

*From the desk of  
Sandeep Patalay*

## **Analysis of Railway Interlocking Systems**

Sandeep Patalay  
Senior Systems Engineer, CMC Ltd  
[sandeep.patalay@gmail.com](mailto:sandeep.patalay@gmail.com)

## *Contents*

<b>1. INTRODUCTION.....</b>	<b>4</b>
1.1. ABOUT INDIAN RAILWAYS.....	4
1.2. SIGNALLING SYSTEMS.....	4
<b>2. SIGNALLING CONCEPTS .....</b>	<b>5</b>
2.1. ROUTE RELAY INTERLOCKING .....	5
2.2. SOLID STATE INTERLOCKING (SSI) OR COMPUTER INTERLOCKING SYSTEM (CIS) .....	7
<b>3. THE COMPUTER BASED INTERLOCKING ARCHITECTURE .....</b>	<b>10</b>
3.1. ARCHITECTURE AND METHODOLOGY .....	10
3.2. INTERLOCKING METHODOLOGY.....	16
<b>4. ANALYSIS OF FAILURES OF SOLID STATE INTERLOCKING SYSTEMS.....</b>	<b>17</b>
<b>5. PROPOSED ARCHITECTURE OF INTERLOCKING SYSTEMS.....</b>	<b>19</b>
5.1. SOFTWARE TO TAKE CARE OF DIFFERENT RAILWAY PRACTICES.....	20

## *List of Figures*

FIGURE 1: TYPICAL RELAY CIRCUIT .....	6
FIGURE 2: TYPICAL RRI INSTALLATION .....	7
FIGURE 3: A TYPICAL SOLID STATE INTERLOCKING SYSTEM IN A STATION YARD .....	8
FIGURE 4: TYPICAL SSI INSTALLATION.....	9
FIGURE 5: TIME REDUNDANCY .....	14
FIGURE 6: HARDWARE REDUNDANCY .....	14
FIGURE 7: HARDWARE DIVERSITY .....	14
FIGURE 8: SOFTWARE DIVERSITY.....	15
FIGURE 9: DIVERSE SOFTWARE ON REDUNDANT HARDWARE .....	15
FIGURE 10: DIVERSE SOFTWARE ON DIVERSE HARDWARE .....	15
FIGURE 11: PROPOSED SSI ARCHITECTURE.....	20

### ***Abstract***

Railway Signalling is safety critical domain, where still traditional technology is in use. There are many reasons for using traditional technology; one of the main reasons being the proven Safety performance of the older systems (Relay Based). As the rail traffic is increasing and with higher speed of trains there is an acute need for modernization of Railway Signalling Technology. Even with the advent of Microprocessor based technology, the problems have not been solved.

This article discusses the various methods used for Signalling and their limitations. It also discusses the various architectures used in the design of Computer based Interlocking systems and details the limitations of each method. Finally a new architecture is proposed which shall mitigate these limitations and create necessary confidence in the railway operators that they can adopt new technologies.

## **1. Introduction**

The railway signalling domain is a safety critical domain, where safety is given utmost importance. The railway signalling domain is mostly operated using traditional technology, which is considered safe and time proven. The New advances in technology have not been able to solve age old problems of safety and reliability. Here we give brief of the signalling domain and signalling concepts

### **1.1. About Indian Railways**

Railways traverse through the length and breadth of the country covering 63,140 route kms, comprising broad gauge (45,099 kms), meter gauge (14,776 kms) and narrow gauge (3,265 kms). As the principal constituent of the nation's transport system, Indian Railways own a fleet of 2, 16,717 wagons (units), 39,236 coaches and 7,739 number of locomotives and manage to run 14,444 trains daily, including about 8,702 passenger trains. They carry more than a million tonne of freight traffic and about 14 million passengers covering 6,856 number of stations daily.

Harnessing the potential of these vast and widespread assets to meet the growing traffic needs of developing economy is no easy task and makes Indian Railways a complex cybernetic system. Over the years, Railways have built up an elaborate and well established manual information system to help them monitoring their moving assets. Supported by a dedicated voice communications network, it collects and transmits information from the remotest corners of the country to control centres, at the highest level. The size and complexity of their operations, growing traffic and changing technologies, placed inevitably a heavy burden on this manual information system. Need for its modernization was therefore felt for sometime.

### **1.2. Signalling Systems**

The most important part of the railways to carry out operations like safe movement of trains and communications between different entities is Signalling. The Railway signalling is governed by a concept called Interlocking. A railway interlocking system controls the traffic in a railway station, and between adjacent stations. The control includes train routes, shunting moves and the movements of all other railway vehicles in accordance with railway rules, regulations and technological processes required for the operation of the railway station.

There are different types of Interlocking Systems available like cabin Interlocking System (Mechanical Interlocking), Panel Interlocking System (PI), Route Relay Interlocking System (RRI) and Solid State Interlocking System (SSI) also known as Computer Interlocking System (CIS). The cabin Interlocking system is obsolete and the Panel interlocking is slowly becoming obsolete. The Route Relay Interlocking System is the widely used system. In the present age of Information technology, the relay based technology is slowly being phased out and replaced with SSIs, but there are operational issues with Computer based interlocking systems.

