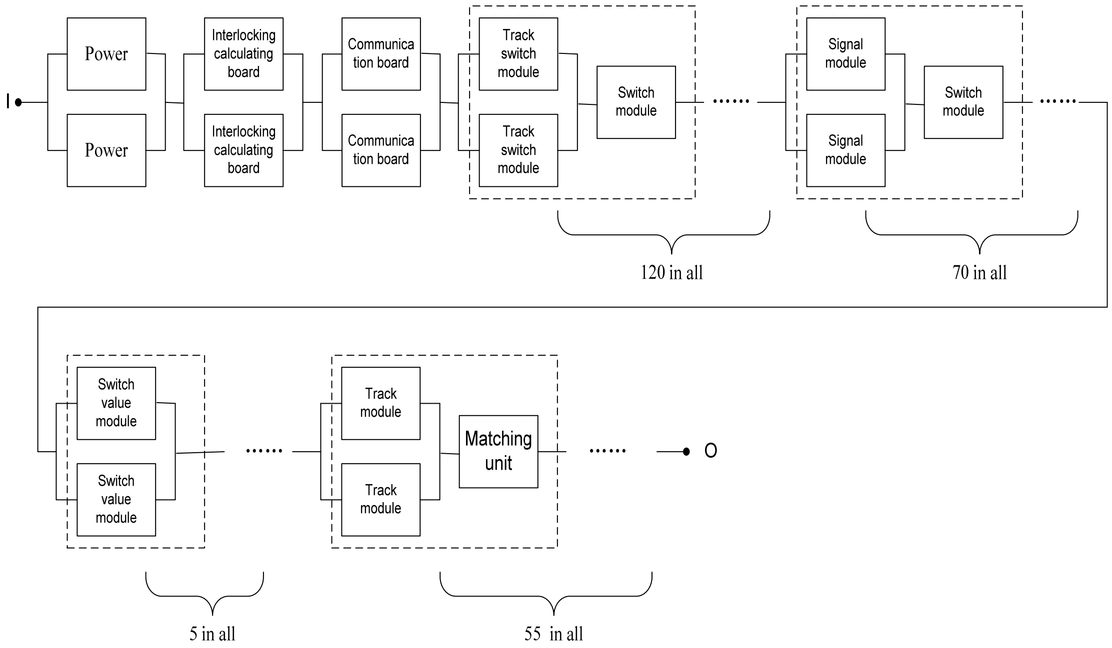


Figure 7. The reliability block diagram of the whole system

So, the Mean Time to Failure ($MTTF_S$) of the system is:

$$MTTF_S = \frac{1}{\lambda_S} = \frac{1}{\sum_{i=1}^{n} \lambda_i} = 1.55 \times 10^4 \text{ h} \approx 1.77 \text{ years} \tag{9}$$

System's availability is:

$$A_S = \frac{MTBF_S}{MTBF_S + MTTR_S} = 99.9982\% \tag{10}$$

Here, $MTTF_S$ is 0.27463 hour ,MTBFS≈ $MTTF_S$.

5. Conclusions

With the analysis above, it is clear that the reliability and availability of the All-electronic Interlocking System is not as good as the traditional interlocking system, but its maintainability is much better than the traditional one; the reliability, availability and maintainability have been greatly improved when the All-electronic Interlocking System adopts redundant configuration. So, the track line which has lower efficiency and is not very busy but sensitive to local economy can be equipped with the single configuration of All-electronic Interlocking System, but for the busy track line, the redundant All-electronic Interlocking System is the best choice. Of course, the redundant configuration can be both adopted in station bottleneck and the main track line so as to improve the system's availability and the local economy.

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