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Original Paper

Mechanism and Protection Optimization for False Loss-of-shunt Judgment in Station Approach Sections

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Abstract

After the section occupancy logic check is enabled, home-signal closing information may enter the train control center judgment process before occupation of the first section inside the home signal is confirmed during normal entry across the home signal. The evidence required for normal entry may therefore be absent when the approach section clears, causing a false loss-of-shunt judgment. Maintenance records from Qiyang Station were used to reconstruct the sequence of home-signal closing, first-section occupation, and approach-section clearance and to analyze the mechanism by which the two types of status information enter the judgment process in different processing cycles. Two protection schemes were developed: a 3 s first-section occupation confirmation window in the train control center and a 2 s delayed closing of the home signal in the interlocking. Timeout exit, out-of-sequence occupation exclusion, route-condition checking, and coding-continuity constraints were incorporated. Case timing analysis and logical checks of abnormal scenarios show that both schemes eliminate the false judgment for the recorded normal-entry sequence while retaining the existing fail-safe response under timeout, out-of-sequence occupation, or invalid route conditions. Multi-station commissioning demonstrates implementability. However, the 3 s and 2 s values are only current engineering initial values; their cross-equipment applicability and long-term effectiveness in preventing false judgments still require operational data.

Keywords

Train control center, Section occupancy logic check, Approach section, Loss of shunt, Route locking, Timing judgment

During the normal wheel-straddling entry process of a train, the closing information of the entry signal and the occupancy confirmation of the first section enter the TCC judgment process through different links. If the closing information arrives first, the current engineering criterion may judge the entry signal as abnormally closed and maintain this conclusion before the first-section occupancy evidence is formed, thereby triggering a lost-shunt misjudgment after the approach section clears. This problem is not a persistent lost shunt of the track circuit, but it can cause abnormal section logic states and alarms, increasing the difficulty of equipment maintenance and fault handling.

Section occupancy logic checking (hereinafter referred to as "section logic checking") verifies the sequential occupancy and clearing relationship of adjacent block sections based on the physical state of track sections, and divides the logic state into four categories: clear, normal occupancy, faulty occupancy, and lost shunt [1-3]. According to the Technical Conditions for Train Control Centers (Q/CR 817-2021), after the first block section outside the entry signal clears, it is judged as clear only when both the train wheel-straddling entry and the first-section occupancy conditions are simultaneously satisfied; otherwise, it is judged as lost shunt [4]; relevant application requirements can be found in reference [5].

Jia Hong et al. [6] analyzed logic checking faults at the junction of 25 Hz phase-sensitive track circuits and ZPW-2000A track circuits; Xie Wenlei et al. [7] discussed the occupancy loss problem of ZPW-2000A track circuits; Zhou Mingjun [8] studied the operating characteristics of 25 Hz phase-sensitive track circuits at special positions in electrified sections; Lai Jinzeng [9] proposed a short-time occupancy confirmation method; Chen Bo [10], Li Gang [11], and Xin Donghong [12] studied delayed release, logic checking applications, and engineering implementation, respectively. The above results provide references for lost-shunt judgment, short-time state confirmation, and engineering modification; however, the research objects are mostly track circuit state abnormalities or the application of existing logic checking functions, with insufficient discussion on the misjudgment caused by cross-cycle arrival of heterogeneous information during normal wheel-straddling train entry, as well as the collaborative constraints of interlocking interface timing, code-sending protection, and carrier-frequency switching continuity.

In response to the above research gaps, based on on-site maintenance records, the misjudgment time sequence was reconstructed, the causes of cross-cycle arrival of heterogeneous information were analyzed, and protection optimization was proposed from two links: the TCC judgment logic and the interlocking closing timing; logical deduction was performed on the case time sequence, and the design boundaries of time parameters, code-sending continuity constraints, and system test requirements were given.

1. On-Site Fault and Misjudgment Mechanism

1.1 Fault Phenomenon and Time-Sequence Record

Qiyang Station adopts the LKD2-2-TH type TCC, with a system processing cycle of 400 ms. The relationship of relevant sections at the X entry is shown in Figure 1, where 1011G is the first block section outside the X entry signal (approach section), and 3DG is the first section inside the X entry signal. The maintenance records shown in Table 1 indicate that at 06:23:28 on July 30, 2024, the logic state of 1011G was normal occupancy; at 06:24:47, 1011G was judged as lost shunt; at 06:37:04, the lost-shunt alarm recovered. The alarm occurred during the normal wheel-straddling entry process of the train, and the fault analysis focused on the sequential relationship between the entry signal closing information and the 3DG occupancy confirmation entering the TCC judgment process.