## 2. Signalling Concepts

A station yard consists of Signals, Track Circuits and Points. These elements are the deciding factors in the safe movement of trains. For Safe movement of trains, some of the factors such as the track on which the train travels is unoccupied until a safe distance, no Conflicting Movement with any other train(s) Etc. are considered.. The presence of the train on certain portion of the track is detected by a device called Track Circuit. The object which gives the information to the train driver is the signal. The Object used to divert the direction or set the direction of the train is a point. All these objects such as Signals, track Circuits and points etc form input to a Centralized system, which monitor the state of these devices and based on the Interlocking rules and Commands given by the station master decide the safe movement of trains inside a station yard. So all the elements in the yard are interlocked with one another, thus the term **INTERLOCKING** comes in to existence. The Control laws or better known as Interlocking rules which decide the safe movements of trains have evolved over a period of 150 years of experience gained in operating trains. These Controls laws are extremely complex.

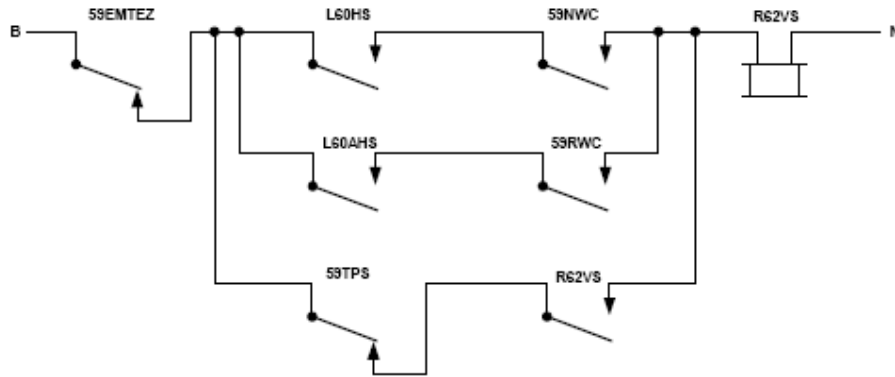
### 2.1. Route Relay Interlocking

In Route Relay Interlocking or popularly known as RRI, the Control Rules are implemented using Relays. These relay based circuits implement all types of Logic and take inputs from Signals, Points and Track Circuits Etc. in the form of relays. The Command to set and clear the route for the train is taken in the form of button form the Station master's console (Control cum Indication panel). When a command is given the RRI checks if the command given is safe and takes necessary action, but if the command given by the station master is invalid and unsafe it does not execute it.

The output of the Interlocking Logic is also a relay, which in turn drive the signals and Point Machines associated with points. RRI till date is the safest system implemented, because it implements the proven interlocking rules and also since the Relays used in RRI are inherently failsafe, they (Contacts) drop to safe state due to gravity even when power supply is not available or in any kind of malfunction.

The relays circuits are build using the station Control Table as the input document and the interlocking rules as the Logic. The Control table decides the possible movements of the train inside a station yard and its relationship with other stations. In traditional RRI (Route Relay Interlocking) systems the interlocking logic is implemented through electromechanical relays. In a typical four road station the number of relays used to implement this type of logic would in the order of thousands of relays and wiring is so complex that the time taken to install and commission a RRI is very long. The testing of the system requires the total station to be setup and testing done during normal train operation. The maintenance of RRI systems is costly and complex. So the need for a better system which would reduce the number of relays and maintenance was needed.

***Implementation of the above equation using relays:***



**Figure 1: Typical Relay Circuit**

A brief list of issues that explain why RRIs are not suitable in the present age of Information technology

1. The Relays used to build the logic circuits are bulky and take a lot of space
2. The relay wiring is very huge and it may take years to complete an installation
3. The wiring from the field object such as Signals, Points and tracks to the Relay Room and entire relay wiring is done using copper cables, which is expensive and it amounts to 50% of the RRI installation cost
4. The testing of RRI is still an informal process that take months to verify and validate the installation
5. Any change to the station yard such as adding an additional line requires most or entire RRI wiring to be changed or replaced, which take years to complete
6. Maintenance of the system is very difficult

Due to the above listed reasons, we conclude that RRI is not acceptable to present day scenarios where traffic needs are growing continuously and the demand for speed of trains is continuously going up

