Supervisory Control for a Class of Hybrid Systems

By

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A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science Electrical Engineering (Control)

In

Pakistan Navy Engineering College, Jauhar,

National University of Sciences and Technology (NUST),

Islamabad, Pakistan.

(February 2016)

Approval

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Abstract

In this technological era, the evolution of sensors and advancement in computer based communication have encouraged to avail the opportunity of dynamic systems which not only have provided the means for automation but also have been broadly adopted in various significant applications such as automotive controllers, intelligent traffic management systems, real-time communication networks, manufacturing systems and robotics. Dynamic systems are governed by the instantaneous occurrence of Discrete Events. Also, it provides the concept of automaton which means a self operating machine. The occurrence of discrete events can be controlled by allowing the events to occur in a desired sequence which is deemed as supervisory control and the sequence of events is termed as language of automaton.

Here, we are taking the problem of conventional signaling mechanism of Pakistan Railways, transforming it into Discrete Event System and designing an automaton for it. At present, Pakistan Railways is using various mechanical and electromechanical signalling methods to steer the trains; these signalling and interlocking events are currently performed by humans. This thesis is focused on designing and developing the viable and effective supervisory control of Signalling and Interlocking mechanism for Pakistan Railways. In the prevalent mechanism, intensive communication and coordination among the duty staff is required to apprise the next person of performing the subsequent event in order to control and manage train movement at a station. Said systems have turned outdated due to minimal reliability. This fragile signaling mechanism has resulted in several train accidents culminating in loss of human life. Hence, we propose an automaton with a supervisory control which can intelligently control and manage the movements of trains at platforms. This supervisory control would be capable to avoid collisions and accidents between the trains. Proposed supervisory control is implementable with the help of various sensors, actuators and Programmable Logic Controller (PLC). This automaton, based on PLC algorithm and signal detection, is capable to take decisions to perform the events in a desired sequence so as to control and manage the arrival and departure of trains efficiently and effectively. This automaton reduces the human effort and is cost effective as well. As regards proper signal detection, a reliable communication among the nodes is required. This communication between the nodes can be through hard wire contact or wireless sensor network (WSN). This thesis would provide a methodology for upgrading the conventional signaling mechanism of Pakistan Railway to a Discrete Event System.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST PNEC or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST PNEC or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

Author Name: **Mudasir Ahmed**

Signature: ________________

Acknowledgment

I am grateful to Cdr. Dr. Attaullah Y. Memon, my supervisor, who consistently provided me the guidance, suggestions and support during this research. At some stages of research work I was in confusion and chaos but he, my supervisor, guided me to figure it out. I am also thankful to Cdr. Dr. Rana Hammad Raza who encouraged me to think over contributing research work to the betterment of Pakistan Railways. Also, I appreciate the efforts of Cdr. Dr. Syed Sajjad Haider zaidi for helping me out to achieve this goal. Cdr. Dr. Attaullah Y. Memon guided me to carry out the research work in the field of Discrete Event Systems and its supervisory control. He provided me with research paper and some relevant study stuff to work on. Subsequently, he instructed me to study few books regarding Discrete Event Systems and hybrid systems which helped me a lot in understanding and completion of my research work. Finally, I am grateful to my parents and eldest brother for their love and moral support.

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Chapter 1

Introduction

In this modern age, the significance of the discrete dynamic system and its supervisory control is growing with alacrity. The characteristics of Discrete dynamic system are different as compared to continuous system in a manner that former is based on happening of instantaneous events and the latter has a distinct value in time scale. Owing to this difference, a problem of combining continuous and discrete systems emerged. Earlier to technological advancement, it seemed impossible to combine the continuous system and discrete system in order to perform coordinated activities to achieve the target. However, with the passage of time the engineering research advanced and provided a methodology, to combine both the continuous systems and Discrete systems, which is called as Hybrid System.

1.1 Hybrid Systems

Hybrid system is, basically, a combination of two unlike systems. Here, two systems viz. time driven component and discrete component of system are considered. The time driven component of system is controlled by the discrete inputs. In the Hybrid Systems, both the Discrete systems and Continuous systems communicate in a way that the input to the plant is of Discrete nature and the output of the plant is of Continuous nature. In hybrid system, there is computer aided control of continuous system and hybrid systems play important role in designing the supervisory control of continuous systems.

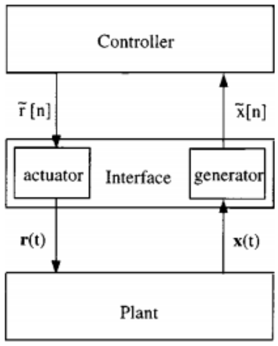


Figure 1.1: Hybrid Control Model [1]

These days, hybrid systems are ubiquitous and widely used in

- industrial control
- manufacturing and chemical processes
- intelligent transportation systems
- computer and communication control for packet arrival and departure

In fig 1.2, the thermostat turns ON when temperature is less than or equal to 19 degree and the thermostat turns OFF when the temperature is greater than or equal to 21 degree. Here the occurrence of event is the discrete input to the system and it causes the transition of system from one state to the other. Actually, it was desperately needed to have automated

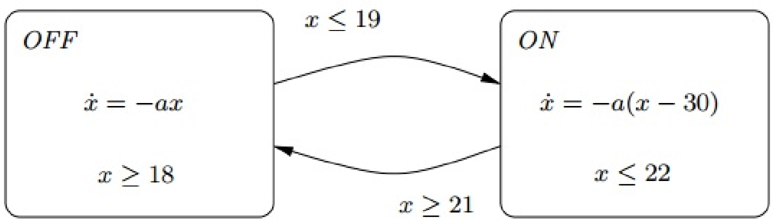


Figure 1.2: Hybrid Control system for room temperature [48]

control over such discrete dynamic systems so that events may occur in a certain order to achieve coordinated operation with minimal human supervision. This issue of having automated control over the dynamic systems has been resolved by adopting a methodology called supervisory control which can be implemented with the help of Programmable Logic Controllers (PLC) hardware and Ladder Logic application of Step-7 software. Supervisory control steers the system to perform according to a certain language which is predefined and ensures that system would not run into any undesired state which may be a cause of any collision or system failure. Supervisory control not only curtails the need of human resources but also performs the tasks more efficiently and effectively as compared to human beings.

1.2 Railways Traffic Management

Trains are the biggest source of the transportation as compared to vehicles. Railway system is more environment friendly and economical. In parallel to positive aspects in prevalent railway system, there is also negative aspect of train delays and train collisions; which whenever happen, result in stress, monetary loss and severe loss of human life. To avoid train collisions and delays, it is required to manage the railway traffic efficiently. The basic aim of railway traffic management is to guide the trains approaching to and departing from railway station so as to achieve successful operation, to maintain the safety and to avoid confusions. So far the railway traffic in Pakistan is managed manually be the humans. Involvement of humans is a major cause of train collisions affecting human life, assets and efficiency. Because humans are affected by emotions, age, physical health condition, stress and attitude. In addition to human reliability, fixed signalling system is also a reason for confusion because the train driver acts according to observance of fixed signals. Actually rail interlocking and fixed signals have to be operated in a desired sequence so as to avoid any mishap and to maintain safety. Said desired sequence of signalling and interlocking can be treated as series of physical events. And the occurrence of these physical events can be controlled with the help of supervisory control.

1.2.1 Signalling

Signal means a sign by which the orders relating to trains are conveyed to the train staff to carry out the operation or to stop. The objective of signalling is to manage rail traffic without compromising safety and speed. Signalling plays a vital role in impeding conflicting movements of trains and ensuring appropriate distance between the trains moving with in the block section or approaching the station. The kinds of signals used in Pakistan railways are as follows:

- Fixed Signals
- Hand and Banner flag signals
- Detonating or fog signal

Fixed Signals

The fixed location signals are used to control the entry and exit of trains into the yard and block section.

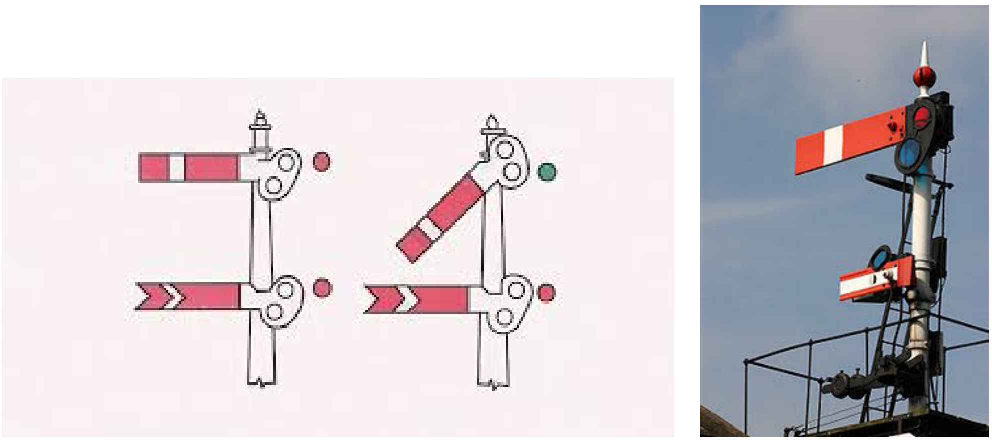


Figure 1.3: Fixed Signals [36]

Hand and Banner flag signals

Hand signals are generally used for shunting purpose. During day time, these are displayed by red or green flag; whereas, hand signal lamp (green or red) is used during the night. Banner flag is a temporary engineering danger signal consists of red cloth used in day time only.

1.2.2 Operation of Fixed Signals

The fixed signals are operated through various means. following are the means used in Pakistan Railways to control the fixed signals:

1. Mechanical Signalling

2. Electrical Signalling

3. Electro Mechanical Signalling

Mechanical Signalling

In mechanical type of signalling, the points and signals are controlled mechanically by point rods and signal wires.

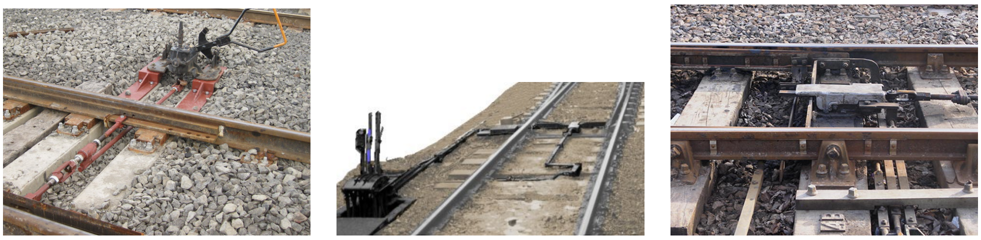


Figure 1.4: Mechanical Signalling [36]

Electrical Signalling

In electrical type of signalling, the points and signals are operated by electric power.

Figure 1.5: Electrical signalling [36]

Electromechanical Signalling

In this type of signalling, the points and signals are controlled with the help of electric power. However, in case of electric power failure, these points and signals can be operated mechanically as well.

1.2.3 Yard Signals

Various signals are used in the yard to control the movement of incoming and outgoing trains. For this purpose, following signals are widely used in Pakistan Railways:

- Home Signal
- Outer Signal
- Warner Signal
- Starter Signal
- Advanced Starter Signal

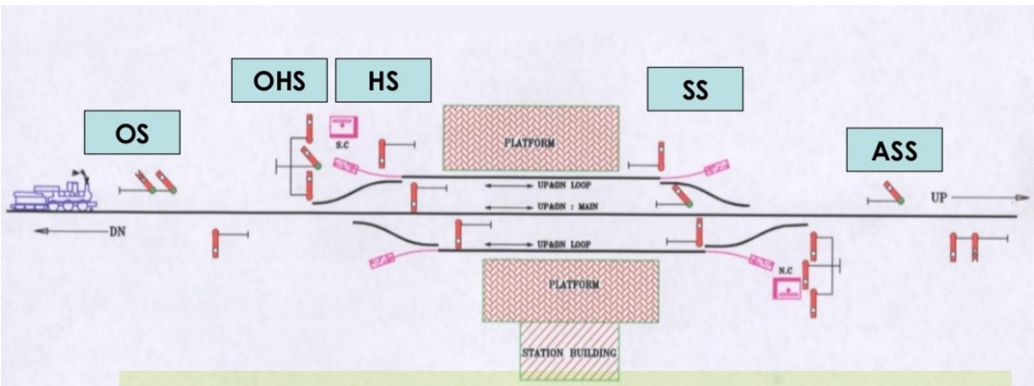


Figure 1.6: Railway Station Infrastructure [33]

Home Signal

It is a semaphore stop signal provided at the facing point of the yard to control the entry of trains coming into the yard. Each line has a separate home signal. Thus driver makes his mind that at which platform train will stop.

Outer Signal

Outer signal is a semaphore stop signal. It is first stop signal which indicates whether the track and platform is clear or not and it is provided at a distance of:

- 580 meters from the outer most facing point of yard (on single line)
- 400 meters from the outer most facing point of yard (on double line)

Starter Signal

It is a semaphore stop signal provided at the exit of the line where two or more line converge in the yard. This signal gives permission to proceed. Each line has a separate starter signal.

Advanced Starter Signal

It is a last stop signal in the station yard. No train can pass it without the authority to proceed. Station master of the next station is the authority to control this signal. This signal is placed at a distance of 180 meters from the outer most facing points.

Warner Signal

It is a fish tailed arm below the outer signal arm. It is not a stop signal, but it enlightens the driver about the status of next block section whether occupied or not.