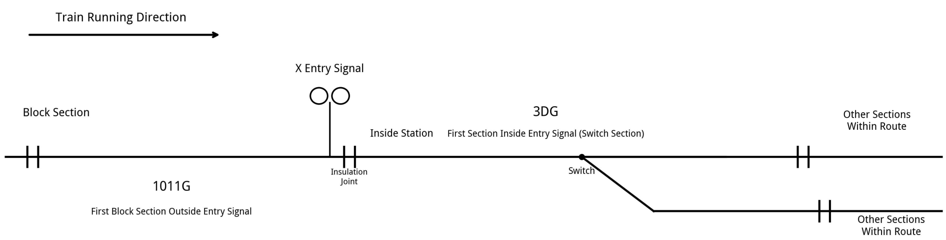

Figure 1. Schematic Diagram of Relevant Sections at the X entry of Qiyang Station

Table 1. Key time sequence of 1011G lost shunt at Qiyang Station

Time	Recorded Content	State Meaning
06:23:28	TCC judges 1011G as normal occupancy	Train approaching X entry, approach section in normal occupancy
06:24:21	TCC receives interlocking information, X entry signal closed	Entry signal closing information arrives first
06:24:22	3DG track relay front contact opens and rear contact closes detected	First section 3DG reflects occupancy
06:24:47	TCC judges 1011G as lost shunt	Existing section logic checking triggers lost shunt judgment
06:37:04	1011G lost shunt alarm recovered	Fault alarm ended

1.2 Standard Judgment Logic and Misjudgment Mechanism

According to Clause 6.3.2.8 of the Technical Conditions for Train Control Centers (Q/CR 817—2021), when the equipment state of the first block section outside the entry signal with a logic state of normal occupancy changes from occupied to clear, it is judged as clear if the following conditions are simultaneously satisfied; otherwise, it is judged as lost shunt:

a) The train enters the station with wheel straddling;

b) The first section inside the entry signal remains occupied or changes from occupied to clear.

In this case, when the TCC executed the section logic checking judgment at 06:24:47, 3DG had remained occupied for approximately 25 s since 06:24:22, so condition b) was satisfied; what was missing was the engineering criterion evidence for condition a). The standard does not specify the concrete engineering criterion for condition a), and the current TCC uses whether the first-section occupancy has been confirmed when the entry signal closing information is received as the judgment basis. At 06:24:21, when the closing information entered the judgment process, the 3DG occupancy had not yet been confirmed, and the TCC accordingly formed and maintained the conclusion of abnormal entry signal closing; at 06:24:47, when the approach section cleared, the evidence for condition a) had still not been formed, thus triggering the lost-shunt misjudgment.

As shown in Figure 2, both types of information originate from the physical process of the train pressing into 3DG, but they enter the TCC through different paths. The interlocking system acquires the section state and completes logic processing, forms the entry signal closing state, and then sends it to the TCC through the interface; the track relay or repeater relay reflects the section state, and the 3DG occupancy confirmation is formed through TCC input acquisition and cycle processing. The specific relay contacts, interlocking processing cycle, and interface delay vary with equipment configuration, and the existing maintenance records are insufficient to quantify the delays of each link separately or determine their upper bounds.

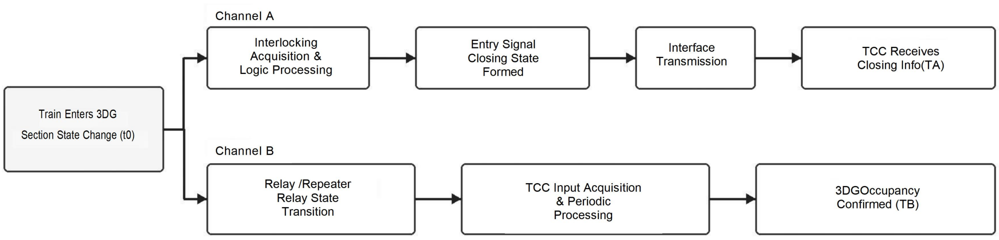

Figure 2. Transmission Paths of two Types of Information Entering the TCC Judgment Process

Let TA denote the time when the TCC receives the entry signal closing information, and TB denote the time when the 3DG occupancy is confirmed. The maintenance terminal uses second-level timestamps, and TA and TB respectively fall on adjacent scales, indicating that the closing information enters the judgment process prior to the 3DG occupancy confirmation; limited by the recording precision, this record is not used to quantify the maximum time-sequence difference between the two channels. Since the abnormal closing conclusion has been formed and maintained according to the current engineering criterion at time TA, the lost shunt is triggered immediately after 1011G clears. This fault is essentially the failure of heterogeneous state information to form effective evidence within the same judgment cycle during the normal wheel-straddling entry process, rather than a persistent lost shunt of the track circuit.

