SMART AND ADAPTIVE TRAFFIC LIGHT SYSTEM

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ABSTRACT

Traffic congestion is still a substantial issue among both developed and developing countries. With the strong development of science and technology, scientific and technical achievements are applied through various means in life. A traffic light system is one of those significant achievements. It is a system of signaling lights to guide vehicles and people in traffic at the nodes. Through means of research of the similar categories for this project, adaptive traffic lights are known to be established to give citizens a huge advantage in allowing them free time in traffic, which is distinctly important in our ever changing and technologically advanced age. The goals of this thesis were to deepen the understanding of smart traffic automation principle to optimize the current traffic system through researching and programming, with a chance of implementing the results for future applications.

To analyze the hypothesis that an adaptive system prompts a smooth and effortless traffic flow, a program in TIA Portal was designed to reproduce the traffic flow of an intersection through virtual inputs with arrays of functions ranging from normal and busy traffic to priority pass for emergency vehicles.

The results through the research and programming with TIA Portal processes illustrate better knowledge and view about adaptive traffic lights with the research about the subject and also a functioning simulation of an intersection that works in multiple settings of traffic which could be used as reference for HAMK campuses.

Keywords Adaptive, automation, simulation, smart, traffic light system

Pages 34 pages including appendices 41 pages

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1 INTRODUCTION

The urbanization of cities around the world brings many conveniences and assets to the daily life of residents, but the damages are also significantly concerning. One of the impacts easily detected is the traffic congestion affecting our everyday activities. Traffic congestion comes with other problems that people must deal with, such as fuel burn, time wastage, exhaust fume, etc. which directly hit the costs of residents overall through the measurements (Schrank, Lomax, & Eisele, 2011). It is likewise reducing the mobility of vehicle users.

From available traffic delay measurements, and even impressionistic evidence, in almost every major city in developing and developed countries, congestion increasingly impedes personal vehicle user's mobility. Mobility decreases even more for the public transport user. This is largely because transportation routes can generally coincide with the highest-flow arteries, those most afflicted by congestion. Furthermore, the public transport networks are mostly radial, and do not allow avoiding congestion when crossing the city. Finally, public transport users cannot follow travel destinations that are outside the most highly accessible locations on the periphery because the public transport system does not provide the specific service. The traffic signal system can very much affect the outcome of traffic jams too. With the currently active fixed time traffic signals, the traffic patterns can get stuck certainly in busy hours or events. Adaptive traffic control represents a clear edge over the conventional one and looks to be the next promising solution to the congestion problem (Cai, et al., 2009).

It is very important to ensure traffic in urban areas, especially at intersections. To make traveling at intersections smooth and convenient, we can rely on the help of the Traffic Police Department and other forces. However, with large cities and many intersections, it is difficult to have enough forces to undertake this work. On the other hand, getting help from the traffic officers and other forces is at times situational and rather inconvenient. Therefore, the answer to the traffic problem is through technology, mainly the current automated traffic light system.

The purpose of this project was to examine various aspects about the possibilities that adaptive traffic can provide through research. In this sense, the problem of urban traffic congestion is highlighted and analyzed from the perspective of an outdated traffic light system. Moreover, to see the improvements that appear with the adaptive traffic light model program which can be applied for HAMK's school campuses.

The objectives of this thesis project were to explain and summarize the theoretical and practical parts of the smart traffic signals for an intersection. Furthermore, to explain the basics and requirements of smart traffic. Lastly, to visualize and simulate an x-crossing multilane with a programmable logic controller.

The aims and benefits of an adaptive traffic light system consist of matters being to reduce pollution caused by traffic jams, prioritize traffic in real-time scenarios, cut down on daily congestion by developing a better traffic flow, smooth out traffic experience and effectively reduce traffic accidents, etc. Overall, it can be said that the main objective is to assess the problems and solutions for the currently implemented intersection traffic system, further enhance the experience for drivers with automated smart traffic.

2 THEORETICAL BACKGROUND

2.1 Automation in traffic

2.1.1 Automation

Automation refers to the processes or procedures that do not require human assistance. The traffic control activities along the automation process are accomplished using sensors that provide primary traffic data and a programmed controller that determines the system output (Groover, 2000). The actuator that turns the lights on and off is controlled by a programmed controller.

