Lifecycle Cost Comparison of Relay-based and Software-based Interlocking Control Systems

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Abstract

This paper presents a comparison of relay-based and software-based Interlocking Control Systems in terms of their overall lifecycle cost, with a view to help Railroads make informed decisions about investing in new installations or in replacing old installations. For simplicity, the lifecycle costs of a relay-based implementation and a software-based non-redundant configuration for a 2-track universal arrangement are derived and compared. Also, the trends in implementing a large interlocking plant with a software-based configuration with hardware redundancy are discussed.

1.0 INTRODUCTION

Relay-based Interlocking Control Systems have been in service for more than 75 years and have proven to be highly reliable and safe. Since the 1980s, software-based designs have been gaining gradual acceptance. The initial concerns about the safety and reliability levels achievable with the software-based designs have been largely eliminated. However, there are still some concerns about the overall cost-effectiveness of software-based designs relative to relay-based systems, and about the extent to which relays are yet being used in some applications of the software-based designs. This paper attempts to provide a cost comparison of the two approaches and brings out the relative benefits of the software-based approach. It
also provides a high-level description of the latest trends in applying software-based designs for control of large interlocking plants.

2.0  COST COMPARISON

For the purpose of bringing out the basic differences in the cost elements associated with the relay-based and software-based approaches, a simple standard double crossover railroad-type interlocking with four signals and four switches is considered. The application features that form the basis for the comparison include control of color-light signals with light-out detection, coded track for approach signal control/indication, a local control panel, codeline equipment, normal ac power with battery back-up for 8 hours, and no cab signaling. Ground equipment such as switches and signals are not included in the cost calculations.

2.1  Initial Costs

Tables 1 and 2 show the representative initial costs of the relay-based and software-based approach to implement the application features listed above. These cost estimates are averages of data from two major operating railroads and two signaling suppliers. From these tables, it can be seen that the software-based approach has a lower initial cost.

2.2  Operating Costs

The major elements of the operating costs of an installation such as the relay-based or software-based interlocking being considered in this paper are the cost of purchasing an initial set of spare parts, added to the cost of preventative and corrective maintenance over the life of the installation.
In our examples, preventive maintenance costs include the cost of the periodic testing of relays per FRA Rule 236.376, but not the periodic testing of interlocking functions per FRA Rules 236.378, 379, 380, 381, etc., since these tests are known to take the same amount of time and resources for both types of installations. Corrective maintenance costs consist of repair and replacement of failed line replaceable units (LRUs) which include all the significant hardware items listed in Tables 1 and 2.

It should be noted that operating and maintenance resources and budgets are allocated by a railroad on a system-wide basis, and NOT on an individual installation basis. For example, the number of spare relays or CPU cards needed are calculated based on the total number of interlocking installations in operation on the railroad, rather than for each installation as an isolated set of hardware items. The operating costs of a system, consisting of a significant number of installations of identical equipment and LRUs, can be calculated easily in a few steps:

1. Compile a list of all LRUs in the system, including a failure rate for each LRU. For each type of LRU, complete steps 2-11.
2. Obtain from the supplier a cost estimate for the LRU.
3. Obtain from the designated service center an estimate of the maximum repair time for the LRU.
4. Obtain from the designated service center an estimate of the average repair cost for the LRU.
5. Calculate the expected number of failures over the repair interval from step (3), at the desired level of confidence, using the Poisson Distribution. This is the number of spare LRUs which need to be purchased.
6. Multiply the result of step (5) by the result of step (2). This is the total cost of the spare parts to be obtained.

7. Calculate the expected number of failures over one year. Multiply this result by the number of years the installations will be in service (useful life), excluding years that they are under warranty. This is the total number of corrective maintenance actions which the railroad must pay for over the life of the LRU.

8. Multiply the result of (7) by the result of (4). This is the total corrective maintenance cost for the LRU.

9. If preventative maintenance is required for the LRU, estimate any preventative maintenance costs for the LRU per year.

10. Multiply the result of step (9) by the number of years defining the useful life of the installations. This is the total preventative maintenance cost for the LRU.

11. Add the results of (6), (8) and (10). This is the operating cost of the LRU over the life of the installations.

12. Add the final result for each LRU (step 11). This is the operating cost of the overall group of installations on the railroad.