It can be seen that the current engineering criterion is relatively sensitive to the arrival order of heterogeneous information. Protection optimization needs to set a limited confirmation time for the normal wheel-straddling entry evidence without changing the safety-side processing and code-sending protection for real lost shunts, and clarify the exit rules when timeout, out-of-order occupancy, or route condition failure occurs.

2. Protection Optimization for Approach Section Misjudgment

2.1 TCC-Side 3 s Occupancy Confirmation Scheme (Scheme 1)

Scheme 1 adds normal wheel-straddling entry confirmation logic to the TCC section logic checking. After the interlocking system sends the entry signal opening information, the TCC checks the logic state of the corresponding approach section; when the entry signal is open and the approach section is in normal occupancy, monitoring is started, the closing cycle counter is set to 0, and the association relationship among the entry signal, approach section, first section, other sections within the route, and the route locking state is recorded. This starting condition limits the processing object to the scenario where an entry route has been established and the train is approaching the station entrance.

After the TCC receives the entry signal closing information, if the first-section occupancy has not yet been confirmed, the closing cycle counter is incremented according to the system cycle, and the first section, other sections within the route, and the route locking state are continuously acquired within 3 s. When the first-section occupancy is acquired within the confirmation window and the route remains locked, the normal wheel-straddling entry evidence is formed, the normal entry confirmation flag is set, and the route association information is kept valid. After the equipment state of the approach section changes from occupied to clear, when the normal entry confirmation flag is valid, its logic state is restored to clear.

If the first-section occupancy is still not confirmed when the 3 s confirmation window expires, or if occupancy of a non-first section within the route occurs before the first-section occupancy, the section occupancy time sequence does not satisfy the normal wheel-straddling entry condition. The TCC should terminate monitoring, reset the closing cycle counter and the normal entry confirmation flag, and release the association between the route and the approach section; thereafter, when the approach section clears, it is still judged as lost shunt. The state transition rules are shown in Table 2, and the judgment flow is shown in Figure 3.

After route cancellation, signal re-opening, abnormal exit, or judgment completion, the software should uniformly reset the closing cycle counter, normal entry confirmation flag, and route association information to prevent the state of the previous entry process from being carried over to subsequent routes.