Automation in various industries is accomplished using various tools that can control the process. They include Programmable logic controller (PLC): the idea was introduced in the 1970s as a solution to the challenges associated with electromechanical switches (Groover, 2000). Like the computer numerical control, programmable logic controllers utilize pre-programmed tasks fed into the memory of a microprocessor-based controller. Others are Computer numerical controllers (CNC), Supervisory control and data acquisition (SCADA), and Remote terminal unit (RTU). There are additional automation tools for various industries, but a PLC was the only one applied in this automated system.

2.1.2 Smart traffic system

A smart traffic light in the context of traffic management refers to an automated system that gives different traffic lights depending on the real-time road conditions using data from sensors located at various locations of the roads and adjacent intersections.

A smart traffic system is a traffic system that cohere other peripherals such as sensors, detectors, communicators, and such to conduct traffic flow where it is. The smart term means that the traffic signals can adapt and adjust to the current situations on the road through the equipped peripherals, then give out the proper response to the cases. Smart traffic lights curtail inefficient problems such as vehicles delay for a long time at an empty lane or traffic jams at busy hours of the day.

One of the outstanding advantages of the application of high technology in traffic management is that it can control and limit traffic congestion and accidents in urban areas. Through the sensor system installed on the road surface to collect information about traffic flow, climate, weather, etc. Through the computer system, the information will be analyzed and processed, information will then be provided to the participants Traffic on the road traffic situation information so that drivers can choose safe traffic routes.

2.2 **Conventional traffic system**

2.2.1 Current state of traffic system

Advances in computerization and control automation bring two developments in the traditional methods currently used. The first is related to the elaboration of a centralized computerized control system, in which a program directly controls the planning of traffic lights, by means of pre-programming, indicating at every moment what the luminous situation must occur. In the second, the sophistication of the traffic light automation method based on immediate and local information, based on ubiquitous computing principles, which corresponds to the control performed by the traffic, where if we measure the flow through detectors, it is possible to improve the performance and maintain the optimal programming, following the random and microscopic fluctuation of traffic, cycle by cycle.

Traffic lights with a fixed time do not have characteristics to meet the traffic variation that exists, they only have different timings depending on the time of day. The cycle is constant and the time for changing stages is fixed for each cycle. Controlling an intersection at a fixed time means determining the green, yellow, and red stages for each traffic stream, regardless of the varied volume of vehicles that approach the intersection. The duration time is calculated according to the characteristics and average volumes of traffic for a given period.

To understand how using adaptive traffic lights can aid congestion management it is important to first understand how congestion occurs on our roads. Congestion can be the result of an excess of the service capacity of the road, can also be the result of a spike in vehicles or a decrease in the throughput of the road due to an incident. Whatever the cause, once the media flow has reached saturation, congestion quickly develops. In addition, on a saturated road, a driver's sudden braking can cause a braking wave of the cars behind, creating a long delay. Accordingly, such a prolonged delay build-up will cause traffic stagnation. The current generations of traffic lights installed here cannot respond to the growing traffic demand. However, the help of smart traffic light control systems has formed part of an integrated approach to traffic management in many developed countries.

2.2.2 Phases of traditional traffic system

Traditional traffic system runs through phases to control the operation of the traffic, specifically the intersection here. The phases are determined by the directions of organized movements. The intersection in Figure 1 (Smith, Barlow, Xie, & Rubinstein, 2013) below shows how each phases work in order. All the phases run through a pre-programmed traffic logic which shares the time for all the lanes active. All the lights will stay on and off for a pre-determined cycle.