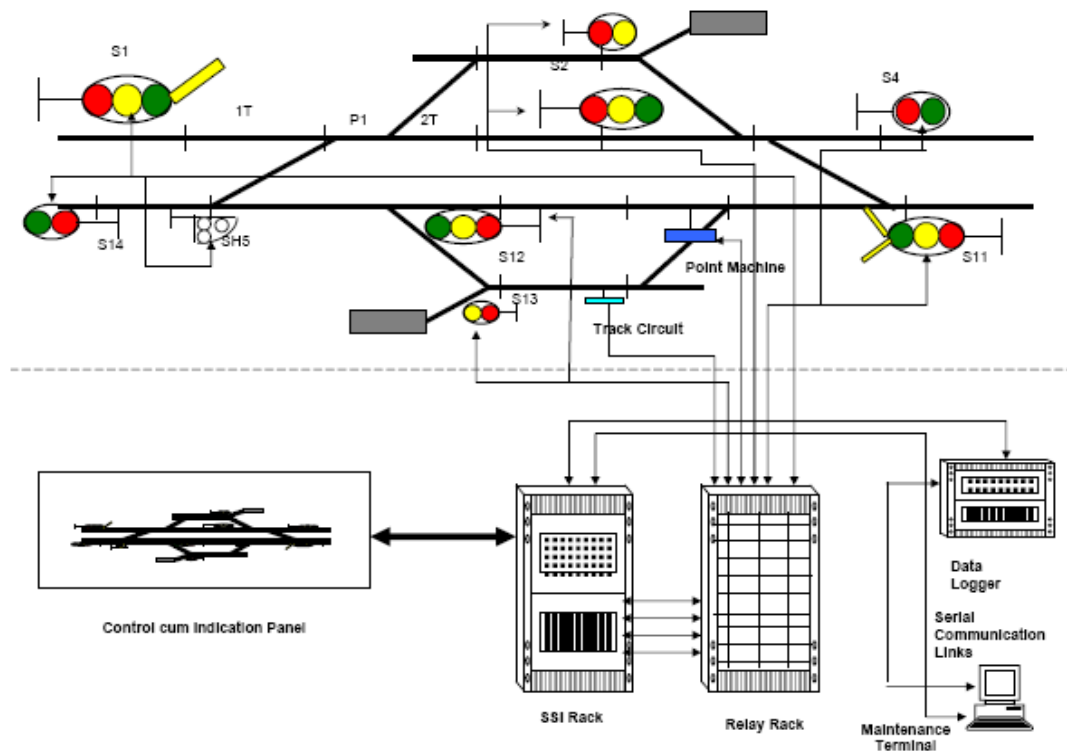


**Figure 2: Typical RRI Installation**

### **2.2. Solid State Interlocking (SSI) or Computer Interlocking System (CIS)**

An Interlocking System When built using Electronics replacing traditional Mechanical Levers and Electro mechanical relays is called as Solid state Interlocking System. The Same Interlocking rules or control equations used in RRI form the basis here also. The relays used to form the logic circuits in RRI are replaced by software variables. The field inputs are collected using digital input cards and outputs are given using digital output cards. The processing is done by a processor where the virtual relays (Software Variables) are evaluated using the Interlocking equations, which are now in digitized form either as Algorithms, Boolean equations or state charts in the processor memory.

SSIs are required to replace the existing RRI and PI Systems Since the traditional systems are very expensive and difficult to maintain because of the huge number of relays and mechanical levers used. SSIs are a better solution to the older systems since they are costing only  $\frac{1}{4}$  the cost of RRI or PI and the maintenance cost is negligible and are easy to maintain.



**Figure 3: A Typical Solid State Interlocking System in a Station Yard**

In SSI system the relays used to implement the interlocking logic in RRI would be simulated by software variables and only the final Output driving relays are needed, so the number of relays is reduced to  $\frac{1}{4}$  of the total RRI relays. The Installation time is also greatly reduced to  $\frac{1}{5}$  of the RRI installation time and the testing can be simulated and be done even at the factory. Thus the need for a SSI System aroused. The Control Laws or the Interlocking equations are modified as software algorithms and are stored in the embedded system memory. The control table of the station yard which gives the possible movements of the trains in the yard is stored as look up tables in software.

Advantages of SSI over RRI:

1. The space taken by SSI system is minimal when compared to RRI
2. Entire logic circuits are simulated in software, no need of Bulky relays
3. Relay wiring cost is saved
4. Installation time comes down drastically to months
5. Verification and Validation of Software is a formal documented process
6. Any change to the Station yard can be quickly addressed by changing the look up tables and can virtually be done in a matter of hours
7. Maintenance of the system is very easy





**Figure 4: Typical SSI Installation**

### 3. The Computer Based Interlocking Architecture

The Solid state Interlocking systems for Railways should ensure the following:

1. Fail safety
2. Availability
3. Reliability
4. Maintainability

#### 3.1. Architecture and methodology

Generally following two types of redundancy techniques are used for achieving fail-safety in the design of signaling systems:

**Hardware Redundancy** – In this case, more than one hardware modules of identical design with common software are used to carry out the safety functions and their outputs are continuously compared. The hardware units operate in tightly synchronised mode with comparison of outputs in every clock cycle. Due to the tight synchronisation, it is not possible to use diverse hardware or software. In this method, although random failures are taken care of, it is difficult to ensure detection of systematic failures due to use of identical hardware and software.

**Software Redundancy** – This approach uses a single hardware unit with diverse software. The two software modules are developed independently and generally utilize inverted data structures to take care of common mode failures. However, rigorous self check procedures are required to be adopted to compensate for use of a single Hardware unit.

**Hybrid Model** - The hardware units have been loosely synchronised where the units operate in alternate cycle and the outputs are compared after full operation of the two modules. Therefore, it is no more required to use identical hardware and software. Although the systems installed in the field utilize identical hardware and software, the architecture permits use of diverse hardware and software. Moreover, operation of the two units in alternate cycles permits use of common system bus and interface circuitry.