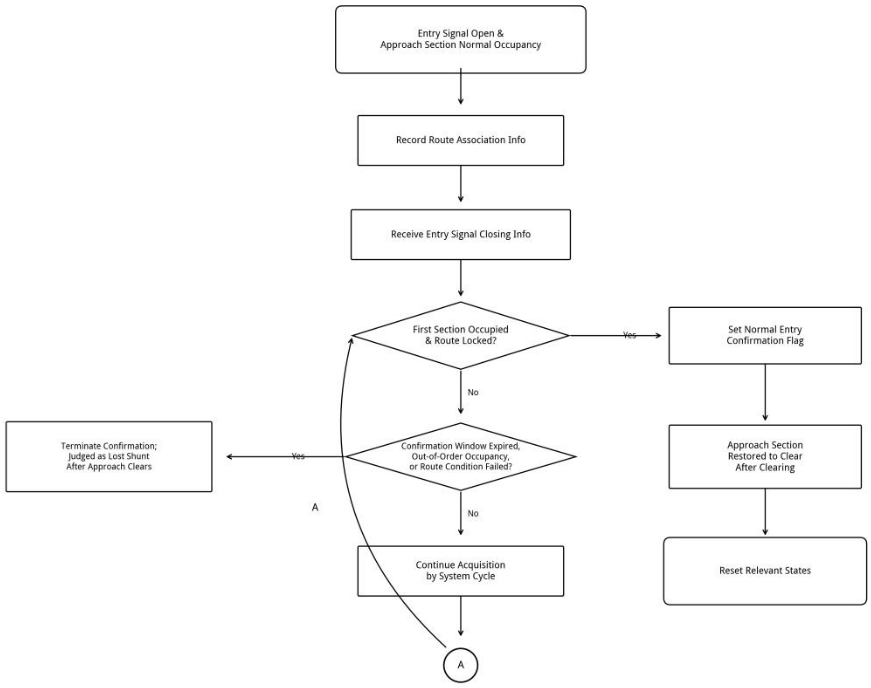

Figure 3. TCC-side 3 s occupancy Confirmation Flow

Table 2. Approach Section Logic State Transition Rules for Scheme 1

Judgment Scenario	First Section Occupancy within 3 s	Other Conditions	Logic State after Approach Section Clears
Normal wheel-straddling train entry	Yes	Route association valid, conforms to normal entry order	Clear
Timeout unconfirmed	No	Confirmation window expires	Lost shunt
Non-first section occupied first	No	Other sections within route occupied first	Lost shunt

2.2 Interlocking-Side 2 s Delayed Closing Scheme (Scheme 2)

Scheme 2 adjusts the signal closing timing during normal entry on the interlocking side. After the entry signal is opened, the interlocking system continuously checks the first section, other sections within the route, and the route locking state; only when it is confirmed that the train normally straddles into the station and occupies the first section, and the route remains locked and the section occupancy order conforms to the normal entry condition, is the 2 s delayed closing timer started. This starting condition limits the timing compensation to the normal wheel-straddling entry process of the train.

During the delay period, the outdoor entry signal remains open, and the interlocking system sends an open state consistent with the actual control state to the TCC. After the 2 s delay expires, the interlocking system controls the entry signal to close and simultaneously sends the normal closing state, enabling the TCC to complete the first-section occupancy confirmation before the closing information participates in the section logic checking. This scheme moves the timing compensation forward to the interlocking control link, and maintains consistency among the outdoor signal indication, interlocking control state, and interface sending state.

If the interlocking system does not confirm the normal wheel-straddling entry of the train, or if the route locking state or section occupancy order does not satisfy the normal entry condition, the delay is not started; when any condition fails during the delay period, the delay is immediately terminated, and the existing interlocking safety logic controls the entry signal closing and sends the corresponding state. The flow is shown in Figure 4, and the implementation scope and applicable conditions of the two schemes are shown in Table 3.

The interlocking software should complete the delay counting with its own system cycle, and ensure that the actual signal control command and the interface state sent to the TCC are updated according to the same logic branch. The normal closing state can only be sent after the delay expires and the closing control is executed; existing emergency closing conditions such as manual closing, route cancellation, and track section abnormality still have priority, and safety-side control must not be delayed due to the delay logic.