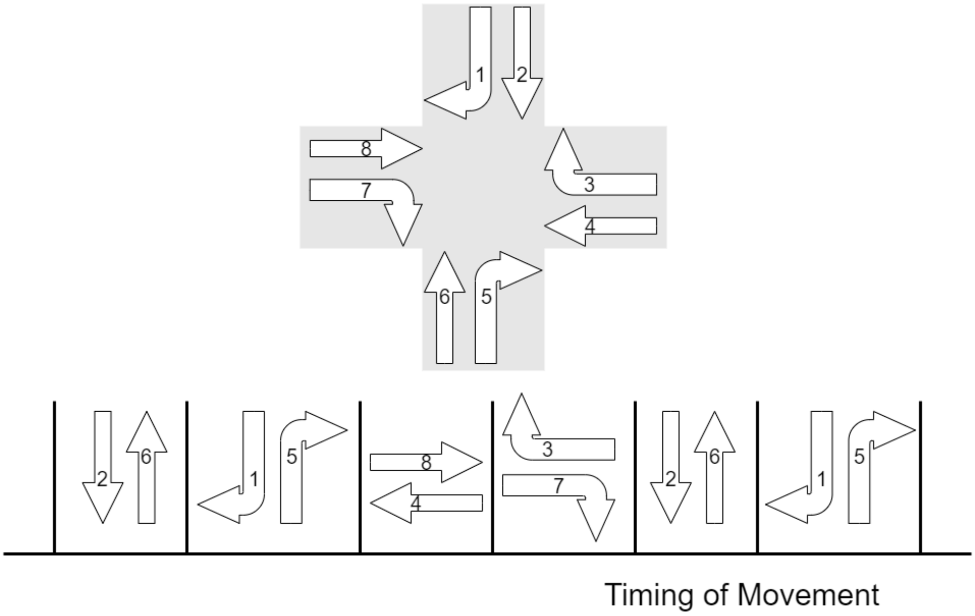


Figure 1 Timing plan of an intersection (Smith et al., 2013, p. 2)

The operation of traditional fixed-time traffic lights is not very efficient: In which the cycle, duration, and sequence of intervals are invariable and are defined by a program set in advance. Red light means the drivers stop regardless of what the situation is. Even if 20 cars are coming from one direction and none from the other, all 20 cars will have to stop and wait for it to turn green.

2.3 **Adaptive traffic system**

With the intelligent traffic control system, traffic lights are provided with information about the traffic volume of the surrounding area and can be changed in time accordingly to ensure that the most congested routes will be prioritize. The use of current information on traffic flow to control traffic lights at intersections provides a clear advantage over the fixed time cycle control, where the green light duration is pre-programmed depending on the flow of vehicles in particular directions. This ensures that when there is a spike in a direction of movement, the intelligent system disperses that traffic flow before the route becomes saturated. This new feature of the smart traffic light system helps to prevent the occurrence of congestion.

Intelligent traffic lights have been developed for more efficient urban area. The new technology works by means of sunlight and batteries, making it easier to use if the electricity is interrupted. Traffic light lights turn on and off as vehicles flow, thus reducing congestion in large cities.

Nearby traffic lights can also share traffic flow information, thus creating a balancing effect in regulating traffic flow over a larger area of the road network. One example is the Smart Traffic Control System based on the Split Cycle Offset Optimization Technique (SCOOT) (Robertson & Bretherton, 1991) developed by TRL and is now jointly owned by TRL, Peek Systems and Siemens Traffic Solution. SCOOT application has been gradually improved and added features such as bus flow priority; traffic lights have adequate timing to ensure that bus-covered roads have priority.

2.3.1 Operator-based traffic system

The operating plan is based on the schedule-driven traffic control system like Scalable Urban Traffic Control (SURTRAC) with a local scheduler, which also maintains a phased schedule, controls each intersection at the lowest level. As a result, there is a minimization of the vehicles traveling total delay through the intersection in question and making decisions continue to assist in updating the schedule depending on the dictates of the rolling horizon, to simply put, schedule with planning layers. As this continues, the intersection scheduler offers communication of outflow information as the current plan implies to its current neighbors. Consequently, the visibility of the incoming traffic is extended as well as the achievement of network-level coordination. The operator traffic system is in line with the schedule-driven one but with an operator as the brain of the whole system (Smith et al., 2013).

The system basically works like this: The flow of vehicles is detected few hundred meters before the traffic light, the moment the vehicle passes through the sensor the data is automatically sent to the controller, which in turn monitors the intervals that the traffic light must operate, aiming the best circulation, both for pedestrians and vehicles. Its main idea is the concept of interrupting as little as possible a main roads, depending on the demand on the secondary or pedestrian roads, generating better operational conditions on the road with the highest flow, especially in relation to the delay. In relation to the absence of traffic light control, the vehicular flow on the secondary road, or on the pedestrian crossing, gains greater security, since it does not have to be subject, at the entrance or crossing, to the existence of a gap in the main road.

Literally, the input of a schedule-driven traffic system is a representation of an ordered sequence of vehicle, departure and arrival time, which act as triples for each road segment approaching current projection as well as queued traffic sensed by the detectors of an intersection. The input is then aggregated into vehicle clusters sequence, which includes platoons and queues with respective arrival and departure times depending on relative vehicle proximity. The scheduling problem then helps in the construction of an optimal sequence of all jobs, interpreting each cluster as an input job. As a result, the development of optimal sequence helps in the preservation of ordering of the jobs along with each inflow, treating all jobs as non-preemptable. A given sequence dictates the order in which jobs pass through the intersection and eventually associated with an expected phase schedule. In addition, the given sequence clears the ordered jobs in the shortest time possible. This time available for clearance depends on the safety and basic timing constraints. All minimal delays for all vehicles are incurred by the optimal sequence (schedule) (Smith et al., 2013).