To ensure the above said points hardware and software is designed accordingly. There are various techniques to meet the above said requirements as discussed below:

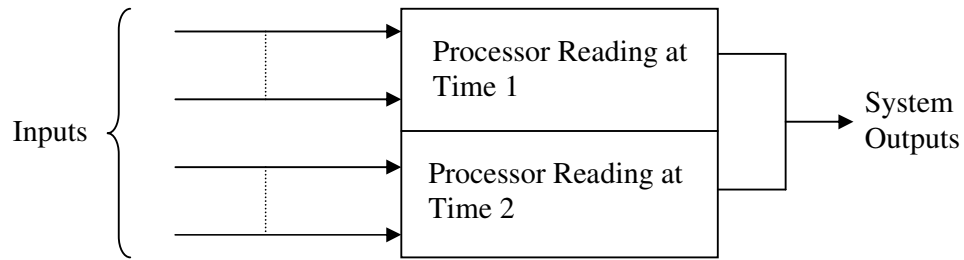
**Table 1: Existing Failsafe Methods employed in Design of Computer Based Interlocking Systems**

Sno	Method Name	Method of Implementation	Type of Errors Detected	Practical Problems with the Method
1	Time Redundancy	The same software is executed on the same hardware during two different time intervals (Refer: Figure 5: Time Redundancy)	Errors Caused by transients. They are avoided by reading at two different time Intervals	Single hardware Fault leads to Shut down of the System. This method is not used since software faults are not completely found in validation. And the Self diagnostics employed for checking of hardware faults is not complete.

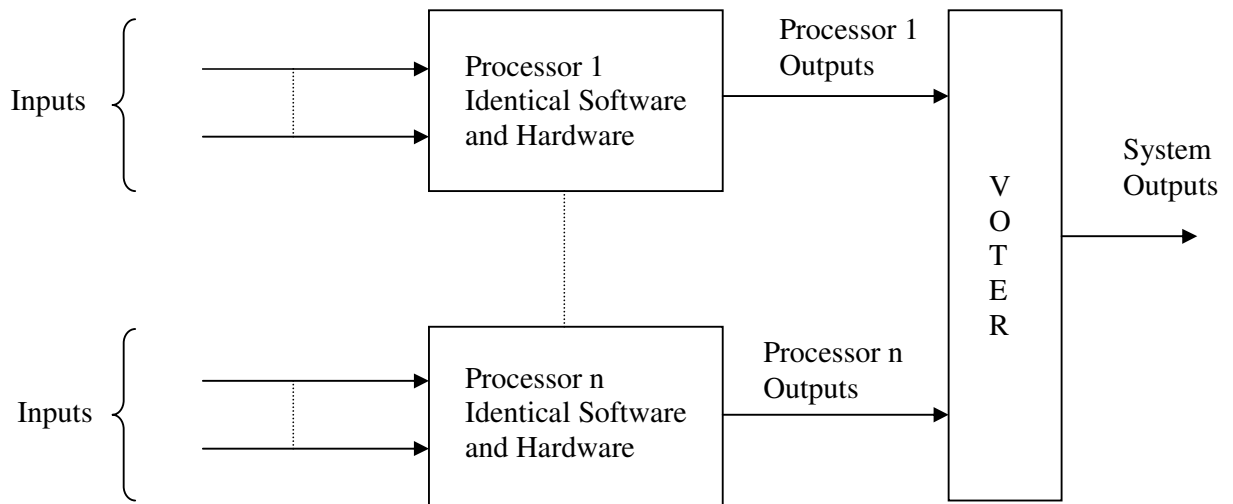
2	Hardware Redundancy	The same software is executed on two identical hardware channels (Refer: Figure 6: Hardware Redundancy)	Hardware faults are detected since outputs from both the channels are compared. And single hardware fault does not lead to shut down of the system	Software faults are not detected since the same software is running on two identical hardware channels. Software Faults at design stage are still not detected.
3	Diverse Hardware	Identical Software is Executed on Different hardware Versions (Refer: Figure 7: Hardware Diversity)	Hardware Design faults at the Initial stage are Detected	Software Faults at the design stage are still not detected
4	Diverse software	The different software versions are executed on the same hardware during two different time intervals (Refer: Figure 8: Software Diversity)	Software Faults at design stage are detected	Even though the software is diverse, they are executed on the single hardware channel; single hardware fault leads to Shut down of the system.