Table 3 presents some typical operating cost data on a per-installation basis for the two types of installation. These data are from calculations made by one of the authors using the steps listed above, based upon operating and maintaining a total of 50 interlocking installations on a major railroad. A significant portion of the operating cost for a relay-based installation is associated with the 4-year periodic inspection and testing of the relays. Table 3 does not include the cost of FRA tests of interlocking functions in either option.
3.0 QUALITATIVE COMPARISON OF THE TWO APPROACHES

Based upon the cost comparisons presented in section 2, and also based upon the experience of the authors, a qualitative discussion on the relative advantages of a software-based approach for interlocking design is presented in this section.

A. Initial Costs:

1. Initial Engineering (Design, Check, Circuit Drawings, Detailing)
   
   i. In a relay-based interlocking, the interlocking logic must be determined first, before the bungalow wiring can begin.

   ii. In a software-based interlocking, the design can be finalized based on a determination of the inputs, outputs and aspects. Wiring can start sooner.

2. Rack Wiring:

   i. Relay racks are wired based upon the relay logic of the control point. These rack layouts can not be designed until the final interlocking logic has been defined.

   ii. Racks for software-based systems consist of card files and wiring harnesses consisting of plug couplers on the PCBs and terminal strips on the interface end. These harnesses can be preassembled and the racks can be assembled in a number of basic standard configurations ahead of time.

   iii. Racks in software-based systems use a limited number of relays. These relays are in standard configurations and can often be assembled ahead of time.

3. Factory Testing/Operational Simulation
i. Relay-based systems have more wires and more components. Point checking and circuit breakdown tests will take longer.

ii. Software-based systems have the benefit of an additional layer of testing of the interlocking logic. There are computer based programs which will allow testing the program logic independent of the bungalow testing.

4. Field Installation and checkout
   
i. Relay-based systems may require larger shelters to have the same level of functionality as a software-based system.

   ii. Individual relays require additional tests and documentation

   iii. Interface requirements for switches, signals and track circuits are the same for a relay-based interlocking as they are for a software-based interlocking. There is only a slight advantage to the software-based interlocking in this regard.

5. Field Operational Testing and Commissioning.
   
i. Both systems require the same basic in-service test suite.

   ii. Tests performed and results can be logged in the recorders of software-based systems and kept as part of the documentation. Anomalies which may not result in improper results but merit investigation are more likely to be noticed. This is a slight advantage to the software-based system.

6. As in Service Baseline Documentation.
   
i. Both systems depend on the diligence and accuracy of field personnel in recording changes to the field wiring.
ii. The application logic software is accurately displayed in the application program sheets. Any changes which may be made during the construction cycle to the program will be recorded without reliance on human factors other than configuration management.

iii. Application logic is immediately available and not dependent upon drafting changes. Slight advantage to the software-based system.

7. Costs of enhanced functionality

i. Additional functions such as return to train logic or overrun protection will require additional relays and bungalow wiring in a relay-based system.

ii. In a software-based system, only additional lines of code are required, no new hardware.

B. Operating Costs (Corrective and preventative maintenance costs over a 25 year life cycle).

i. Relay-based systems would require additional wiring and monitoring equipment to detect components which require attention before resulting in train delays.

ii. Software-based systems have these inherent capabilities.

iii. Software-based systems can allow for a graceful degradation of functionality before resulting in restrictions to train operations. For example lamp out detection, notification and downgrading.

iv. Software-based systems can be remotely queried.
v. Software-based systems can be installed with fully redundant hardware to mitigate the effects of catastrophic failures.

vi. Software-based systems have the potential for automating many required tests.

C. Costs associated with disarrangement.

i. Application program changes and addition/deletion of I/O are relatively easy and less time-consuming in a software-based system when the interlocking plant is disarranged.

ii. The amount of re-testing required is about the same in both implementations.

4.0 LARGE INTERLOCKING PLANTS

In light of its advantages, the software-based approach is becoming more accepted even for very large interlocking plants. For instance, an interlocking plant consisting of 99 switches and 133 signals is being modernized by a major U.S. passenger railroad, with the use of software-based systems. Also, two large yards are being modernized by a major U.S. transit authority, using a similar approach. The following features are being widely used:

- The plant is divided into small zones and each zone is controlled by decentralized processor units, communicating with each other over fiber optic high-speed serial connections. This approach reduces or eliminates cable between locations.
- The zones within the plant are arranged so as to minimize train delays in the event of an unplanned outage, and based on logical and physical guidelines such as awareness.
of high usage routes and normal traffic direction, interlocking limits and back-to-back signal locations.

- The processor units are being configured in active-redundancy (hot-standby) for seamless transfer of operation from a failed unit to an operational unit. This provides an extremely high level of availability (99.99%) through-out the interlocking plant.