The schedule-driven traffic control works in a sequence of data communicated by the components. The concept of operation runs in the order of current traffic situation information pulled from the sensor’s data stream. Then the system computes phase schedule that optimizes flow at intersection and sends commands to the controller when it is time to change phases. The schedule in place is now communicated to downstream neighbors to indicate what is coming in the way. Finally, the cycle of scheduling is repeated every few seconds (Smith et al., 2013).

The operator traffic control works in the same fashion as the schedule-driven one mentioned. Typically, the vehicles are identified by sensors that are placed under the asphalt, when they receive electric current, they create a magnetic field, which serves to recognize the metal of the vehicle that passes over it. The general data is received in a controller, this controller is a module that is in each traffic light, controlling the same, these data go to a control center, via telephone, fiber optic or wireless networks. In this control center, a computer or operator receives information from several of the control modules and can act on them optimally in real time.

It is possible for any control scheme of a local intersection to be vulnerable to myopic decisions, which only appear perfect locally but not in the global platforms. The layering of network-level coordination mechanisms over control strategy of the basic schedule-driven intersection is therefore necessary to help in the reduction of this possibility.

2.3.2 Smart traffic unit

The smart system is flexible with many peripherals for instance sensors and communicators, the software is accessibly integrated to the hardware from different varieties. It is an operator traffic control model that makes it function as a multi-unit system that is fully decentralized, meaning a unit operate on a local scale of information to achieve global goals. A unit running on an embedded computer controls each intersection. Such embedded processors can be found in the traffic cabinet assigned to the specific intersection. Each intersection has a unit which manages the traffic signal control and all vehicle detectors within that intersection's location (Smith et al., 2013).

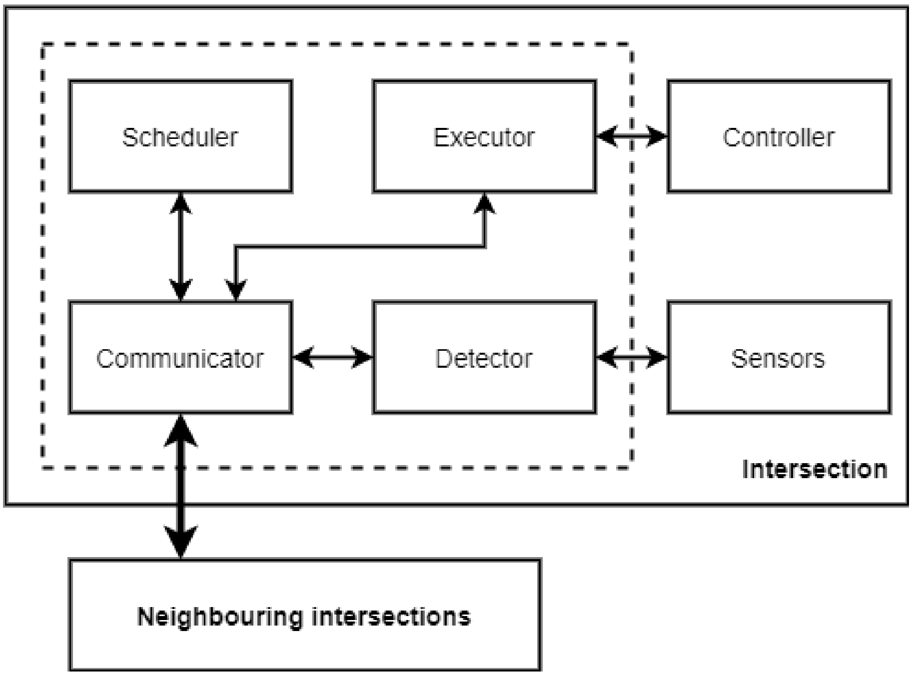


Figure 2 System architecture of an intersection (Smith et al., 2013)

The components in a single unit have their own functions that can work cohesively as a small system as seen in Figure 2 (Smith et al., 2013). Firstly, the sensor in the system gives out the data broken down to the detector altogether. The executor's service is to support with the controller's interface for the traffic signals. The executor, otherwise, can gather information that relates to the current state of traffic. All the real-time data will then be processed and sent to the communicator for handling. After that, the operator will receive and go through the utilized data to give out the changes to be made for the traffic state in real time. Finally, the operator can decide however long green time is needed in the situation of traffic. Furthermore, when equipped on nearby neighboring intersections and traffic zones, the network between systems can communicate and share the data with each other for an improved traffic flow in real-time elements.