## Analysis of Railway Interlocking Systems

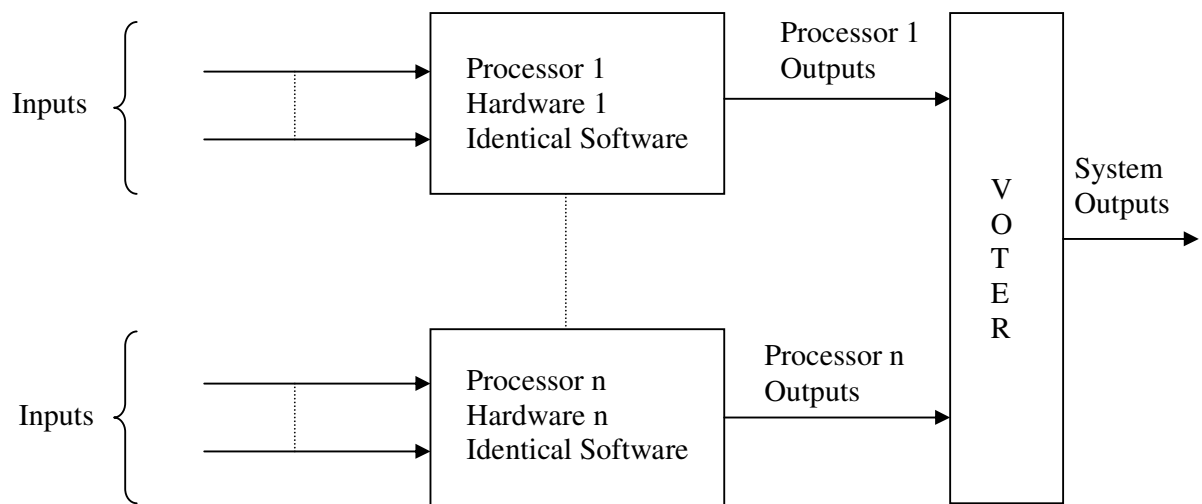
5	Diverse software on redundant hardware	The different software versions are executed on two identical hardware channels <b>(Refer: Figure 9: Diverse software on redundant hardware)</b>	Software Faults at design stage are detected and single hardware faults does not lead to system shut down	Hardware faults at the design stage are not detected.
6	Diverse software on diverse hardware	The different software versions are executed on two different hardware channels <b>(Refer: Figure 10: Diverse software on Diverse Hardware)</b>	Software Faults and Hardware Faults are detected at the design stage.	This methods is rarely used, Since design complexity involved is high