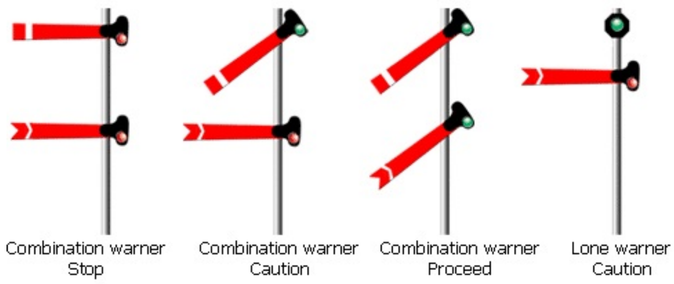


Figure 1.7: Warner signal [36]

1.2.4 Interlocking

Interlocking is the interconnection of points, locks and signals in such a way that they must succeed each other in a predetermined order. Purpose of interlocking is to ensure safe and quick operations of trains inside yard and in block section.

Basic Interlocking Principle

Interlocking is performed step by step in predetermined order. This interlocking principle behaves like a discrete event system. Each step is deemed as an event. Interlocking is carried out as follows:

- All the facing points in the route should be set and locked properly for incoming or outgoing trains.
- All the trailing points in route should be set correctly

- All the conflicting signals should be in ON position
- L-XING gate should be closed, if controlled by station master
- Isolation of main should be provided
- Outer signal should be lowered if Home signal is lowered
- Advanced starter signal should not be lowered without getting permission from next station master
- Before lowering warner signal, all the reception and departure signals of main line must be lowered

1.3 Configuration of Supervisory Control

With the inception of Discrete Event System theory, the term Automata emerged. Automaton is a self operating machine or widely known as Robot. Automaton can supervise the plant and control the plant accordingly. Supervisory control is basically a methodology under which the automaton receives the input signal from the current state of the plant; based on said input signal, the automaton makes decision whether or not to actuate the subsequent state of plant. The control of discrete event systems depends on the switching of control input through a sequence of elements in response to the observed string of previously generated events; said controller is deemed as supervisor. [3] fig.1.1. Formally a supervisor is a map

$$f : L \to \Gamma$$

this manifests possible string of generated events and the control input applied at that point[3]. Having the Supervisory control characteristic, an automaton takes decisions according to the sequential occurrence of events which are deemed as Language. The language, that is, sequence of events be well defined and preserved inside the controller. Basically, it is the language which paves the way for automaton to comprehend the input signal and to perform accordingly in order to run the plant without going into any unwanted state. For effective and efficient supervisory control of plant, it is desperately required to define the language properly so that no confusion may arise for the automaton for taking decisions.

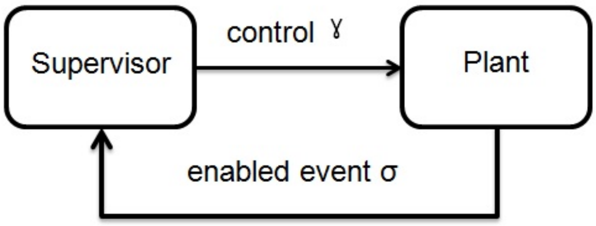


Figure 1.8: Supervisory Control of DES [3]

1.4 Advantages of Supervisory Control

Supervisory control is adopted to get fail proof operations and to maintain the safety. Supervisory control of system lets the events occur in a desired sequence. A system without supervisory control requires more manpower to perform various tasks in a certain sequence. More the number of humans involved requires extensive coordination among them; and there is greater risk of misunderstandings, collisions, accidents. Contrary to this scenario, supervisory control acquires the real time data received from various sensors and manipulates the acquired data to perform subsequent events in a predefined order in an effective manner having maximum reliability.

Supervisory control of system is more viable and economical. Supervisory control discussed in this thesis is implementable by making Ladder Logic code and the Programmable Logic Controllers Siemens-300 which are easily available.

1.5 Applications of Supervisory Control

Nowadays, supervisory control is being used in many applications such as manufacturing systems, robotics, intelligent traffic management and communications and industrial control. For instance, in manufacturing system, there are multiple machines which need to operate in a sequence or a number of activities need to be performed in a certain sequence. To achieve successful operation, a close supervision is required so that each event should occur at its turn and no event should occur before or after its turn. If human beings are assigned to carry out the activities in a certain sequence, then intensive communication is required to have efficient control over the occurrence of events. Despite intensive coordination and communication among the staff, there is chance of any mishap due to human error. However, an automaton designed to perform the supervisory control of said manufacturing system would perform the activities in sequence more intelligently with more flexibility and reliability.

1.6 Fundamental Issue of Railway Traffic

Basic problem of this thesis is to make an effort to transform signalling and interlocking system of Pakistan railway from conventional methods to more convenient, rapid and reliable methods. Signals are used to control the entry and exit of trains into the yard and in block section. Whereas, interlocking is provided to promote safe and quick operations. So far, Pakistan Railway is using fixed signals, hand and banner flag signals. Currently, a large number of duty staff is undertaking multiple activities for interlocking and signalling for railway traffic management.

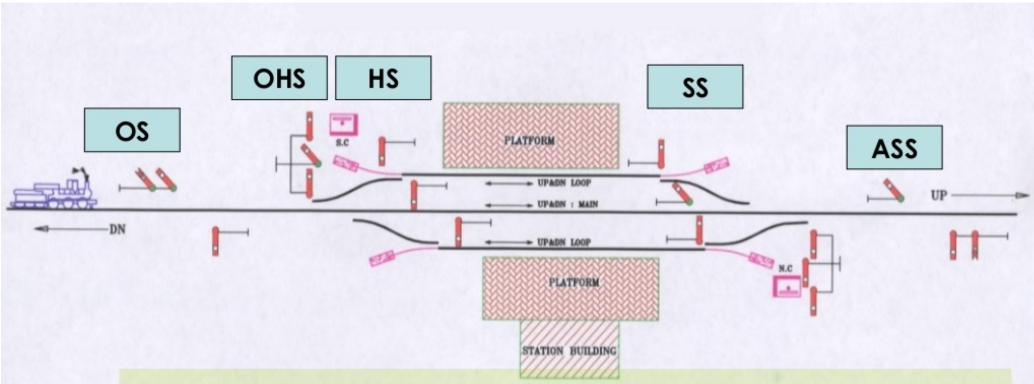


Figure 1.9: Railway Station Infrastructure [33]

Sequence of interlocking and signalling is undertaken as follow:

- First of all, train driver apprises the station master of train approaching the station.
- Station master checks which platform is unoccupied so that train may stop there.
- Station master asks a person to set the points of railway line correctly so that train may come at unoccupied platform.
- The points are locked properly so that set route may not be disturbed. Because if the route gets disturbed, the train may move to undesired location which can create trouble and lives of passengers may be lost.
- Home signal of respective unoccupied platform is turned Green.

- Outer signal turns Green.
- When the train driver observes outer signal and home signal green, then he deems that the platform is empty so he approaches the respective platform at station.
- When the train arrives at platform then outer signal turns Red
- Home signal turns Red
- Points are unlocked
- Points are reset.

Figure 1.10: Mechanical Interlocking in Pakistan Railway [45]

This all happens in a sequence. It is necessary to follow the sequence otherwise there may be train accident resulting in loss of human lives. Presently, this sequence of activities is performed by staff. When an activity is completed by one person, he then apprises the next person to carry out subsequent activity. For successful operation, profound coordination among the staff is essential. Lack of coordination among the staff and human negligence has resulted in many accidents at platforms and in block sections. Keeping in

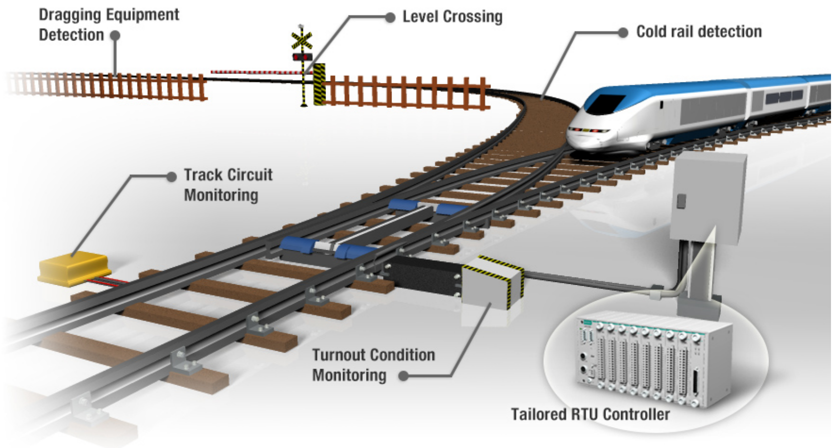


Figure 1.11: shifting from one rail track to other [45]

view above scenario, supervisory control can be applied on Railway signalling and interlocking to achieve safe operations. Because the supervisory control works by following the occurrence of events in a sequence. In this case, human resource would be replaced with the various sensors such as proximity sensors, infra red sensor, radar speed gun, track circuits and etc. Output of these sensors would be provided to controller to take decision judiciously. With the supervisory control, need of human resource would be minimal and the same operation of the system would be achieved with maximum safety and economy of effort.

1.7 Current and Future Work

Prevalent infrastructure of signalling and interlocking in Pakistan Railway is neither efficient nor reliable in terms of safety. Because all the activities of interlocking and signalling are undertaken by staff. Any negligence or lax response of staff can be cause of any mishap. As the world is going towards technological advancement of automation, also it is time for

Pakistan Railway to get itself upgraded to the standards of modern world. With the help of Programmable Logic Controller, all the sequential activities of signalling and interlocking can be controlled automatically instead of human resources. For up-gradation of signalling and interlocking of Pakistan Railway, following are required:

1. Siemens PLC 300
2. Step-7 software for writing PLC algorithm
3. Wired network by means of hard wire or optical fibre for sensors data collection

This wired network would transmit the data to the controller. Similarly, the controller would also pass the instructions through wired network. The wired network should be reliable enough so that proper transmission and reception of data may be ensured. Because loss of data may create troublesome. In future, this wired data transmission may be replaced with Wireless Sensor Network (WSN) which is more efficient and reliable. In WSN, which is a modern technology, each sensor would transmit wireless data to the controller.

1.8 Scope of Thesis

Signalling and interlocking plays an important role in railway traffic management. The main objective of signalling and interlocking is to maintain safety, that is, thwart collisions and delays by taking decisions judiciously. In case of high speed trains, it is more significant to have more reliable and fail-safe signalling and interlocking system. This thesis would focus on designing asynchronous discrete event system automaton which by adopting supervisory control theory would enhance the safety and reliability of signalling and interlocking mechanism in Pakistan Railway. Actually, an automaton decides judiciously and quickly which would help to impede time delays and collisions between trains. The thesis would focus on designing various test models of railway signalling and interlocking and the algorithm for its supervisory control. Said test models would be verified with the help of TCT software [43] which determines if the DES automaton is deterministic or nondeterministic and produces the graphical representation of DES models. TCT software displays total number of states of DES plant and the arrows indicating transition from one state to another due to occurrence of respective events. Said algorithm would be implementable by using Siemens PLC. The algorithm would be coded in ladder Logic which could be downloaded into the siemens PLC to control the occurrence of events in a predefined sequence. While designing PLC algorithm, a problem of avalanche effect emerged; which means if algorithm has two same events occurring one after other in a single code. Then due to avalanche effect, both same events are actuated with a single input and system does not behave as required and designed, rather system runs into undesired state. Therefore, a tactic would be used while writing PLC algorithm to counter the avalanche effect so that system may behave as per requirement of the plant. By introducing above concept in Pakistan railway, it would not only enhance the capability and efficiency of railway but also reduce human involvement and the recurrent expenditures being paid to ghost employees who are economic burden on it. Moreover, by doing this all indigenously, Pakistan Railways can have monetary benefit as well.

1.9 Research Goals

The objective of this thesis is to transform the conventional railway system to more advanced and reliable method. Research would be carried out to achieve the following goals:

1. Model of proposed infrastructure of signalling and interlocking
2. Designing Discrete Event system automaton for Railways signalling
3. Designing supervisory control algorithm of various test cases of signalling and interlocking
4. Implementing the supervisory control algorithm with the help of Siemens PLC-300

An endeavour is being made to modernize and to upgrade Pakistan Railway infrastructure by applying supervisory control methodology in order to control signalling and interlocking more conveniently and economically.

1.10 Discrete Event Systems

DES is a dynamic system with discrete state space and piecewise constant state trajectories[3]. The occurrence of events controls the transition among states. The state trajectory of such a system is shown in Fig1.10 [3].

In above figure we observe that the transition of states occurs with the occurrence of DES. These state transitions are called events, and each of the events is labeled with some element which actuates the events occurrence. Each event is connected with two states, that is, exit state and entrance state. In DES, there are two possible systems. One is time-driven system or continuous system which means the state of the system changes with

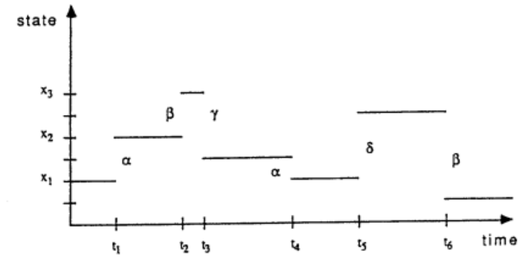


Figure 1.12: Occurrence of Discrete Events [3]

respect to the time such as velocity, acceleration, temperature and etc. Other is event-driven system or Discrete system which changes its state with the occurrence of an event as shown in above figure. In figure 1.11, we consider the order of occurrence of events and ignore the time of occurrence of events. Here the sequence $\Sigma = \{\alpha, \beta, \gamma, \delta, \dots\}$ is the order of occurrence of events. Note that each event has different time interval, this is so because the DES systems are event driven rather than time driven.