3 STRUCTURE OF ADAPTIVE TRAFFIC SYSTEM

3.1 Main components

The main components of the system are specified by their functions and placement. These parts are installed mostly on the traffic lights and roads nearby for precise read of the information.

3.1.1 Detector/sensor

The detector service is essential because it helps to manage the interfaces with all sensors equipped in an intersection. There must be retrieval of real-time data, encoding into a message then finally sent to the local service that is scheduled. It is also necessary to send the message to the remote scheduler in circumstances where the sensor operates as an advanced neighboring intersection detector (Smith et al., 2013). Currently, there are multiple types of detection sensors use in traffic systems around the world including sonic sensors, infrared sensors, video detection, inductive loop, etc. In this thesis project supposed placement, there will be either inductive loop sensor under the road or video detection integrated into the system, which will induce more information about the current condition of the intersection. Additionally, the system would help with the traffic flow more in-depth data then working with only one type of detector.

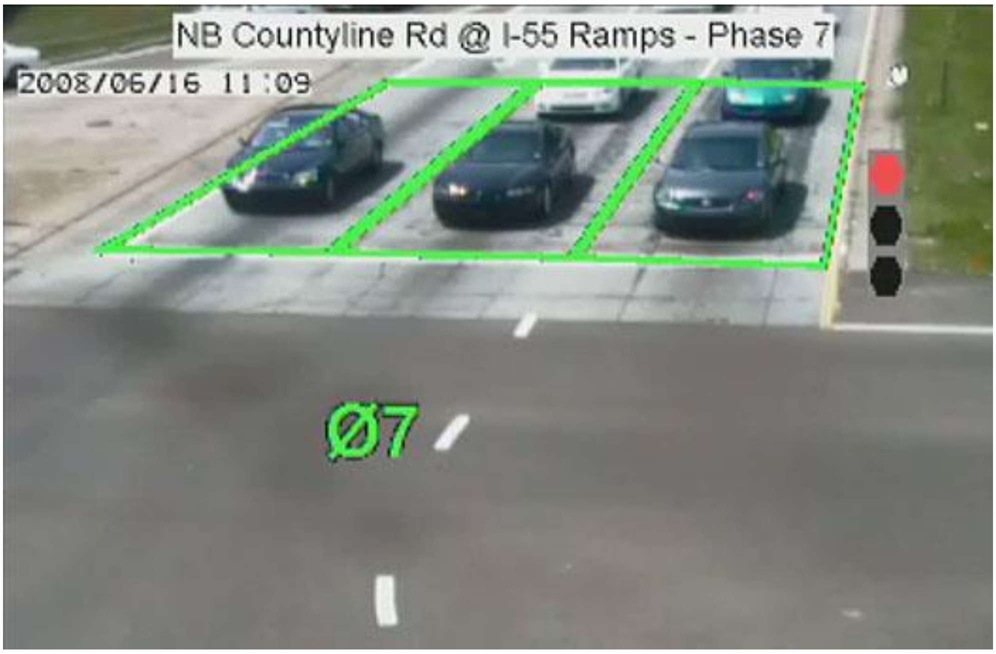
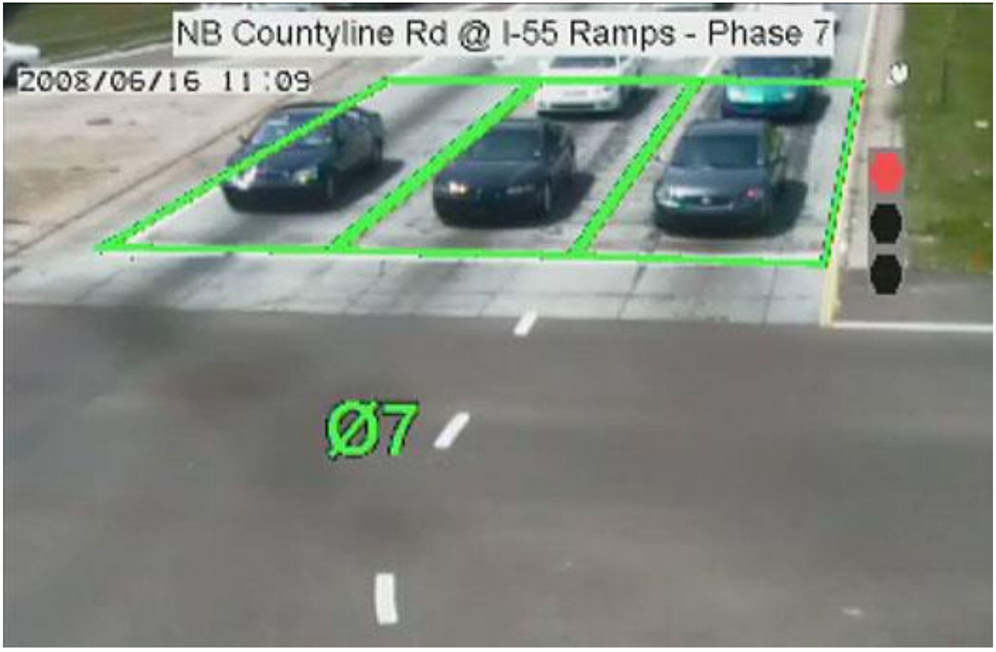