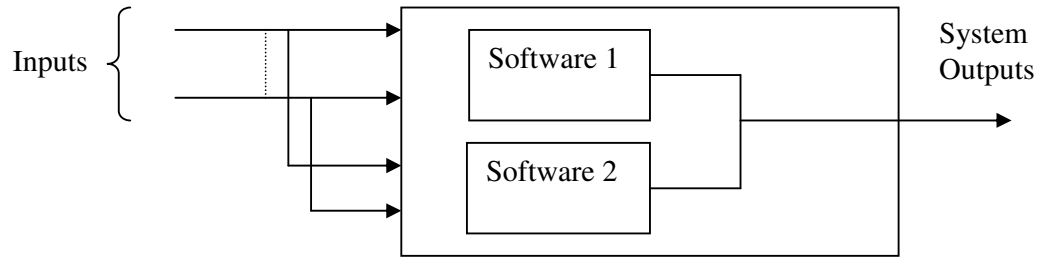
**Figure 5: Time Redundancy**



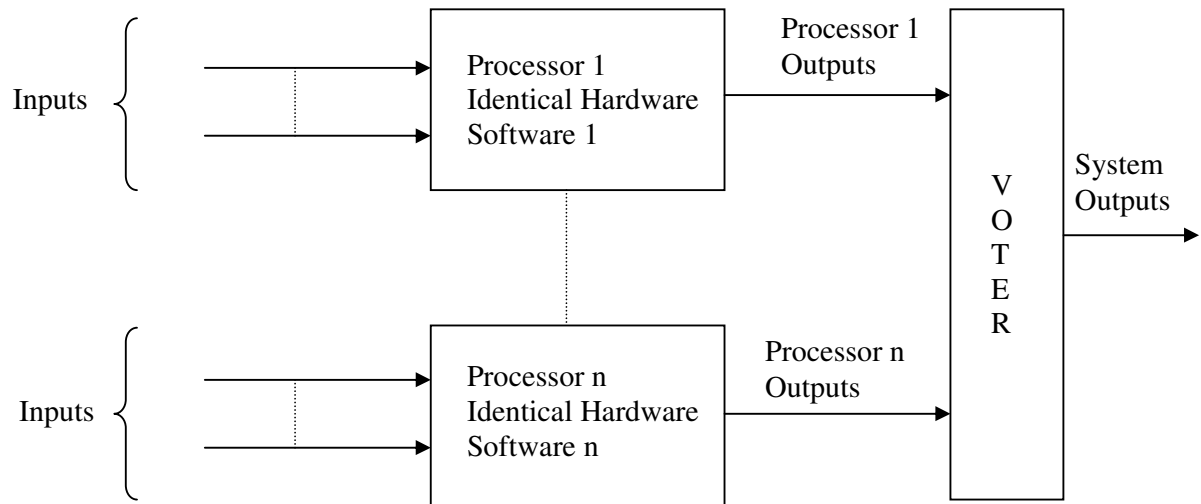
**Figure 6: Hardware Redundancy**



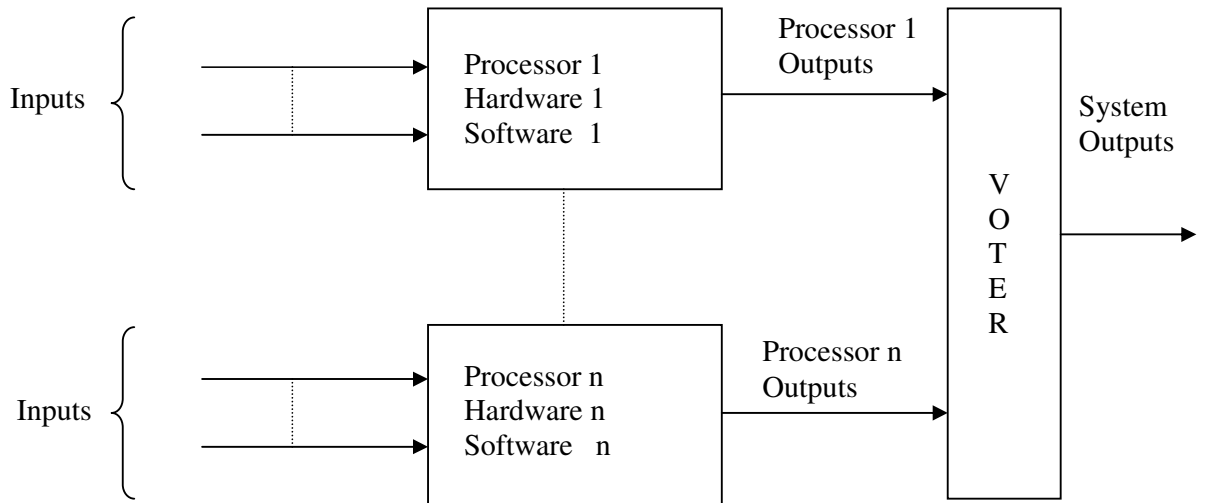
**Figure 7: Hardware Diversity**



**Figure 8: Software Diversity**



**Figure 9: Diverse software on redundant hardware**



**Figure 10: Diverse software on Diverse Hardware**

### **3.2. Interlocking Methodology**

Types of Methods applied in software for Interlocking is discussed below:

#### **Geographical Method:**

In the Geographical method the input to the SSI is given as the position of the signals, points, tracks Circuits and Slots. The Interlocking is implemented based on the generic rules that no part of the track are shared by the two routes at a time, Conflicting routes should not be set at a time etc. This type of implementation requires a great knowledge of the Yard Elements and the interconnection between them. In this method the software does not have one to one relation ship to the relay circuits used for RRI and is very difficult validate, so this method has failed to create the necessary confidence in the railway operators

#### **Boolean Equation Method:**

The Boolean equation method is the implementation of the traditional relay interlocking principles. In this method the relay circuits are implemented as Boolean equations, so there is one to one relation ship between the relay circuits and the software variables. Since there is a one to one relation ship between the software and the RRI Relay circuits, Railway operator can easily validate the software entrees made and this method will give him sufficient confidence.



#### **4. Analysis of Failures of Solid State Interlocking Systems**

Even after employing one of the above methods to ensure fail Safety, practically Reliability and maintainability of these systems has not been proved in the Interlocking systems installed worldwide. The reasons for the non reliability can be explained as follows:

1. Lack of domain Knowledge in Signalling and Traditional Route Relay interlocking Systems, This creates a technological gap between the software programmers and the Domain consultants. This leads to Errors in software, which might lead to unsafe failures of the system.
2. Increasing the complexity of the System by Employing distributed architecture, which is difficult to validate and verify and difficult to maintain, thus leading to very high time repair.
3. Extending the working scope of the Interlocking systems for monitoring and other non-Interlocking functions, this leads to degraded performance of the system.
4. Employing Non-Formal Interlocking principles instead of traditional RRI Principles leads to software complexity. For Ex: The Geographical method needs every system that is installed for new Yard needs validation, which is not practicable.
5. Since the software and hardware is so complex, complete test of the system is not possible and most of the faults are revealed at the field Installation stage or during normal working of the system in field.
6. The software is to be changed for every yard, the software structure should be in a generic form, but we seldom see a generic form and at this the stage errors creep in.
7. The lack of standardization in the railway working principles and the core Interlocking principles, the software developers are forced to do changes in the software for every yard in Different railway zones, this is the time that errors in the software creep in.
8. Lack of standardization of interlocking principles, every railway zone has its own set of rules and principles which are conflicting with other railways; this makes the life of the developers difficult because they have change their systems settings and software accordingly.
9. There is no standard book or reference available describing the core interlocking principles, since these rules are only known by the people working in this domain.

## Analysis of Railway Interlocking Systems

10. Increase in the complexity of the software leads to difficulty in testing, since most of the Interlocking systems are sequential machines they are error prone and are very difficult to test.

Because of the above said reasons the Interlocking systems have failed to create the necessary confidence in the railway operators and have become unpopular.