- Use of interface relays for switch and signal control functions is being reduced to a minimum due to the availability of solid-state add-on devices such as ac lamp drivers for both incandescent as well as LED signal lamps, switch motor drives, and circuit controllers, etc., from various suppliers.

- Improved lightning protection schemes and isolation devices for field connections are available from various suppliers to reduce failures from external sources (lightning, 3rd rail, high tension lines, etc.).

- A processor unit similar to that used for individual zone control is being used on a major railroad to reduce the time required conduct the FRA tests on the interlocking functions in the zone.

5.0 CONCLUSIONS

Software-based interlocking control systems have reached a high level of maturity in terms of ease of application, reliability, maintainability, and safety. They offer many benefits, including an overall cost advantage relative to relay-based systems, across a spectrum of applications that include simple ends-of-siding and large interlocking plants that control routes over hundreds of switches and signals.
Lifecycle Cost Comparison of Relay-based and Software-based
Interlocking Control Systems

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Table 1. Cost of Relay-based Interlocking (Standard Double Cross-over)

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Approx Qty</th>
<th>Approx Cost ($)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital Relays</td>
<td>80</td>
<td>60,000</td>
<td>Including vital timers, code transmitters and followers</td>
</tr>
<tr>
<td>Non-Vital Relays</td>
<td>15</td>
<td>1,100</td>
<td></td>
</tr>
<tr>
<td>Power Supplies</td>
<td>3</td>
<td>2,500</td>
<td></td>
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<tr>
<td>Code System equipment</td>
<td>1</td>
<td>6,500</td>
<td>including local control panel</td>
</tr>
<tr>
<td>Hardware (racks, house, etc.)</td>
<td>6</td>
<td>12,500</td>
<td></td>
</tr>
<tr>
<td>Initial Engineering</td>
<td>120 hours</td>
<td>12,000</td>
<td>1 week each for design, checking, and corrections, using typicals.</td>
</tr>
<tr>
<td>Wire and Cable</td>
<td></td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Rack wiring labor</td>
<td>160 hours</td>
<td>7,500</td>
<td>2 persons, two weeks including installation of plugboards, and wiring relays</td>
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<tr>
<td>Factory / Shop Testing/Operational Simulation</td>
<td>80 hours</td>
<td>5,000</td>
<td>2 persons, one week</td>
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<tr>
<td>Field Installation and Checkout</td>
<td>48 hours</td>
<td>3,000</td>
<td>6 persons, 1 day, includes terminating cables in house, setting foundations, setting house</td>
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<tr>
<td>Field Operational Testing and Commissioning</td>
<td>240 hours</td>
<td>15,000</td>
<td>6 persons, one week</td>
</tr>
<tr>
<td>As-in-Service Baseline documentation</td>
<td>40 hours</td>
<td>2,500</td>
<td>Total = $137,600</td>
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<tr>
<td>Cost Item</td>
<td>Approx Qty</td>
<td>Approx Cost ($)</td>
<td>Comments</td>
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<td>------------</td>
<td>-----------------</td>
<td>---------------------------------------------------------------------------------------------</td>
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<tr>
<td>Electronics hardware (CPU, I/O, other peripheral h/w)</td>
<td>1</td>
<td>25,000</td>
<td>Includes factory-wired processor equipment installed on a rack, including codeline equipment and local control panel.</td>
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<tr>
<td>Vital Relays</td>
<td>4</td>
<td>2,600</td>
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<td>Vital Solid State Switch Controllers</td>
<td>2</td>
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<tr>
<td>Power Supplies</td>
<td>2</td>
<td>2,600</td>
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<td>Hardware (racks, house, etc.)</td>
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<td>9,500</td>
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<tr>
<td>Initial Engineering</td>
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<tr>
<td>Wire &amp; Cable</td>
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<td>6 persons, 1 week</td>
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<td>As-in-Service Baseline documentation</td>
<td>40 hours</td>
<td>2,500</td>
<td>Total = $90,000</td>
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### Table 3. Operating Costs of the Two Types of Implementation

<table>
<thead>
<tr>
<th>Implementation</th>
<th>Initial Spares Cost ($)</th>
<th>25-year Corrective Maintenance Cost ($)</th>
<th>25-year Preventive Maintenance Cost ($)</th>
<th>Total Cost ($)</th>
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</thead>
<tbody>
<tr>
<td>Relay-based</td>
<td>500</td>
<td>1,200</td>
<td>48,000</td>
<td>49,700</td>
</tr>
<tr>
<td>Software-based</td>
<td>1,000</td>
<td>7,600</td>
<td>2,500</td>
<td>11,100</td>
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</table>