Figure 3 Possible placement of video detection at an intersection (Hanson, 2017)

The camera is connected to a system capable of encoding the video in search of unusual actions in the specific zone, so that when an object or vehicle enters the area of operation of the virtual zone, detection occurs. Also, the written algorithms are applied that work under any light or weather situation, to offer distinct types of info about traffic like traffic data for statistical analysis, incident-related data, and presence data. Placement of cameras on traffic signals can mark the areas of interest through virtual zones. The illustration of video detection in (Hanson, 2017) shows the presence detection zone technique of video detector.



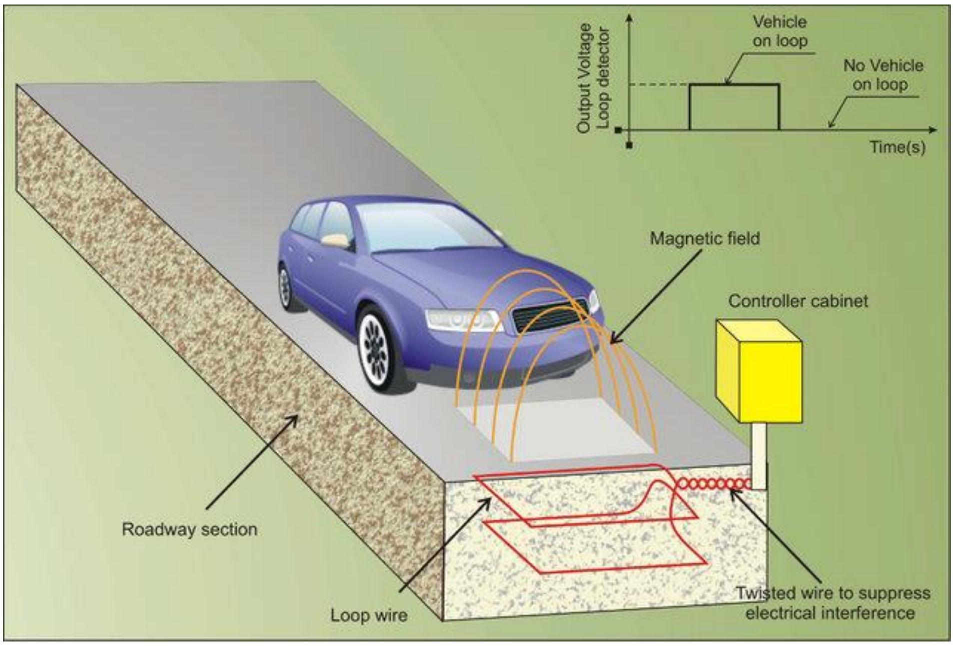


Figure 4 Inductive loop sensor operation (Mircea & Nicolae, 2014)

As indicated in Figure 4 (Mircea & Nicolae, 2014), The inductive loop sensors on the other hand are installed under the road. With the proximity of a metallic mass, the magnetic field changes and, consequently, the electric current that generates it, as well as the voltage in the loop, decrease. This occurs over time in which the mass remains within the detector's area of operation. It is the variation perceived in the voltage that is used to indicate the presence of vehicles, and this data can be processed to estimate vehicle occupancy. This type of system offers high precision in terms of occupancy data (Klein et al., 2006).