## **5. Proposed Architecture of Interlocking Systems**

The Proposed solutions for the above discussed problems are as follows:

1. Work towards the standardization of Interlocking principles and develop generic set of Equations.
2. Keep the hardware Complexity to a bare minimum so that fool proof testing of the system is achieved.
3. Keep the system centralized so that complexity involved is less, this automatically improves the maintainability.
4. Most of the Solid state Interlocking Systems developed to date follow one of the method described in Table 1, Which is either by software voting or hardware voting, a new method in which the two different software versions are implemented on both of the Processors of the system and the processors are having the identical design, this way the functionality of both the software voter and hardware voter are met, thus the system gives additional reliability by having software voter and availability is achieved by hardware redundancy.
5. To date Systems have been developed to detect a fault and isolate them selves, a system hardware must be developed in such a manner that detects a fault and repairs itself or have an alternate to the faulty portion.
6. The best fool proof method to solve unnecessary complexity is to load the SSI only with the Control/Selection table directly, this requires the system to have the generic interlocking equations embedded in the system. Since Each yard has its own set of Specifics, software must be developed in such a manner that only the yard specific data can be changed for every yard and the core software remains the same, so that for each system only the yard specific part of the software needs to be validated and this should be in a manner that is understood by the railway operators, so that this creates the necessary confidence in them and are sure of the entries made.
7. Today most of the Solid state Interlocking Systems use the black box testing, this is full of flaws because all the conditions in Interlocking cannot be tested with the test forms existing on present day, so a system must be developed so that a white box testing can be carried out and individual testing on the yard specific data can be carried out. Complete IV&V (Independent Verification and Validation) as per CENELEC standards shall be carried out to verify the design and field performance of the product.
8. Software should be written in such a manner that a layman or the railway operator can make an entry in his own relay logic and this should be compiled and should generate an executable file.

9. The software should be written in such a manner that is fool proof and crystal clear that total unit testing and validation is possible.