1.11 Discrete Event System Modeling

Modeling of Discrete event System is based on the language which refers to the set of all possible event sequences that a given DES can execute. Here DES represents an automaton which is capable of representing language according to the well defined rules [2].

$$G = (X, E, f, \Gamma, x0, Xm)$$

Here the automaton G is represented as six tuple which means as follows:
X is set of states
E is finite set of events
f = X×E→X is transition function

$\Gamma : X \rightarrow 2^E$ is Active event function (or feasible event function) : $\Gamma(x)$ is set of all events e for which $f(x, e)$ is defined

X_0 = initial state

X_m = set of marked states

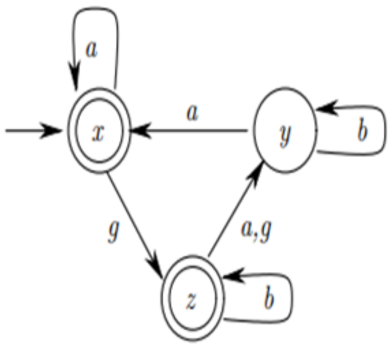


Figure 1.13: Machine Model [2]

f = X×E→X

$f(x, a) = x$	$f(x, g) = z$
$f(y, a) = x$	$f(y, b) = y$
$f(z, b) = z$	$f(z, a) = f(z, g) = y$

From Fig.1.12, we observe that system goes from state y to state x with the occurrence of event a, from state x to state z with the occurrence of event g and from state z to state x with the occurrence of event a or g. Here we observe one more interesting thing that state x does not change with the occurrence of event a, similarly states z and y do not change with the occurrence of event b. Such events are considered as empty events ϵ which means the event has occurred but the state of the system remains the same.

1.12 Automaton

Automaton is s self operating machine which performs according some predefined rules. There are two types of automaton time driven automaton and event driven automaton.

Time-driven Automaton

In this type of automaton, each event is allocated certain time. When clock reaches the defined time limit then the transition between states occurs.

Event-driven Automaton

This type of automaton is asynchronous finite state discrete event system. The transition between states occurs subject to the occurrence of event.

1.13 Time Complexity of Automaton

The time taken by the algorithm to perform the operation by accepting the input of size n. It is estimated by considering number of elementary operations and the time taken by each operation. [47] There are various kinds of time complexity. of those, few are discussed as follows:

Constant time

An algorithm is said to be constant time (also written as $O(1)$ time) if the value of $T(n)$ is bounded by a value that does not depend on the size of the input.

Polynomial time

The running time of algorithm is upper bounded by a polynomial expression in the size of the input for the algorithm,

$$T(n) = O^{(n^k)}$$

for some constant k. All the basic arithmetic operations (addition, subtraction, multiplication, division, and comparison) can be done in polynomial time. [47]

Exponential time

An algorithm is said to be exponential time, if T(n) is upper bounded by

$$2^{poly(n)}$$

, where poly(n) is some polynomial in n. More formally, an algorithm is exponential time if T(n) is bounded by

$$O(2^{n^k})$$

for some constant k. [47]

1.14 Linguistic Preliminaries

Set of events E of an automaton is considered as an alphabet which is also a set of finite events. A series of events happening in an order makes a word which is also called as string. A string without any event is called empty string denoted by ϵ. Length of string is number of all events including repeated events. If string is denoted by s then its length is $|s|$.

1.14.1 Language

Language is set of finite length strings formed from event set. let $E = \{a, b, c\}$ be set of events. The language may be

$$L_1 = \{\epsilon, a, abb\} \tag{1.1}$$

and another language consists of two strings

$$L_2 = \{aa, ab, ac, ba, bb, bc, ca, cb, cc\} \tag{1.2}$$

Concatenation is a major operation performed in making strings and subsequently a language. From the above *equation 1.1* the string abb is a concatenation of string ab with string b. By definition, the concatenation uv of two strings is a new string consisting of the events in u immediately followed by the events in v. [2] Set of all finite strings of elements of E including the empty string ϵ is denoted by E^* where * is called *kleene-closure*. A language over an event set E is subset of E^*. For instance, if $abc = s$ with a,b, c $\in E^*$ then

- a is called *prefix* of s
- b is called *substring* of s and
- c is called *suffix* of s

Let L$\subseteq E^*$ then a *prefix-closure* is set of prefixes of all strings of language L and it is denoted as $\overline{L}$; that is

$$\overline{L} := \{s \in E^* : (\exists t \in E^*)[st \in L]\}$$

Language L is *prefix closed* if any prefix of any string in L is also an element of L.

The *closed behaviour* of automaton G, denoted by L(G), represents all possible event sequences taking automaton G from initial state to a reachable state.

Language generated by $G = (X, E, f, \Gamma, x0, Xm)$ is

$$\mathcal{L}(G) := \{s \in E^* \colon f(x_0, s)\text{is defined}\}$$

Language marked by G is

$$\mathcal{L}_m(G) := \{s \in \mathcal{L}(G) \colon f(x_0, s) \in X_m\}$$

one can easily verify that L(G) is always a closed language $L(G) = \overline{L(G)}$; whereas $L_m(G)$ may not be closed. In general following relation always remains [19]

$$L_m(G) \subseteq \overline{L_m(G)} \subseteq L(G) = \overline{L(G)}$$

1.14.2 Regular Language Expressions

- ${L_1}^*$ Kleene-closure
- ${L_1}^c$ Complement
- $L_1 L_2$ Concatenation
- $L_1 \cup L_2$ Union
- $L_1 \cap L_2$ Intersection

These expressions are discussed at length in section 1.14.1 above.

1.14.3 Blocking

An automaton may enter blocking and nonblocking mode. Blocking is further divided as *deadlock* and *livelock*.

Deadlock

Deadlock means an automaton reaches a state and from that state it can not move to any other state because there is no any event to occur, that is, $\Gamma(x) = 0$ but $x \notin X_m$..

Livelock

Livelock means that system switches between few unmarked states and is unable to reach the marked state because system can not to get out of those unmarked states.

An automaton G in *blocking* mode is represented as

$$\overline{\mathcal{L}_m(G)} \subset \mathcal{L}(G)$$

that means that system does not accomplish the required task and $\overline{\mathcal{L}_m(G)}$ is proper subset of $\mathcal{L}(G)$.

An automaton is in *nonblocking* mode if there is no deadlock or livelock

$$\overline{\mathcal{L}_m(G)} = \mathcal{L}(G)$$

G is nonblocking if there is path from initial state to marked state.

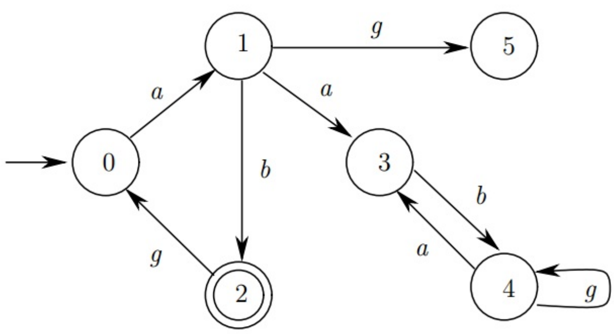


Figure 1.14: Automaton in Blocking and Nonblocking mode [2]

$f = \mathrm{X}\times\mathrm{E}\rightarrow\mathrm{X}$

Deadlock

. $f(1, g) = 5$

Livelock

. $f(3, b) = 4$ $f(4, g) = 4$ $f(4, a) = 3$

From fig. above, it is obvious that system runs into blocking mode when it reaches state 3, 4 and 5. State 5 is deadlock because the system may not get out of state 5; whereas, state 3 and state 4 is livelock because the system may switch between state 3 and state 4 with the occurrence of events *a, b and g.* Again with the happening of events *a, a* from initial state 0, system goes into nonblocking mode. But with the occurrence of events *a,b* from initial state 0 to state 2, the system is in nonblocking mode.

Chapter 2

Literature Review

2.1 Railways Traffic

Railway, being the biggest economical source of passenger and goods transportation, need to be managed properly so as to thwart any collisions and accidents. Signalling plays a vital role in railway traffic management; railway signalling is a system used to direct railway traffic and keep the trains away from each other [42]. To keep the trains apart, it is required to set the route of train, to raise and to lower home signal, outer signals, advanced starter signal and starter signal in a certain series in order to shun the confusion. World is shifting from manual operation to computer based railway traffic management. Because the rate of train accidents is more in manual operations as it is carried out by humans who are prone to stress, physical health condition, state of mind [29]. Since the railway traffic is managed by undertaking the actions viz. checking the platform occupancy, setting rail route, raising home signal and outer signal etc. These actions can be considered as events by applying the theory of discrete events system which can be monitored by the supervisory control.

2.2 Modern Train Traffic Management

Currently, in developed countries, advanced systems for railway traffic management are being practised in order to impede train collisions and delays. Of these systems are GSM based tracking of trains, computer based interlocking and Radio based interlocking (less wayside equipment for radio based train control is needed so it is cost effective). Moreover, the research is going on in the field of supervisory control for train traffic management as well. But the scenario in Pakistan is converse. Still the outdated system for railways traffic management is being practised. This is due to lack of infrastructure and resources and less attention towards Research and Design. But now it is need of time to pay attention towards the Research and Design in railway department. For this purpose, it is need to put indigenous efforts so as meet the international standards for railways traffic management. This thesis is a step towards the betterment of railway traffic management in Pakistan.

2.3 Computer Based Interlocking in Pakistan

Actually, Pakistan is a developing country. So far, railway traffic management in Pakistan has not been given due attention owing to lack of infrastructure and minimal focus on Research and Design. Few years back, Pakistan Railways made a contract with Equinox Bombardier company for introducing state of the art technology; that is computer based interlocking (CBI). The Project for Computer based interlocking was initiated few years ago and in the first phase the Bombardier company was supposed to complete the installation and commissioning of Computer based interlocking for certain number of stations but so far it has not completed the project. Moreover, there is no Transfer of Technology so in future we will be dependent upon the Equinox Bombardier company. The Equinox Bombardier Com-

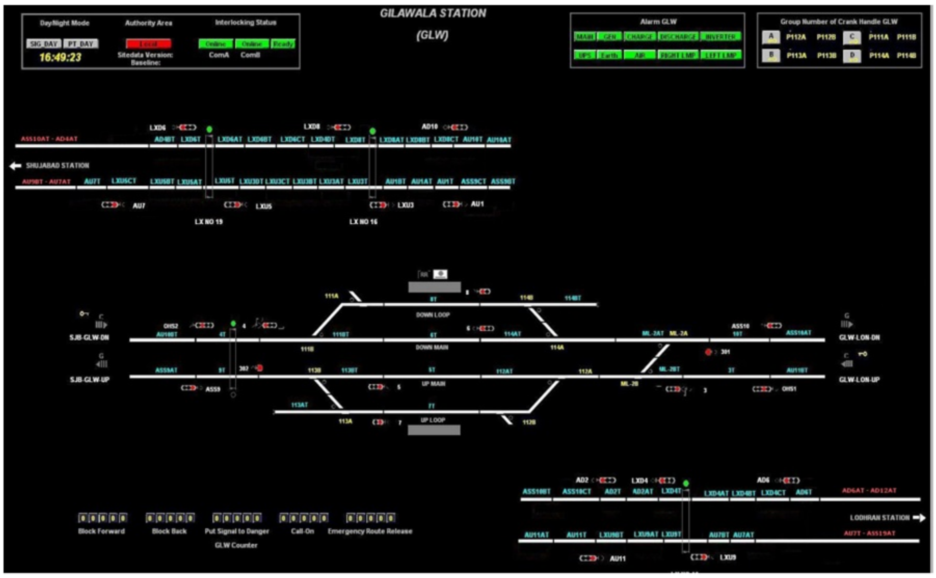


Figure 2.1: Pakistan: Computer based interlocking [46]

pany provides a GUI screen (fig 2.1) [46]to the station master who performs the interlocking activities by clicking the button. No doubt this reduces the human involvement. But again, there are some limitations such as the computer operator, who is a human, performs the signalling and interlocking activities. Secondly, the software is used as a black box. There is no access to the software. So whenever, in future, if it is required to redesign railway yard infrastructure such as add or delete a loop line (platform) then Pakistan railways will have to contact Equinox Bombardier Company for such modification.

2.4 Supervisory Control

Supervisory control of discrete events is widely used for continuous processes controlled by computer. Hybrid system encompasses continuous plant, discrete event controller and interface.[1][2]. It is very important to study hybrid systems in order to make supervisory control for continuous systems and intelligent control with high degree of autonomy.[1][20] Examples of such intelligent control systems are in[25][17][12][26][23] .The continuous system, that is, plant is controlled with discrete events.The continuous system is analog and described by differential equations and discrete is digital described by difference equation. [13] Discrete event system arises from the random occurrence of physical events. The events appear irregularly and system changes its state according to the appearance of events. The system is termed as automata which means self operating machine.[6] The states are represented by circles and events are represented by arrows.[6]This automata may be deterministic, that is, it can accomplish the task and has a unique event for each state transition and nondeterministic, that is, it is unable to accomplish the task because the same event may cause transition for two or more states. However, it is supervisory control which makes the system to behave deterministically.[3] [1] Ramadge-Wonham initiated the concept of supervisory control over discrete events.[3]. RW supervisor can be implemented by writing Ladder logic code of state transitions.[7][14][21][22][24]. A way to transform finite state automaton to Ladder Logic code is given in[16][18]. Solution of problems witnessed during ladder logic code are mentioned in [14]. Of these problems, one of the most important problems is an avalanche effect. When an event repeats twice or more in the ladder logic code, the program omits some states which are reachable by the happening of the repeated event during the same PLC scan cycle. This phenomenon is deemed as avalanche effect. A methodology regarding writing the ladder logic code so as to get rid of avalanche effect is proposed in [15]. Ladder Logic code for two machines sharing a buffer has been made in Programmable Logic Controller. These two machines operate in such a way that there is no collision. The machines are in one of three states idle, working, or down and buffer has two states either full or empty. Machine 1 brings a piece from some place an drops it in buffer, then Machine 2 approaches to buffer to pick that piece placed in buffer.[7]These two machines do not approach the buffer at the same time. Because it may disrupt the working and there are highly likely chances of collision.[7] Supervisory Control Theory stipulates that controlled system should be nonblocking (the target states should be reachable) and maximally permissive, that is, allow the occurrence of all events which do not violate the specified conditions. In [32] a model automaton has been designed for scheduling aircraft landing in a certain order by controlling speed and route of a large number of aircraft with in limited airspace. The [34] shows the application of supervisory control for networked discrete event systems. An other application [37] manifests the integration of PLC code of supervisory control and SCADA for manufacturing cell. In [40] a timed supervisory control approach has been used to counter the problem regarding the planning and scheduling of operations under the job deadlines. There are multiple softwares viz. UMDES, DESUMA, SUPREMICA and TCT for implementing the algorithm of discrete event systems [2]. An approach for Railway interlocking automata is discussed at length in [44][30]; said automata are a step towards maintaining safety by allowing trains to move on rails.