There are two types of data that are converted and transferred back to the head-operator, which include vehicle number counts and occupancy time. The system could be much more accurate with decisions with the information combined.

3.1.2 Executor

The executor is a service that regulates the interface and information of the traffic controller. With the given schedule from the head-operator It plays a big role in setting the traffic state through communicating with the controller. Extension of the current phase helps the executor to notify the scheduler of the upcoming decision point within the schedule. The decision point provides a subsequent update when the extended phase must be received. The executor then also sends back the information through the communicator for the operator to decide the next cycle of traffic flow.

The interface fitted with a traffic signal controller helps in controlling traffic signals at the intersections. At this point, the interface uses combinations of simple actuations and timing plans to allocate the intersection green time. Provided the system is active, the controller would be in the continuous process of enforcing minimum and maximum phase transitions and durations between phases as well as other safety constraints. However, it allocates the intersection green time adaptively. In the process, the device places the controller into free mode. The free mode is significant in utilizing vehicle calls from detectors (service requests) for simple actuated control. Provided the system is active, configuration occurs, which only allows the controller to accept calls. This occurrence happens in a similar way to other real-time adaptive systems. Similarly, an extension of phase maximum is necessary to allow longer phases as well as gap time necessary for allowing the controller to change phases. The changing process is shortened to permit quicker transitions. Upon activation of the system, configuration changes are written to automate the start-up process. To enable the intersection to revert quickly to its original state, placement of the new configuration in a separate memory page is significant (Smith et al., 2013).

3.1.3 Communicator

The communicator has been long-established as the mediator for communications between the traffic center/operator and controllers through information initiated. There could be both wired and wireless connection for the communicator such as through fiber, copper cable or wavelength and ethernet connection which makes the communicator highly versatile for broad-range or even narrow-range. The data being transferred through the agents is sturdy enough for the network to minimum failure (Gordon & Tighe, 2005).

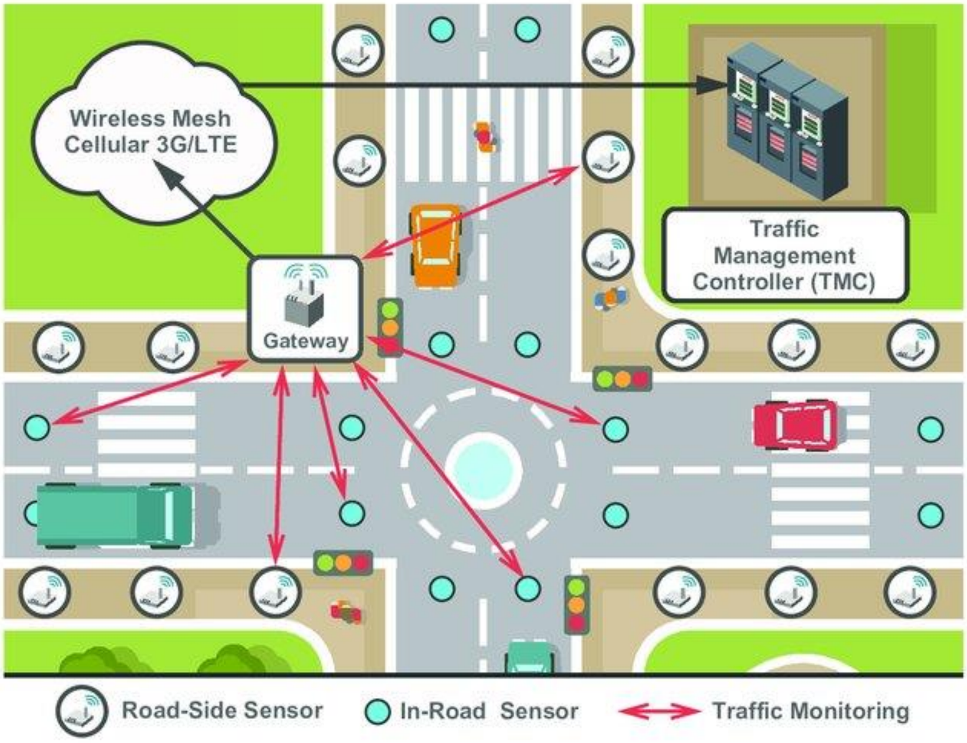


Figure 5 Communications chain of data feeds in traffic (Masek, et al., 2016)