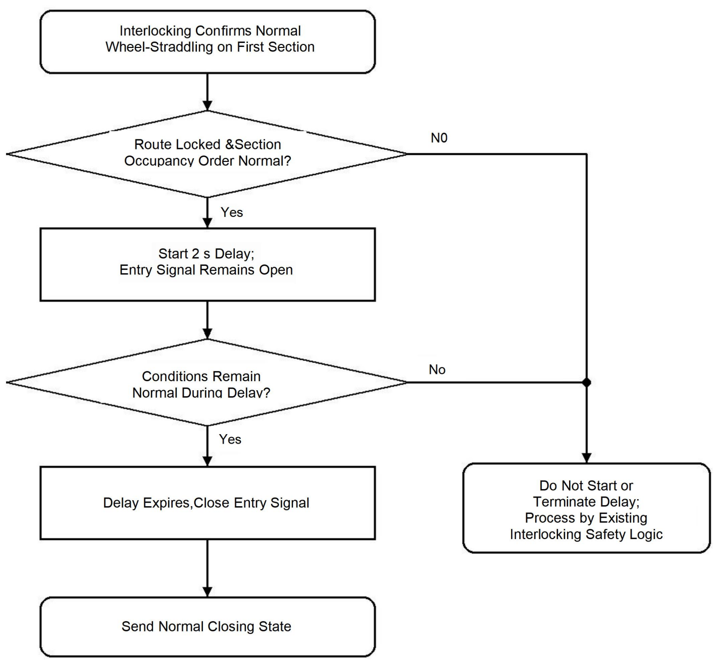

Figure 4. Interlocking-side 2 s Delayed Closing Flow

Table 3. Comparison of two Engineering Implementation Schemes

Comparison Item	Scheme 1: Modify TCC Software	Scheme 2: Modify Interlocking Software
Compensation Position	After TCC receives signal closing, delay confirmation of first section occupancy within TCC	After interlocking confirms normal wheel-straddling on first section, delay closing of entry signal
Core Mechanism	Confirm first section occupancy within 3 s window, and exclude non-first section first occupancy	Delay 2 s keeping entry signal open, close signal and send normal closing state after expiration
Application Focus	Suitable for absorbing acquisition processing timing differences in TCC section logic checking	Current engineering adopts 2 s initial value; suitable for coordinating closing state and first section occupancy confirmation timing from interlocking signal control link, value needs verification through system tests
Safety Boundary	Still judged as lost shunt when timeout unconfirmed or non-first section occupied first	Delay only started when interlocking confirms normal wheel-straddling on first section and safety conditions are satisfied

2.3 Code-Sending Protection Constraints

Timing compensation is used to adjust the logic judgment or signal control timing, and must not change the train protection code sending. When Scheme 1 enters the 3 s confirmation window, both the console indication and the outdoor entry signal have been closed. Although the TCC temporarily suspends the final judgment of the logic state after the approach section clears, the approach section must not continue to be processed according to the signal-open condition, and should immediately perform protection code sending according to the closing condition; the throat sections within the route maintain normal tracking code sending according to the actual wheel-straddling position of the train. If the first-section occupancy is not confirmed upon timeout or a non-first section is occupied first, the approach section is still processed as lost shunt, the throat sections transition to the corresponding safety protection state, and the corresponding restricted code sequence is sent according to regulations.

Scheme 2 maintains the entry signal open during the 2 s delay period, and the delay is only used to enable the TCC to complete the first-section occupancy confirmation before receiving the normal closing state, not as a basis for delaying the execution of post-entry code-sending protection. After the

TCC confirms that the train normally straddles into the station and occupies the first section, it should immediately switch the protection code sending of the approach section and throat sections according to the actual operating state after the train passes the signal, without waiting for the delay to expire; the normal closing state after the delay expires is only used for interface synchronization and consistency verification. Otherwise, the train may experience code sequence interruption, short-time code loss, or discontinuous carrier-frequency switching at the junction between the approach section and the throat sections [13-15].

2.4 Time Parameter Design Principles and Verification Requirements

3 s and 2 s act on the TCC judgment link and the interlocking control link, respectively, and their values should satisfy the respective timing coverage conditions. The TCC-side confirmation window starts timing from the receipt of the entry signal closing information, and its lower limit should cover the maximum reasonable time-sequence difference between the closing information and the first-section occupancy confirmation under specified equipment and interface conditions, with a processing margin reserved. In Scheme 1, only the final judgment of the approach section logic state is suspended within the window, and the protection code sending under the closing condition is still executed immediately. The current software adopts the 3 s engineering initial value, which cannot be directly derived from the single second-level record of Qiyang Station, nor does it represent the theoretical optimal value.

The interlocking-side delay starts timing when the interlocking system confirms that the train normally straddles into the station and occupies the first section, and its lower limit should cover the maximum time required for the first-section occupancy evidence to be formed on the TCC side, with interface transmission and cycle boundary margins reserved; at the same time, it should be ensured that emergency closing conditions such as manual closing, route cancellation, and track section abnormality are not affected by the delay, and that the outdoor signal indication, interlocking control state, interface sending state, and post-entry protection code sending remain consistent. The current engineering practice adopts the 2 s initial value; the uniform adoption of this value by manufacturers only indicates the engineering source and cannot replace the delay upper-bound analysis and system tests.

The LKD2-2-TH type TCC has a system processing cycle of 400 ms, which determines the discrete granularity of the timing implementation in Scheme 1. When 3 s is counted by the TCC according to the system cycle, an integer number of cycles not less than the configured value should be adopted according to the actual software timing mechanism; the TCC processing cycle cannot be used as the basis for the value of the interlocking-side 2 s. When the equipment model, interface cycle, or relay acquisition mode changes, the delay upper bounds of relevant links should be re-obtained, or the maximum coverable time-sequence difference should be determined through phase traversal and delay injection tests in an equivalent system environment.

Parameter verification should record the test equipment and software version, interlocking and TCC processing cycles, interface update cycle, input sequence, number of repetitions, and the maximum measured time-sequence difference between the two types of information; tests should cover working conditions such as cycle phase boundaries, interface delays, continuous multi-train entry, and communication recovery. During acceptance, the following should be simultaneously confirmed: normal wheel-straddling entry no longer triggers lost shunt due to short-time sequence differences; real lost shunts are not masked by the confirmation window or delay logic; and the code sequence and carrier-frequency switching between the approach section and throat sections remain continuous. If the above conditions cannot be simultaneously satisfied, the parameters should be re-verified or the corresponding timing compensation should be cancelled.