2.5 Programmable Logic Controllers

A programmable logic controller, PLC, is a digital computer which is widely used for automation of industrial electromechanical processes, such as control of machines in factory assembly lines, manufacturing processes and intelligent controllers. PLCs are used in many machines, in many industries. PLCs are designed for multiple arrangements of digital and analog inputs and outputs, immunity to electrical noise, extended temperature ranges and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory. A PLC is an example of a "hard" real-time system in which output results are obtained in response to input conditions within a limited time, otherwise unintended operation will result. Before the PLCs, control, sequencing, and safety interlock logic for manufacturing automobiles was mainly composed of relays, drum sequencers, cam timers, and dedicated closed-loop controllers [38]. PLCs are designed for severe environmental conditions and have the facility for extensive input/output (I/O) arrangements. These connect the PLC to sensors and actuators. The input/output arrangements may be built into a simple PLC, or the PLC may have external I/O modules attached to a computer network that plugs into PLC.

Similarly, the PLCs can be used for signalling system in Pakistan railways. Railways signalling system behaves like a discrete event system; for which the supervisory control theory introduced by the Ramadge-Wonham can be implemented with the help of Siemens-300 PLCs. And Step-7 software is used to write a ladder logic code for the railway signalling system.

2.6 Softwares for Discrete Event systems

There are multiple softwares viz. UMDES, DESUMA, SUPREMICA and TCT for the implementing the algorithm of discrete event systems [2]. This thesis would use TCT software which is a program for the synthesis of supervisory control of discrete event system [35]. TCT software has been designed by the research group of W.M Wonham. TCT software shows size which means total number of states of DES plant, initial state, marker states and transition from one state to another state. All the states are shown in circles and arrows indicate transition from state to next due to happening of an event. Moreover, TCT software verifies and determines either the DES plant is deterministic or nondeterministic.

Chapter 3

Control Design and Simulation

3.1 Proposed Signalling Hardware Design

For the upgradation and transformation from conventional methods of interlocking and signalling to modern techniques of signalling and interlocking is proposed here. If the real implemented arrangement is complex then the system block and circuit diagram would be different but the main idea for ladder logic code would remain the same. For the design of this modern signalling and interlocking, following equipment is required:

- Track circuit
- Proximity capacitive sensor
- Proximity inductive sensor
- Infra Red Sensors
- Photoelectric Sensor
- Stepper Motors

- Traffic Colour Lights
- Programmable Logic Controller PLC S7-300
- Electric power

3.1.1 Platform status check

When a train approaches the station, it must be checked whether the platform is occupied or not. When a signal is received that train needs to stop at platform, then track circuit status should be checked to confirm the platform occupancy status. If the platform if empty then a signal should be generated to set respective points. But, if the platform is occupied then a signal should be generated to check another platform.

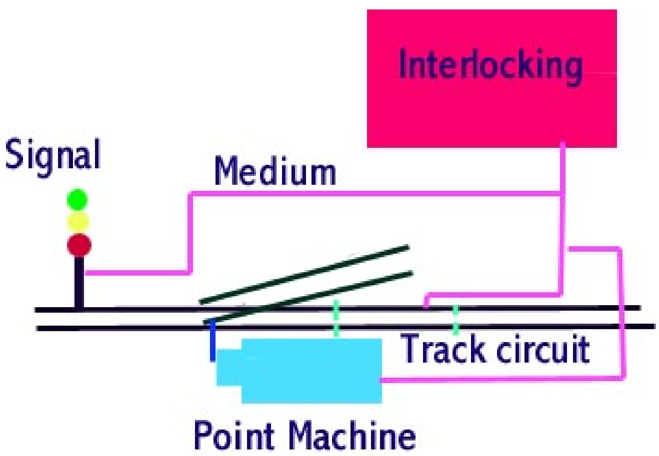


Figure 3.1: Platform checking [41]

3.1.2 Point Setting

When a signal is received, then respective point should be set. For setting the point, a stepper motor should be commissioned to control the point machine. An inductive sensor be placed on the rail. This inductive sensor would detect the movement of rail and ensure that point(switch) blades have been set properly. Capacitive sensor can also be used for the same purpose as it would measure the density of dielectric (air) between the stock rail and switch blades.

$$C \propto 1/d \tag{3.1}$$

Capacitance varies if the distance varies. Resultantly, capacitive sensor

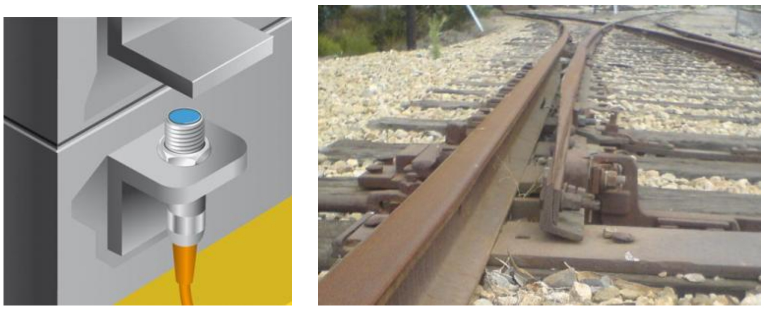


Figure 3.2: Detection of point setting by inductive sensor [31][36]

generates a signal for the actuation of another event which is to lock the points so that point blades remain stick to required position and train moves safely towards respective platform. Locking is a foremost aspect because it provides additional safety.

3.1.3 Home Signal Status

when points are set and locked properly then the light of Home signal turns green which is a result of signal generated by the inductive

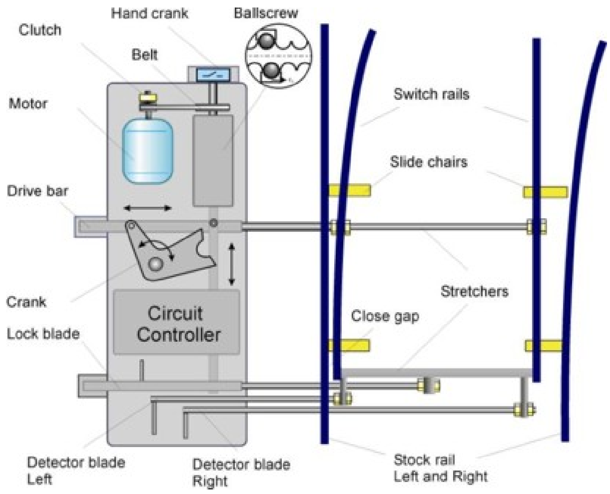


Figure 3.3: Point Machine setting [36]

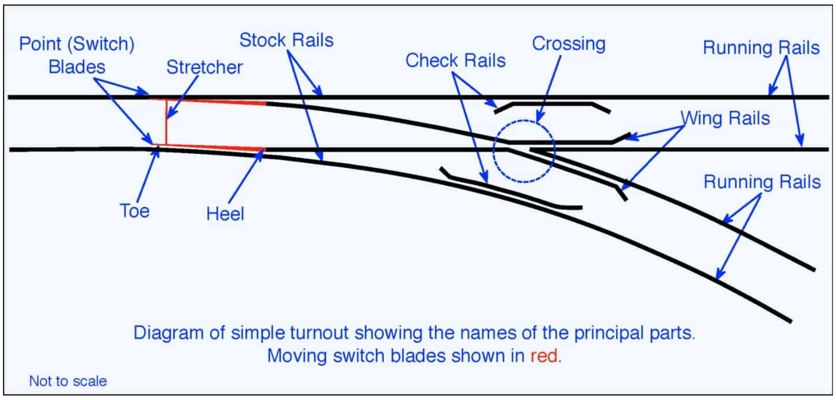


Figure 3.4: Railways Track [45]

sensor showing that points are locked properly. The Infra Red light sensor should be installed near the light signal to detect the status of traffic light whether it has turned ON or not. Besides this an inductive sensor be placed to detect the presence and movement of the semaphore arm signal.

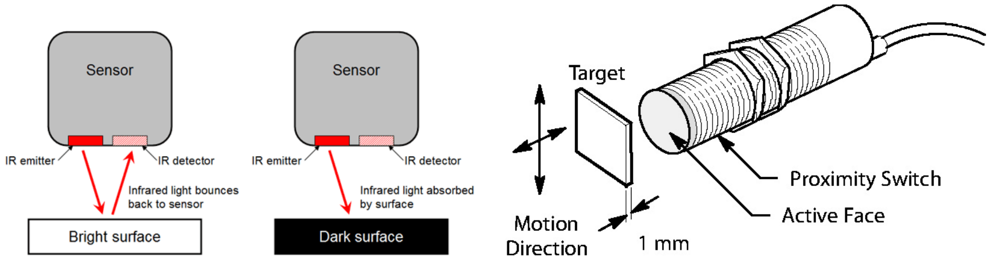


Figure 3.5: Sensors for Home signal detection [31]

3.1.4 Outer Signal Status

After turning ON the home signal of respective platform, outer signal gets turned ON. As earlier stated about the Infra Red light sensor and inductive sensor can be used for checking the status of the outer signal. The outer signal status changes based on the status of Home signal. When the home signal is turned ON then outer signal turns ON as well. When Outer signal is tuned ON, it means that all the previous events have happened in a predetermined order, that is, points are set and locked, home signal is ON and train driver deems that it is safe to proceed. Subsequently, train moves towards respective platform.

3.1.5 Train received at Platform

When the train is received at the platform, the respective track circuit turn RED, that means platform is occupied. This generated signal is supplied to outer signal to turn it OFF. the signal generated from outer signal is provided to Home signal to turn it RED. Subsequently, a signal generated by the Infra red light sensor is provided to unlock the points. After unlocking the points, a signal is generated by the inductive sensor. This signal is supplied to the stepper motor to reset the points.

3.1.6 Train Leaving the Station

Similarly, when the train leaves the station, a series of events happens to set the route and to give permission to proceed.

- Driver clicks the move button mentioned in the touch panel installed near the driver cabin at platform
- Generated signal is provided to the inductive switch room at station.
- The signal generated from the switch room is goes to stepper motor to set the points.
- Capacitive sensor shows the status of switch blades are set or not. If the points are set then a signal is generated to lock the points to ensure safety.
- Inductive sensor shows the status if locking the points. When the points are locked properly, then inductive sensor send a signal to Advanced Starter signal
- When Advanced starter signal receives this signal then it turn ON and semaphore arm signal moves to proceed position
- Infra red light sensor and inductive sensor send a signal to Starter signal to turn ON
- When driver observes Starter signal ON, then train proceeds
- When train passes the Advanced starter signal, then it turns OFF
- inductive sensor and IR light sensor send the signal to Starter signal which then turns OFF

- A signal from IR light sensor is sent to point machine to unlock the points
- When points are unlocked then a signal generated by inductive sensor is sent to stepper motor to reset the points

In this way, a supervisory control can be made for both the trains coming into yard and leaving the yard.

3.2 Test Scenarios

In this section, multiple scenarios of railway signalling are taken as examples. Asynchronous discrete event system automaton for each case is designed here. Subsequently, supervisory control scheme for these test scenarios has been designed. It is important to ***note*** here that these automata are asynchronous DES automaton so the time complexity is constant time because the algorithm performs one operation at a time. The test scenarios are discussed as follows:

3.2.1 Test Scenario 1: Train moving in Block section

Actually in Pakistan, there is single track of railways which is used for all types of trains such as freight trains, passenger trains including local and non-stop trains. Due to this complex situations, many train collisions have been witnessed in the past; in which a train coming after the other had collided with the train ahead. To minimize these types of collisions and to enlighten the train drivers about the occupancy status of block section ahead, a sample railways block section is modeled. Here the block section is divided into slots which are connected with track circuit relays. The track circuit relay apprises the presence of a train in a slot. Each slot is provided with a light signal having red, green and yellow lights. For instance, when the train occupies slot 2, the signal of slot 2 turns red; and based on the status of slot 2 signal, the status of signal of slot 1 turn yellow. Similarly when train occupies slot 3, then status of slot 3 signal turns red; and based on such status the signal of slot 2 turns yellow and signal of slot 1 turns green.