The Block diagram for the proposed architecture for SSI is shown in Figure 11

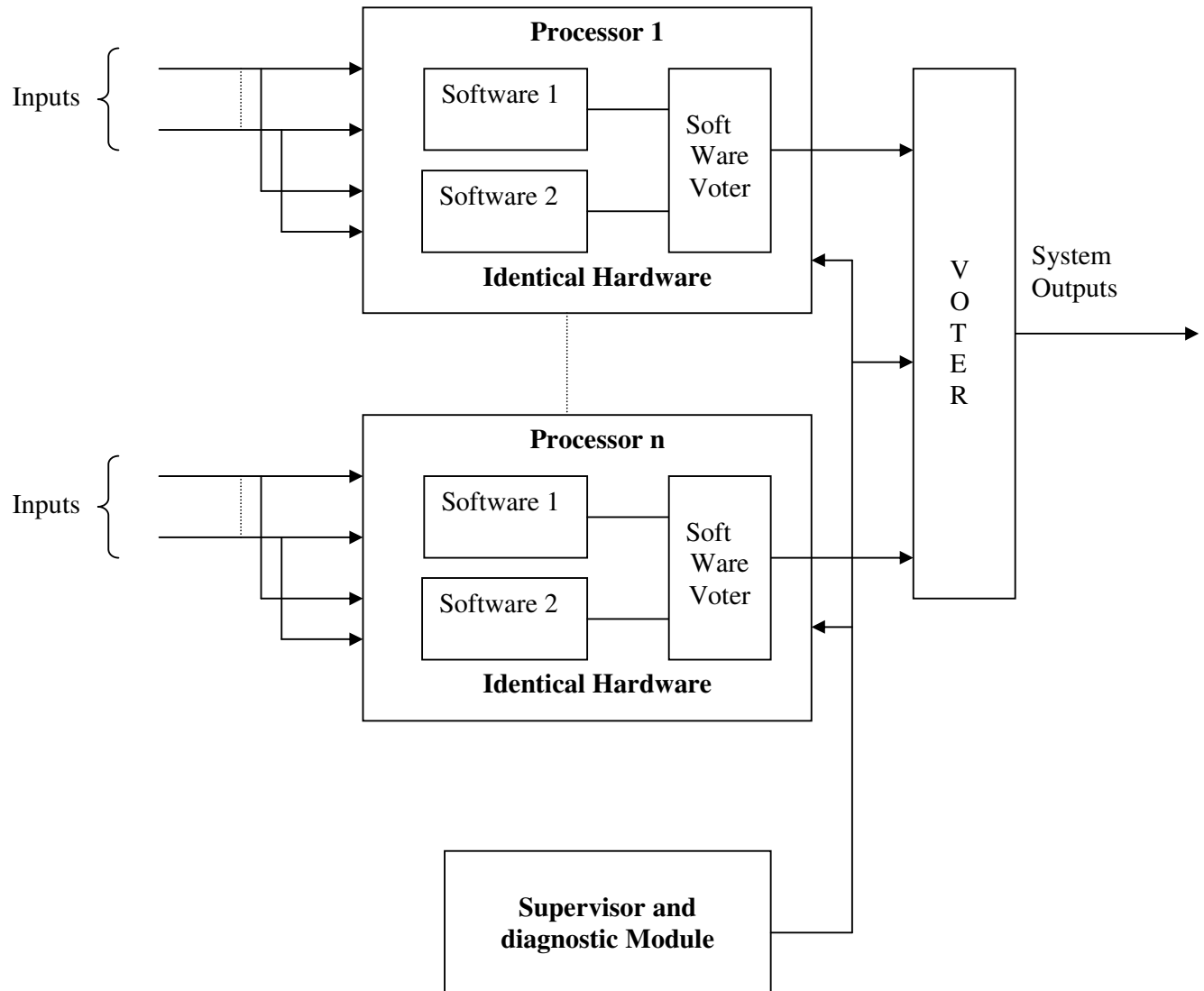


Figure 11: Proposed SSI Architecture

### 5.1. Software to Take Care of Different Railway Practices

There are two methods of programming the SSI for a particular station, namely – Geographical Programming & Free-wire Programming. SSI systems shall adopt programming where Control Table of the station is fed to the SSI system. This gives great relief to the user as he is not required to make the circuit diagram; data for any station can be programmed very easily. Adoption of change in interlocking practice of

## Analysis of Railway Interlocking Systems

a particular railway requires changes to be made in the executive software and entails revalidation of the software. On the other hand, Free-wire programming, which requires circuit diagram to be prepared for each station and programmed into the EPROM as Boolean expressions is cumbersome and leads to errors and is highly time consuming in terms of preparation of circuit diagram for each station.

By Employing the above said points the SSIs shall have increased reliability, availability and maintainability. This also creates necessary confidence in the railway operators that they can adopt new technologies.

### 5. Research done in this area:

The research in the field of solid state interlocking systems data back to 1970s, the first prototypes came in to existence in Britain in the early 80s. In India the research in this area started in the mid 80s by IIT Delhi, the project was funded by RDSO, Lucknow. Prof. Vinod Chandra and Dr. M. Verma were involved in this project. They developed a prototype in which they allocated different Safety Integrity Levels to each module so that the complexity involved in validating the whole system which has only one safety integrity level is solved. The Prototype was developed by 2/2 hardware redundancy Method.

Union switch and Signal Company developed a System with single processor with diverse software method. The Total system had a hot stand by system that would take over if one system failed. Westrace Inc, Australia has implemented the Distributed architecture of SSI where the control is distributed in the Entire Yard as apposed to Centralized Systems. Michele Banci, ISTI - CNR, Formal Methods and Tools Group Pisa, Italy has worked on the method of state charts and graphical method to implement Interlocking. Dejan Lutovac and Tatjana Lutovac of RMIT University, Melbourne, Australia has worked on generalizing the software and working towards an Universal Interlocking System. Peter Wigger, Institute for Software, Electronics, Railroad Technology (ISEB), TÜV InterTraffic GmbH, Berlin-Brandenburg Group has worked on the allocating Safety Integrity Level (SIL) in Railway Applications. Radek Dobias, Hana Kubatova, Department of Computer Science and Engineering, Czech Technical University Prague have worked on the use of FPGAs in safety critical railway applications. Kotaro Shimamura, Shin'ichiro Yamaguchi of Hitachi Research Laboratory, Hitachi Ltd have worked on fail safe hardware by using dual synthesizable processor cores which gives redundancy in the component level itself Tomoji Kishi, Natsuko Noda of Software Design Laboratories, NEC Corporation has worked on software architecture, architecture conformance, non-functional properties, design method, layered system for Interlocking software.

### Conclusion:

It is suggested that in the complex field of Railway Signalling, where safety, availability and maintainability are the prime issues, the railway operators must be taken in to confidence and the method applied to design these systems should be reliable, verifiable and should create confidence in the railway operators. The Method suggested in the paper describes the method to be employed for design and development of SSIs for safe and reliable operation.

**References:**

1. TOWARDS AN UNIVERSAL COMPUTER INTERLOCKING SYSTEM by Dejan Lutovac and Tatjana Lutovac, FACTA UNIVERSITATIS (NI\_S) Series: Electronics and Energetics vol. 11, No.1 (1998), 25-49.
2. Geographical vs. Functional modelling by statecharts of interlocking systems- Michele Banci 1 Formal Methods and Tools Group ISTI – CNR Pisa, Italy, FMICS 2004 Preliminary Versi
3. Independent Verification and Validation<sup>1</sup> of interlocking in the Netherlands By: P. Musters and T. van de Ven, V&V-article (version 2.2).
4. The Safety Philosophy Behind the CENELEC Railway Standards, Dr. Hendrik Schäbe TÜV InterTraffic GmbH Institute for Software, Electronics, Railroad Technology AmGrauen Stein D-51105 Köln, Germany.
5. FPGA Based Design of the Railway's Interlocking Equipments Radek Dobias, Hana Kubatova Department of Computer Science and Engineering, Czech Technical University Prague
6. A Fail-Safe Microprocessor Using Dual Synthesizable Processor Cores Kotaro Shimamura, Shin'ichiro Yamaguchi.
7. Fault Tolerance in Railway Signalling System: A study of the Elektra Interlocking Systems Alexandre Denault McGill University Quebec, Canada
8. Software Design based on Architecture Conformance Tomoji Kishi, Natsuko Noda Software Design Laboratories, NEC Corporation.
9. Solid State Interlocking Systems, US & S Solutions.
10. A Fail Safe Interlocking System for Railways by V.Chandra and M.Verma.