3. Case Time-Sequence Analysis and Engineering Application

3.1 Case Time-Sequence Analysis

Using the maintenance records in Table 1 as input, combined with the 400 ms TCC processing cycle, time-sequence deduction was performed on the existing logic and the two schemes. This analysis keeps the physical state sequence and sequential relationship in the records unchanged, and only compares the state transition results under different judgment logics or closing timings. In the existing logic, the normal wheel-straddling entry evidence for condition a) had not been formed when the closing information arrived, and 1011G was judged as lost shunt after clearing; Scheme 1 supplements and forms the first-section occupancy evidence within the 3 s window, and Scheme 2 enables the normal closing information to enter the TCC judgment process after the 3DG occupancy is confirmed. Under both schemes, 1011G is restored to clear after clearing, and the results are shown in Table 4. This result only indicates that the schemes can eliminate the misjudgment under the time sequence of this case, and cannot replace system tests or prove the universality of the time parameters.

Table 4. Case time-sequence Analysis Results for 1011G at Qiyang Station

Logic Scheme	Key Time Sequence	Analysis Result	Logic State after Approach Section Clears
Existing Logic	Closing information recorded one second-level scale earlier than 3DG occupancy confirmation (interval less than 2 s)	Normal wheel-straddling entry evidence not formed at closing time, abnormal closing conclusion maintained	Lost shunt
Scheme 1	3DG occupancy confirmation recorded one second-level scale later than closing information, still within 3 s confirmation window	Normal wheel-straddling entry evidence formed within confirmation window	Clear
Scheme	After interlocking confirms normal	Normal closing state enters	Clear

2	wheel-straddling entry and 3DG occupancy, delay 2 s to close X entry signal and send normal closing state	TCC after first occupancy confirmation	section

3.2 Engineering Application and Follow-Up Verification

The TCC-side 3 s software has been commissioned at Nantong Station and Yulin North Station, and has been included in the commissioning plans for some stations on the Nanchang-Jiujiang section of the Beijing-Hong Kong High-Speed Railway and the Chengdu-Chongqing Middle Line High-Speed Railway; the interlocking-side 2 s software has been commissioned at Hengshui South Station and Qinzhuang Line Post on the Beijing-Hong Kong High-Speed Railway, as well as in relevant projects of the Shanghai-Chongqing-Chengdu High-Speed Railway. Scheme 1 mainly modifies the TCC application software, and Scheme 2 adjusts the interlocking closing control timing for the entry signal and synchronizes the interface state. The above commissioning situations indicate that both schemes possess engineering implementation conditions, but cannot replace the application effect evaluation.

At present, comparative data before and after modification using indicators such as operation duration, number of train passages, and number of misjudgment alarms has not yet been formed, and the single maintenance record of Qiyang Station can only be used for case time-sequence analysis. In the follow-up, repeatable input sequences should be set in actual equipment or equivalent system environments to compare the existing logic, Scheme 1, and Scheme 2 under the same conditions, recording the relative times of the closing information and first-section occupancy confirmation, approach section logic state, signal control and interface state, code-sending continuity, and emergency closing response; at the same time, multi-station and long-cycle operation statistics should be conducted to verify the parameter application scope and quantitatively evaluate the anti-misjudgment effect.

4. Conclusion

The 1011G misjudgment at Qiyang Station originates from the failure of the normal wheel-straddling entry evidence to satisfy the current engineering criterion: when the entry signal closing information entered the judgment process, the first-section occupancy had not yet been confirmed, and the abnormal closing conclusion was immediately formed and maintained. The TCC-side 3 s confirmation window and the interlocking-side 2 s delayed closing scheme supplement the normal wheel-straddling entry evidence from the two links of judgment logic and signal closing timing, respectively, and limit their scope of action through timeout exit, out-of-order occupancy exclusion, route condition verification, and code-sending continuity constraints. Case time-sequence analysis shows that both schemes can eliminate the approach section misjudgment under the recorded time sequence; the multi-station commissioning situation indicates that the schemes possess engineering implementation conditions. Due to the lack of cross-equipment delay upper bounds, system comparative tests, and long-term operation statistics, the application scope of the time parameters and the anti-misjudgment effect still require further verification.

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