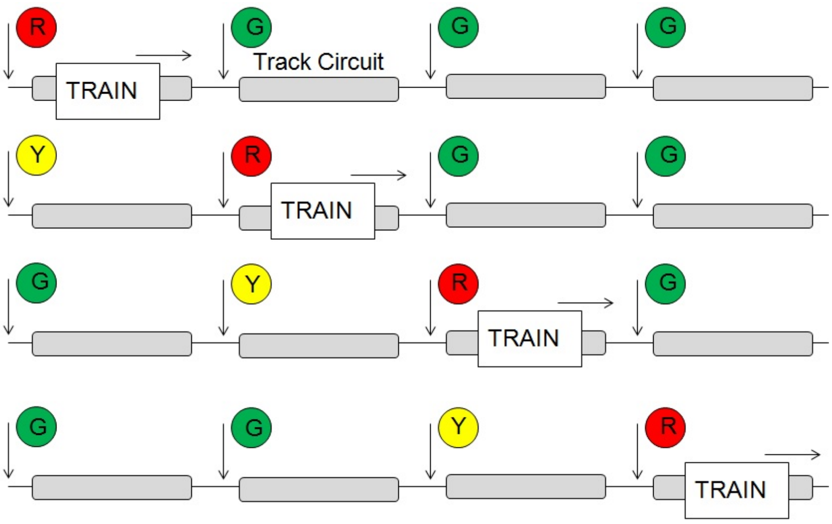


Figure 3.6: Model Block Section

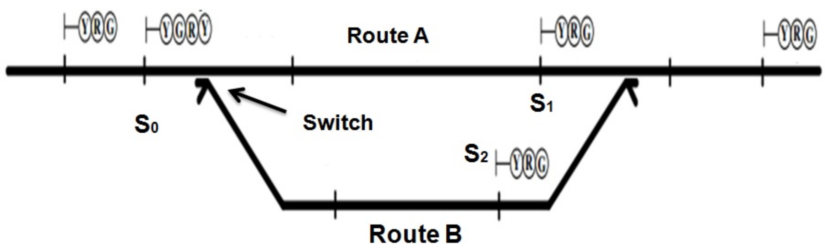


Figure 3.7: Model Railways yard

In figure 3.7, there are two routes viz. route A and route B, Switch has two positions viz. normal and reverse, Signal S_0 contains four lights viz. two yellow, one red and one green, and signals S_1 and S_2 have three lights viz. yellow, green and red. In this scenario, Discrete event systems and the supervisory control theory is applied for signal lights, switch and route selection. This model can be converted to a PLC code. This approach allows to reach safe states and human errors can be eliminated.

Bold and overlined letters in the following vectors show the current status of the signals. If route A is selected, the switch is in normal position

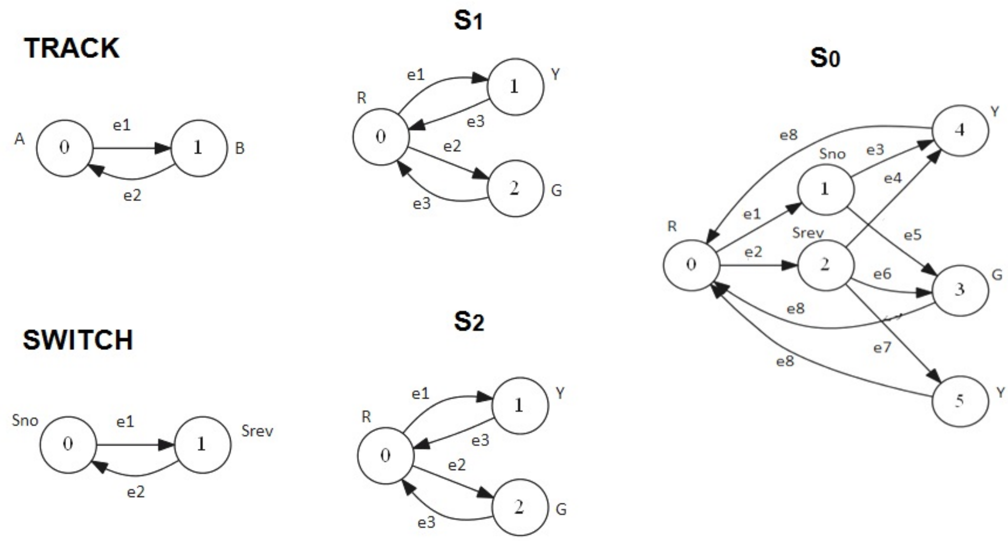


Figure 3.8: Discrete Event System model

and the signals S_0 and S_1 have different status due to moving train. If train is in slot of signal S_1 then the signal S_1 turns red and accordingly signal S_0 turns yellow. When train moves ahead and the status of signal S_1 changes from red to yellow and subsequently green then signal S_0 turns green.

Table 3.1: Selecting route and signal status

Route	**Switch**	**Signal S_0**	**Signal S_1**	**Signal S_2**
A	Normal	Yellow	Red	
		Green	Yellow or Green	
B	Reverse	Yellow-Yellow		Red
		Yellow-Green		Yellow or Green

$$Route = \begin{bmatrix} \overline{\mathbf{A}} \\ B \end{bmatrix} \qquad Switch = \begin{bmatrix} \overline{\mathbf{0}} \\ 1 \end{bmatrix} \qquad S_0 = \begin{bmatrix} \overline{\mathbf{Y}} \\ R \\ G \\ Y \end{bmatrix} \qquad S_1 = \begin{bmatrix} \overline{\mathbf{R}} \\ G \\ Y \end{bmatrix}$$

$$S_0 = \begin{bmatrix} Y \\ R \\ \overline{\mathbf{G}} \\ Y \end{bmatrix} \qquad S_1 = \begin{bmatrix} R \\ G \\ \overline{\mathbf{Y}} \end{bmatrix}$$

$$S_0 = \begin{bmatrix} Y \\ R \\ \overline{\mathbf{G}} \\ Y \end{bmatrix} \qquad S_1 = \begin{bmatrix} R \\ \overline{\mathbf{G}} \\ Y \end{bmatrix}$$

$$Route = \begin{bmatrix} A \\ \overline{\mathbf{B}} \end{bmatrix} \qquad Switch = \begin{bmatrix} 0 \\ \overline{\mathbf{1}} \end{bmatrix} \qquad S_0 = \begin{bmatrix} \overline{\mathbf{Y}} \\ R \\ G \\ \overline{\mathbf{Y}} \end{bmatrix} \qquad S_2 = \begin{bmatrix} \overline{\mathbf{R}} \\ G \\ Y \end{bmatrix}$$

$$S_0 = \begin{bmatrix} Y \\ R \\ \overline{\mathbf{G}} \\ \overline{\mathbf{Y}} \end{bmatrix} \qquad S_2 = \begin{bmatrix} R \\ G \\ \overline{\mathbf{Y}} \end{bmatrix}$$

$$S_0 = \begin{bmatrix} Y \\ R \\ \overline{\mathbf{G}} \\ \overline{\mathbf{Y}} \end{bmatrix} \qquad S_2 = \begin{bmatrix} R \\ \overline{\mathbf{G}} \\ Y \end{bmatrix}$$

If route B is selected, the switch is in reverse position and the signals S_0 and S_2 have different status due to moving train. If train is in slot of signal S_2 then the signal S_2 turns red and accordingly signal S_0 turns to yellow and yellow. When train moves ahead and the status of signal S_2 changes from red to yellow and subsequently green then signal S_0 turns to yellow and green. Note that, here a Yellow signal indicates that train has to move via loop line. This additional yellow signal is for the information of train driver.

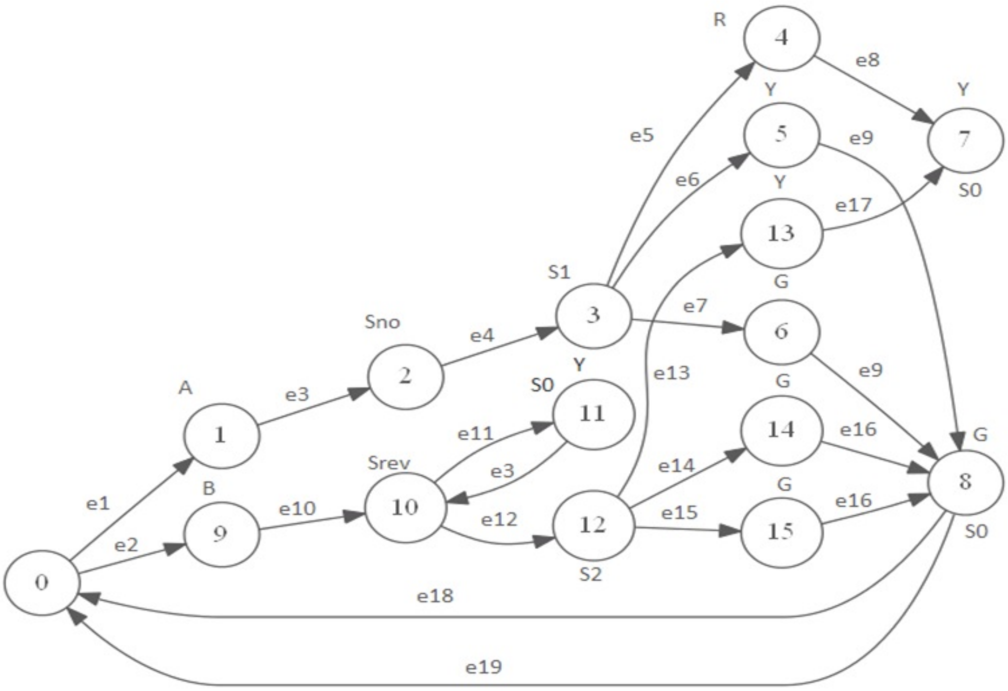


Figure 3.9: Supervisory control for problem in section 3.2.1

3.2.2 Test Scenario 02 : Train Arrival

In this example, train approaches the platform for which a number of events are to be performed in a defined series which is deemed as language. Fig 3.7 depicts the events to be actuated for the train approaching the platform and following flow chart shows the requirements to be met to achieve the successful operation.

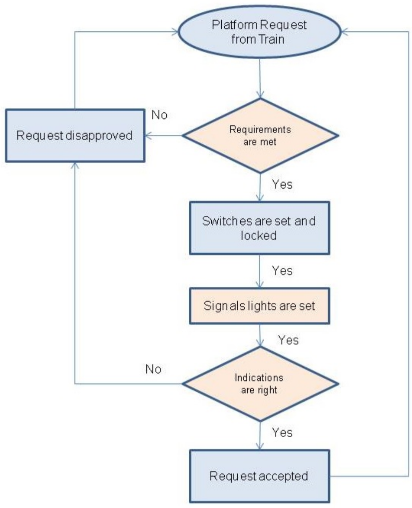


Figure 3.10: Flow Chart for Train arrival and departure

The following figure shows the series of events relating to train arrival operation and the description of these events is given in the subsequent table 3.1. The events are generated depending upon the occupancy of platform. If one platform is occupied, then second platform is selected. Similarly, this program may run for multiple platforms where train may stop.

$$Platform\ status = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \Rightarrow \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \Rightarrow \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} \Rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

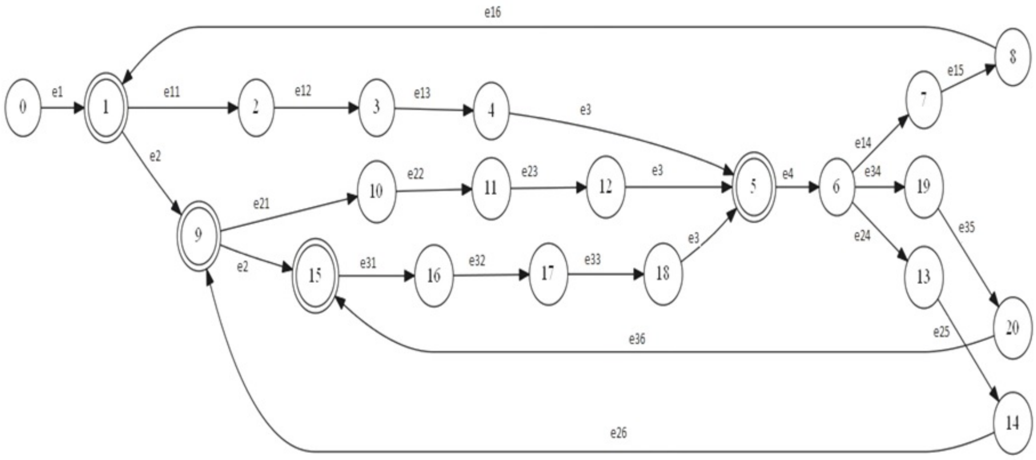


Figure 3.11: Train arrival events

$$0 \Rightarrow \ platform \ is \ unoccupied$$

$$1 \Rightarrow \ platform \ is \ occupied$$

$$X = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20\}$$

$$E = \{e1, e2, e3, e4, e11, e12, e13, e14, e15, e16, e21, e22, e23, e24,$$
$$e25, e26, e31, e32, e33, e34, e35, e36\}$$

$$X_0 = \{0\}$$

$$X_m = \{5, 10, 15\}$$

$$L_{m1}(G) = \{e1, e11, e12, e13, e3, e4, e14, e15, e16\}$$

$$L_{m2}(G) = \{e1, e2, e21, e22, e23, e3, e4, e24, e25, e26\}$$

$$L_{m3}(G) = \{e1, e2, e31, e32, e33, e3, e4, e34, e35, e36\}$$

Event	**Meaning**
e1	Check the platform occupancy
e2	Check other platform
e11, e21, e31	Set the rail points of empty platform
e12, e22, e32	Lock the rail points
e13, e23, e33	Turn Home signal green
e3	Turn Outer signal green
e4	Turn Outer signal Red
e14, e24, e34	Turn Home signal Red
e15, e25, e35	Unlock the rail points
e16, e26, e36	Reset the rail points

Table 3.2: Description of Train arrival events

3.2.3 Test Scenario 03 : Train Departure

In this example, a number of trains are at multiple platforms. Now if any train needs to leave the station, then events are generated to check the block section occupancy and to set the signalling and interlocking events. If block section is occupied, then train driver has to wait till it is clear. Once the block section is clear, then rail points, starter signal and advanced starter signal are set accordingly.

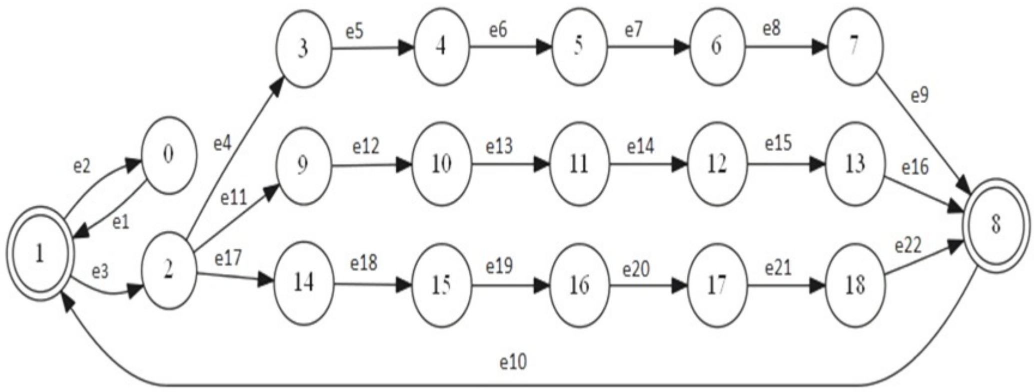


Figure 3.12: Train departure events

$$X = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18\}$$

$$E = \{e1, e2, e3, e4, e5, e6, e7, e8, e9, e10, e11, e12, e13,$$
$$e14, e15, e16, e17, e18, e19, e20, e21, e22\}$$

$$X_0 = \{0\}$$

$$X_m = \{1, 8\}$$

$$L_{m1}(G) = \{e1, e3, e4, e5, e6, e7, e8, e9, e10, e2\}$$

$$L_{m2}(G) = \{e1, e3, e11, e12, e13, e14, e15, e16, e10, e2\}$$

$$L_{m3}(G) = \{e1, e3, e17, e18, e19, e20, e21, e22, e10, e2\}$$

Event	**Meaning**
e1	ready to depart
e2	block section occupied
e3	advanced starter signal green
e4, e11, e17	set points
e5, e12, e18	lock points
e6, e13, e19	starter signal green
e7, e14, e20	starter signal red
e8, e15, e21	unlock points
e9, e16, e22	reset points
e10	advanced starter signal red

Table 3.3: Description of Train departure Events

3.2.4 Test Scenario 04 : Level Crossing Gate

In this scenario, level crossing gate is depicted. There are many level crossing gates across the rail track. It is foremost important to manage the level crossing gates. Because many accidents have been witnessed in Pakistan while crossing these gates. In this example, if train approaches the level crossing gate, then it is closed so as to halt the movement of any human being or vehicle. Once the train passes away, then the gate is opened for movement of humans and vehicles.

$$X = \{0, 1, 2, 3, 4\}$$

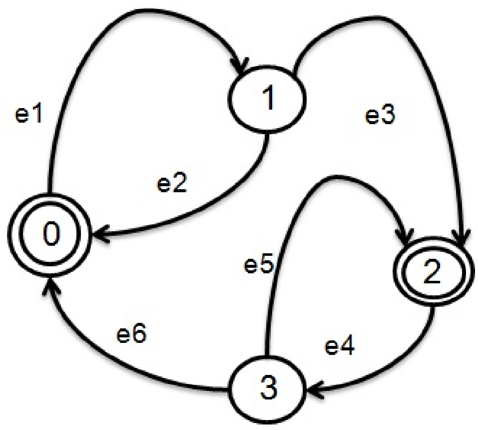


Figure 3.13: Level crossing gate

$$E = \{e1, e2, e3, e4, e5, e6\}$$

$$X_0 = \{0\}$$

$$X_m = \{0, 2\}$$

$$L_{m1}(G) = \{e1, e3\}$$

$$L_{m2}(G) = \{e4, e6\}$$

Event	**Meaning**
e1	Request to close gate
e2	Timer Expired
e3	Indication of closed gate
e4	Request to open gate
e5	Timer Expired
e6	Indication of open gate

Table 3.4: Description of Events of level crossing gate

3.2.5 Test Scenario 05: Shunting Movement

This scenario is witnessed within the railway yard. In this example, some coaches are either attached to or detached from train. Suppose, there is a train moving from Islamabad to Karachi via Lahore and additional coaches are to be attached to the train at Lahore station. Thus, when train reaches Lahore, engine of train is detached and sent to a track, additional coaches are attached and the engine attached with additional coaches is detached and moves back, then main engine is attached attached with train. Subsequently, the route of train is set and train moves ahead leaving the station.

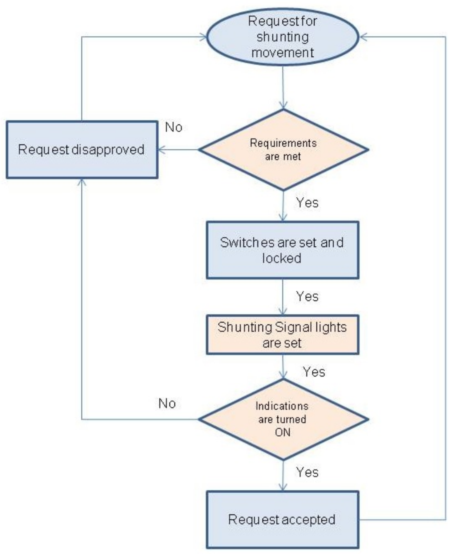


Figure 3.14: Flow Chart for shunting movement inside yard

Above flow chart manifests actions to be taken to meet the requirement for shunting movement. If the requirements are fulfilled then shunting movement is performed accordingly. During the LLD code for shunting movement, a problem of avalanche effect is experienced. To overcome the avalanche effect, a strategy has been devised and discussed in simulation section of this chapter.

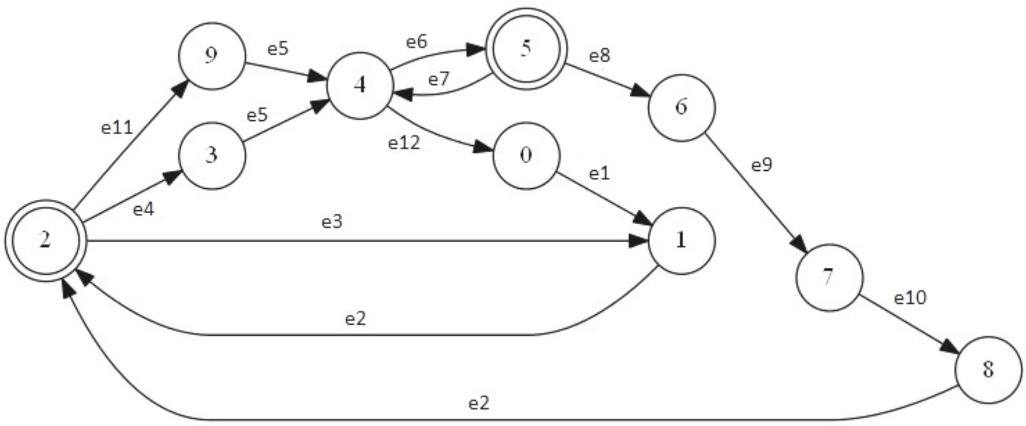


Figure 3.15: Shunting movement events

$$X = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$$

$$E = \{e1, e2, e3, e4, e5, e6, e7, e8, e9, e10, e11, e12\}$$

$$X_0 = \{0\}$$

$$X_m = \{2, 5\}$$

$$L_{m1}(G) = \{e1, e2, e4, e5, e6, e8, e9, e10, e2, e11, e12\}$$

Event	**Meaning**
e1	Track occupied
e2	set points 1
e3	timer 1 expires
e4	detach engine 1
e5	reset points 1
e6	set points 2
e7	timer 2 expires
e8	attach coaches
e9	detach engine 2
e10	reset points 2
e11	attach engine 1
e12	set route

Table 3.5: Description of shunting movement events

3.3 Simulations

In this section, algorithm for signalling and interlocking in Pakistan Railways is created. And the same algorithm is implemented with the help of Ladder Logic in Siemens PLC-300. Graphical representation of occurrence of events for signalling and interlocking is made with the help of TCT software. While writing LLD code for Railway signalling system, a problem of avalanche effect emerged. Let us discuss said problem and its solution so as to implement LLD code on Siemens PLC S7-300.

3.3.1 Avalanche effect

avalanche effect is observed when two or more number of same events appears in a dynamic system. While writing LLD code for such a system a problem emerges that during a PLC scan cycle, the system skips initial states which are actuated due to the occurrence of same event. Following figure 3.6 depicts the problem stated here. In this figure 3.6, four states are actuated with the occurrence of two events $\{a, b\}$. When event a occurs first time, then there is transition from state 0 to state 1. With the second time occurrence of event a, there is transition from state 1 to state 2. Now at state 2 with the occurrence of event a system would revert to state 1 but for event b system would enter state 3.

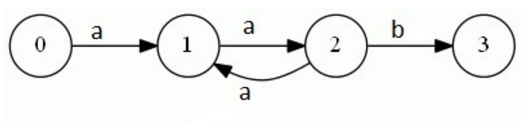
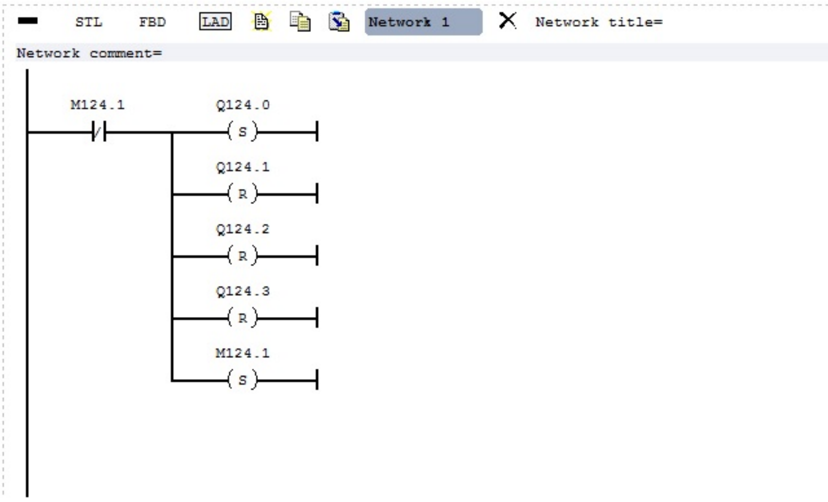
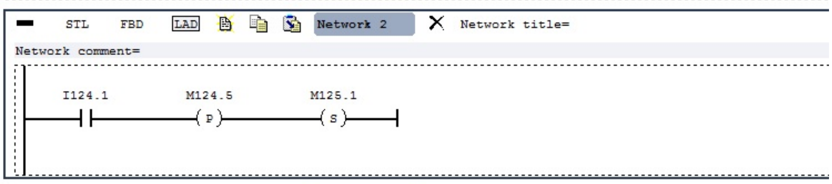
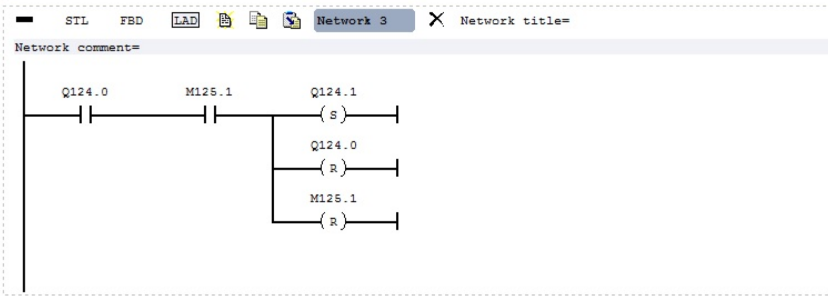


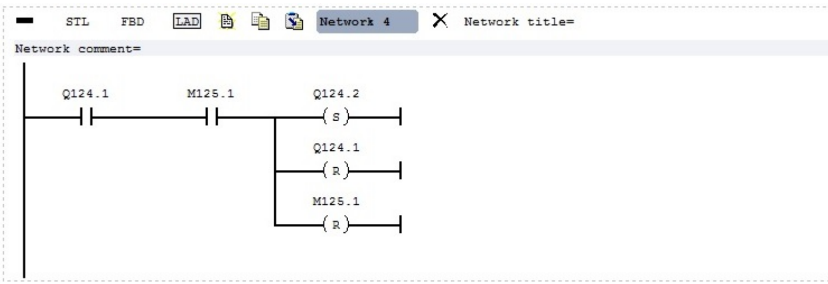
Figure 3.16: Avalanche Effect

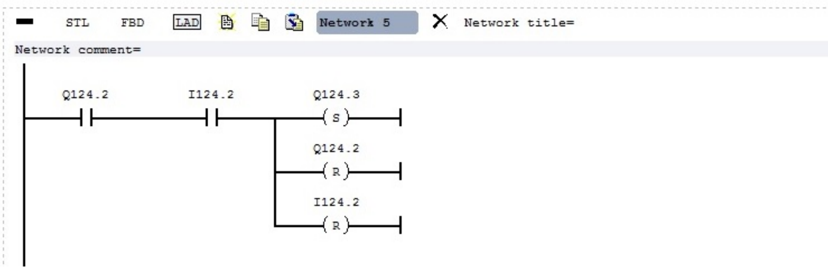
Ladder Logic code for the problem depicted in fig 3.6 is given as follows:

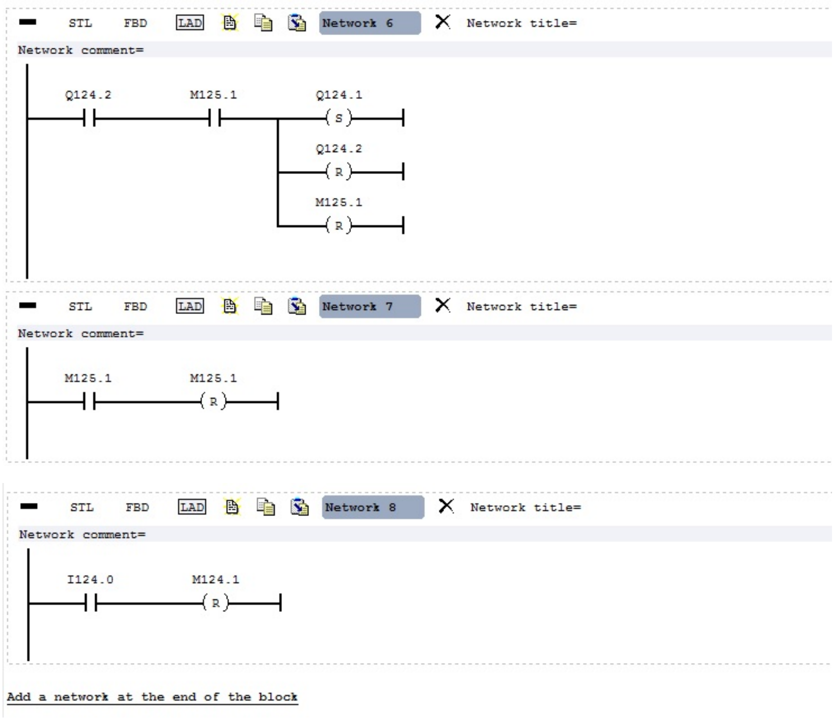

STL FBD LAD Network 1 Network title=
Network comment=
M124.1
Q124.0
S
Q124.1
R
Q124.2
R
Q124.3
R
M124.1
S


STL FBD LAD Network 2 Network title=
Network comment=
I124.1
M124.5
P
M125.1
S


STL FBD LAD Network 3 Network title=
Network comment=
Q124.0
M125.1
Q124.1
S
Q124.0
R
M125.1
R


STL FBD LAD Network 4 Network title=
Network comment=
Q124.1
M125.1
Q124.2
S
Q124.1
R
M125.1
R


STL FBD LAD Network 5 Network title=
Network comment=
Q124.2
I124.2
Q124.3
S
Q124.2
R
I124.2
R


STL FBD LAD Network 6 Network title=
Network comment=
Q124.2
M125.1
Q124.1
S
Q124.2
R
M125.1
R
STL FBD LAD Network 7 Network title=
Network comment=
M125.1
M125.1
R
STL FBD LAD Network 8 Network title=
Network comment=
I124.0
M124.1
R
Add a network at the end of the block

3.3.2 PLC Simulation of Train Shunting movement

As it is discussed at length that the step by step operation of signalling and interlocking can be deemed as DES model. TCT software is used for the verification of deterministic and nondeterministic DES model. TCT software also produces the graphical representation of DES model. Following is the graphical representation of signalling and interlocking for train shunting movement. Following figure displays a series of various events which take place in order to guide the trains to achieve the successful arrival and departure of trains.

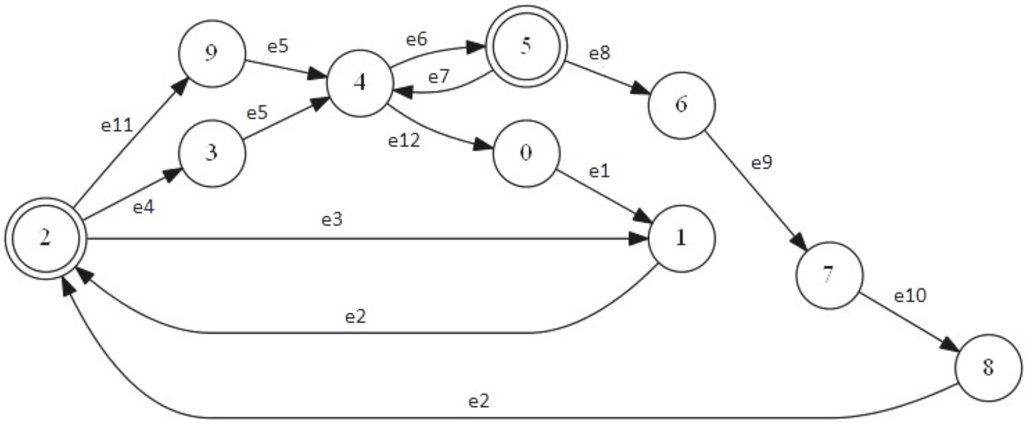


Figure 3.17: Railways signalling events

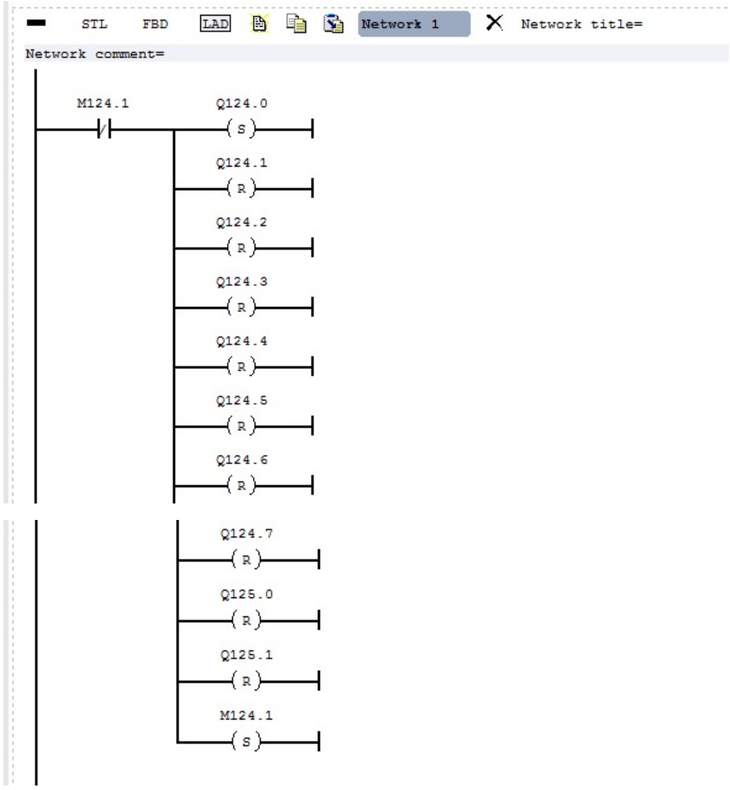
For the ease of understanding and writing ladder logic code of railway signalling and interlocking, the above fig 3.13 is further elaborated in following mentioned tables. These tables show the details of total number of states, events actuating the transition between states and memory bits assigned to states and events which are inputs and outputs of PLC Siemens-300. These memory bit addresses are assigned carefully because an error can result in mishap. This LLD code has been checked and verified.

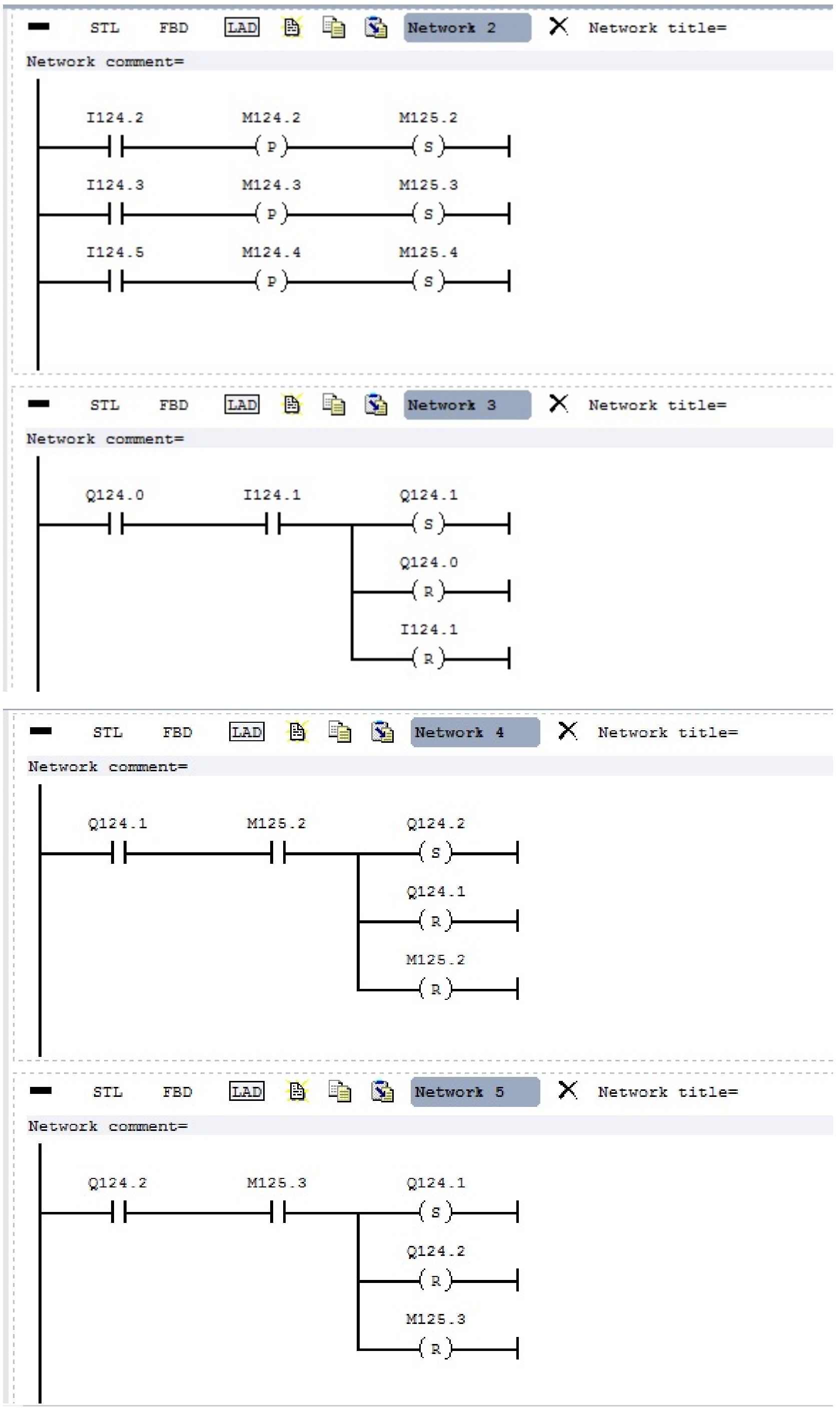
Table 3.6: Allocating PLC memory bits to states and events of shunting movement

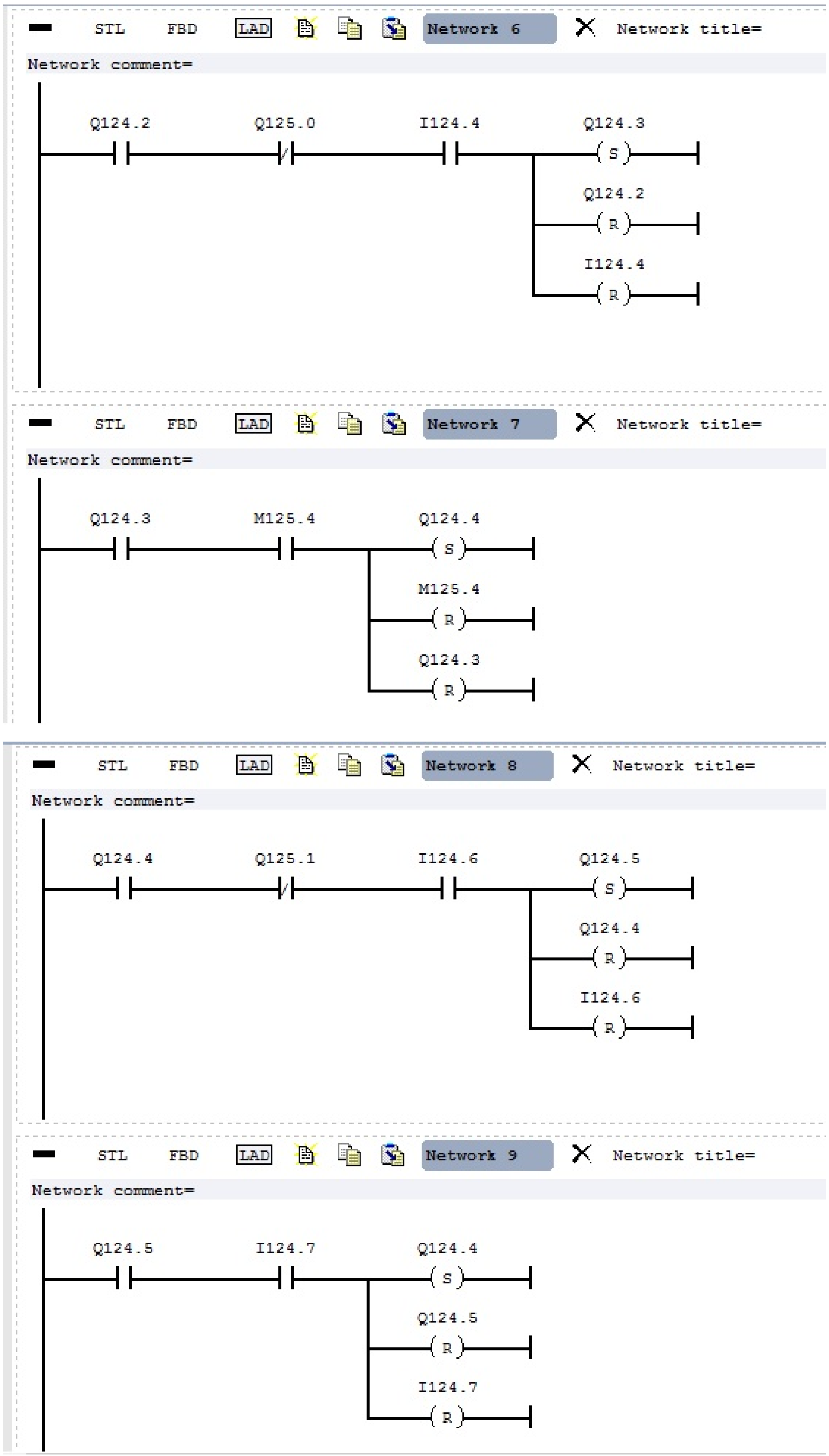
State No.	**PLC Memory Bit**	**Event**	**PLC Memory Bit**
0	Q124.0	e1	I124.1
1	Q124.1	e2	M125.2
2	Q124.2	e3	M125.3
3	Q124.3	e4	I124.4
4	Q124.4	e5	M125.4
5	Q124.5	e6	I124.6
6	Q124.6	e7	I124.7
7	Q124.7	e8	I125.0
8	Q125.0	e9	I125.1
9	Q125.1	e10	I125.2
		e11	I125.3
		e12	I125.4

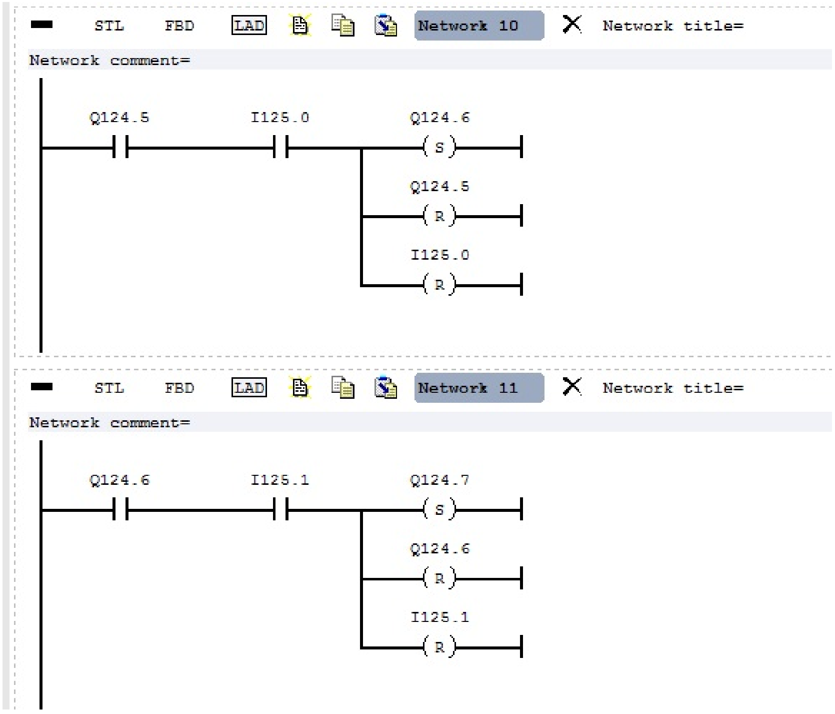
Ladder Logic Code for Train shunting movement

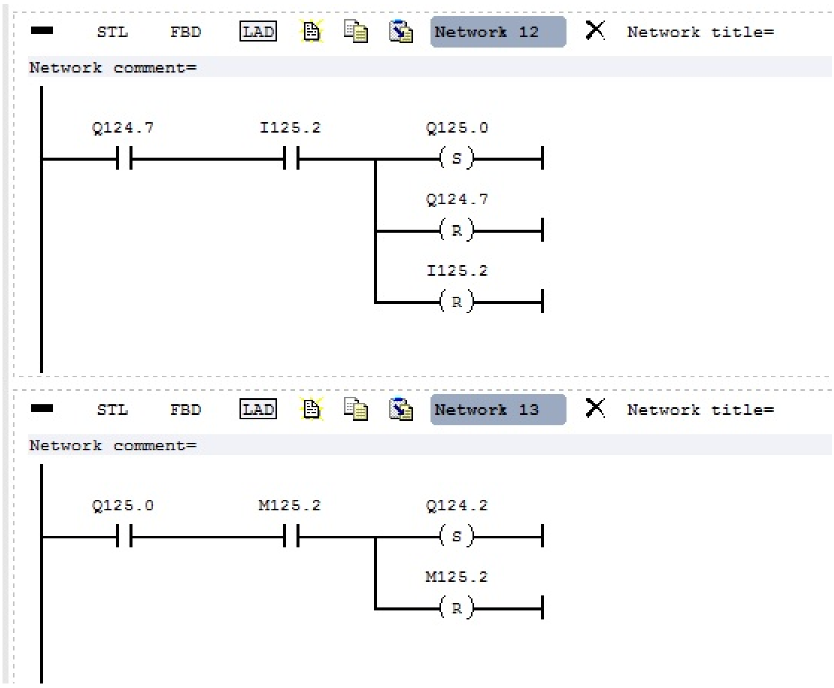
Ladder logic code for the above discussed supervisory control for signalling and interlocking of Pakistan Railways is written and verified with the help of Siemens PLC-300. The LLD code for proposed supervisory control is as follows:

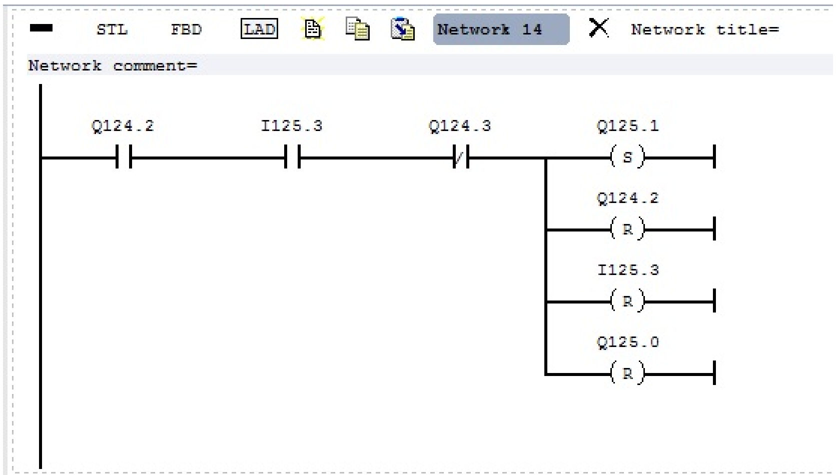


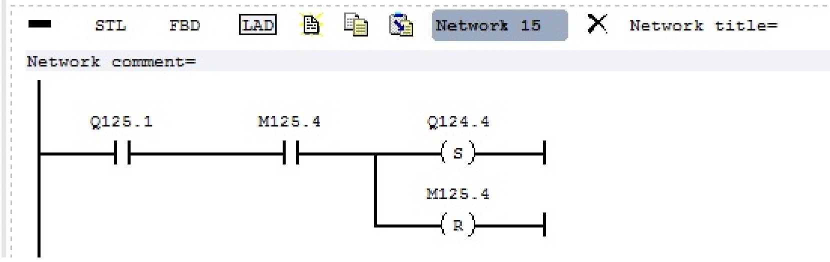

STL FBD LAD Network 2 Network title=
Network comment=
I124.2 M124.2 M125.2
P S
I124.3 M124.3 M125.3
P S
I124.5 M124.4 M125.4
P S
STL FBD LAD Network 3 Network title=
Network comment=
Q124.0 I124.1 Q124.1
S
Q124.0
R
I124.1
R
STL FBD LAD Network 4 Network title=
Network comment=
Q124.1 M125.2 Q124.2
S
Q124.1
R
M125.2
R
STL FBD LAD Network 5 Network title=
Network comment=
Q124.2 M125.3 Q124.1
S
Q124.2
R
M125.3
R

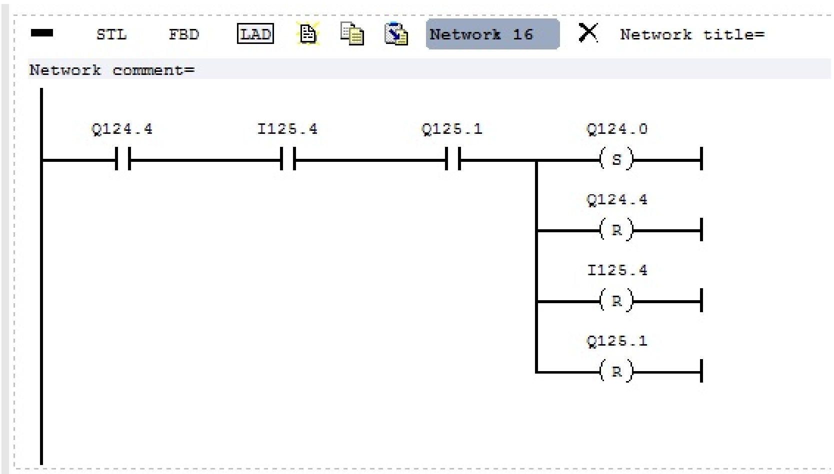

STL FBD LAD Network 6 Network title=
Network comment=
Q124.2
Q125.0
I124.4
Q124.3
S
Q124.2
R
I124.4
R
STL FBD LAD Network 7 Network title=
Network comment=
Q124.3
M125.4
Q124.4
S
M125.4
R
Q124.3
R
STL FBD LAD Network 8 Network title=
Network comment=
Q124.4
Q125.1
I124.6
Q124.5
S
Q124.4
R
I124.6
R
STL FBD LAD Network 9 Network title=
Network comment=
Q124.5
I124.7
Q124.4
S
Q124.5
R
I124.7
R

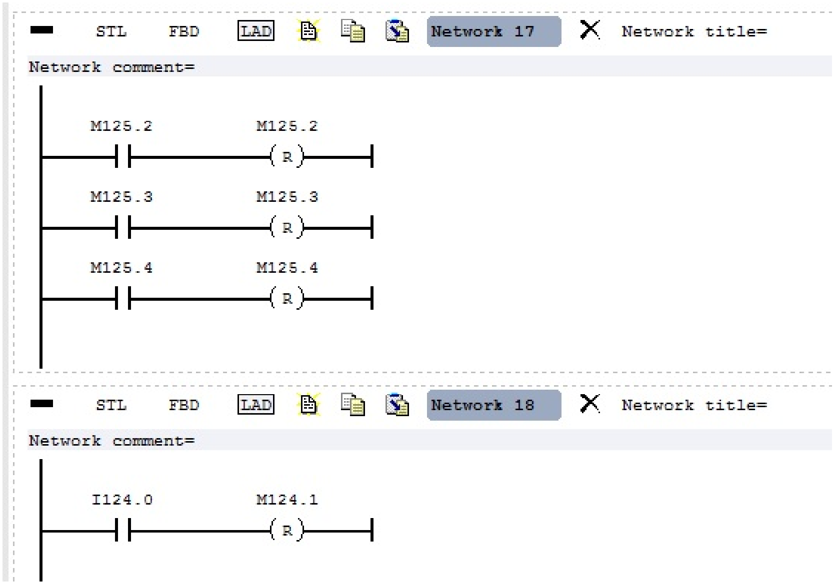

STL FBD LAD Network 10 Network title=
Network comment=
Q124.5
I125.0
Q124.6
S
Q124.5
R
I125.0
R
STL FBD LAD Network 11 Network title=
Network comment=
Q124.6
I125.1
Q124.7
S
Q124.6
R
I125.1
R


STL FBD LAD Network 12 Network title=
Network comment=
Q124.7
I125.2
Q125.0
S
Q124.7
R
I125.2
R
STL FBD LAD Network 13 Network title=
Network comment=
Q125.0
M125.2
Q124.2
S
M125.2
R


STL FBD LAD
Network 14
Network title=
Network comment=
Q124.2
I125.3
Q124.3
Q125.1
S
Q124.2
R
I125.3
R
Q125.0
R


STL FBD LAD
Network 15
Network title=
Network comment=
Q125.1
M125.4
Q124.4
S
M125.4
R


STL FBD LAD
Network 16
Network title=
Network comment=
Q124.4
I125.4
Q125.1
Q124.0
S
Q124.4
R
I125.4
R
Q125.1
R


STL
FBD
LAD
Network 17
Network title=
Network comment=
M125.2
M125.2
R
M125.3
M125.3
R
M125.4
M125.4
R
STL
FBD
LAD
Network 18
Network title=
Network comment=
I124.0
M124.1
R

Chapter 4

Conclusion and Future Work

4.1 Conclusion

In conclusion, at this time where technology has advanced at its horizon, Pakistan Railways must upgrade itself from conventional system to most modern system by taking advantage of modern technology. This thesis work has enlightened about the transformation of prevalent signalling and interlocking mechanism of Pakistan Railways to modern signalling and interlocking mechanism by designing asynchronous discrete event system automaton and adopting the supervisory control methodology for the dynamic systems. For this purpose, it is also needed to upgrade the infrastructure with the help of some actuators and sensors, as stated in chapter 3, which transmit and receive the the data to and from the central location with the help of hard wire connections. In this manner, a deterministic automaton for the Pakistan Railways signalling can be achieved successfully. By adopting supervisory control technology, number of collisions and accidents between trains cab be minimized, human involvement reduces, efficiency increases and lives of passengers become more safe and secure.

4.2 Future Work

In this research work, PLC algorithm is proposed. In future an effort be made to implement this PLC algorithm on a prototype of railway systems. If the real implemented system arrangement is complex, then the circuit diagram and system block will be different but the main concept would remain the same. Moreover, in this thesis the data transmission is supposed to be carried via hard wire connections which, in future, can be replaced with the Wireless Sensor Network (WSN) technology. The reliability of WSN technology is far better than that of hard wire connections. In case of WSN, all the sensors would transmit the data to a central location which would have control over the happening of events. A research be made in this area to have detailed knowledge by studying wireless sensor network to dig out the feasibility and required equipment for having improved signalling and interlocking in Pakistan Railways.

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