The example of Figure 5 (Masek, et al., 2016) shows that all communication is routed through the communicator gateway at a specific intersection. Detector and executor service modules characterized with the ability to integrate hardware from different varieties by using standard types can provide the same information to the other remaining parts of the system. Regularly, it is possible to describe each message as tuple type, source, data, destination, origin, time of the message type, and the time the message was generated. In addition, the description can also reveal the intersection origin of the signal, intersection destination for the message, the detector, or service that created the message as well as the content of the message as JavaScript Object Notation (JSON)-encoded string (Smith et al., 2013).

3.1.4 Head-operator

The head-operator service is important in the implementation of the traffic control approach that is conducted by a main operator. The operator receives real-time detection data and condition every few seconds. In addition, the operator also builds its schedule for green light windows of the intersection approaching traffic cycle whether it is busy or sparse and constructs a new schedule for communication. Upon construction of a new plan, the executor receives the leading portion for controlling the traffic signal through the communicator then the working intersection receives a new schedule. On the other hand, the detector and controller will give the data back with the same connection to the communicator, reading and concluding the information received for a new instruction from the head-operator. As the cycle continues, the traffic will obtain new schedule and plan for the condition concurrently. The system transfer and interpret data steadily for the best experience of traffic flow as possible.

3.2 **Methodology**

This chapter illustrates the procedure of collecting data from the road and processing this data in the programmable logic controller. The data is handled through the working cycle of the operator system.

3.2.1 Data collection

The traffic flow in terms of vehicle count in adjacent intersections is collected from the sensors and detectors placed on different strategic locations of the street. Inductive loop sensors can be used to collect these data to sense the presence of vehicles and to count their number. A loop of wires is placed under the road to create an inductive loop, and then connected using cables to an electronic unit located nearby (Klein, Mills, & Gibson, 2006).The electronic unit transmits energy at a frequency of 10 kHz - 20 kHz to the loops of wires. The loop inductivity decreases when a vehicle passes and vice versa. The electronic unit sends a pulse to the controller of whether the vehicle passed or not (Klein et al., 2006). The rate at which the pulses are sent to the controller enables the determination of the number of vehicles passing those points with a defined period. Figure 6 (Klein et al., 2006) is a diagrammatic representation of loops in road lanes connected in series to the electronic unit.

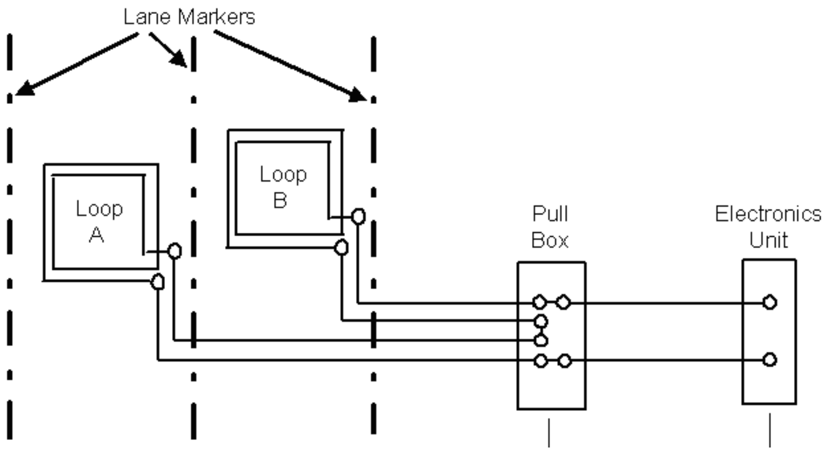


Figure 6 Connection of inductive loops to the electronic unit in series (Klein et al., 2006)

According to the reports, vehicle sensing using inductive loops is cost effective because of the low cost of installation and maintenance compared to other instances (Sobie, 2016).

The second type of data that need to be collected for smart and adaptive traffic lights is associated with the presence of priority passage such as ambulances and fire fighters. Radio frequency identification is one of the best sensors for approaching vehicles. This technology uses electromagnetic fields to identify tags storing information readable by a receiver. The presence of specific vehicles can be identified safely because the receiver can read a unique ID from the tag attached to the vehicle (Finkenzeller, 2010). The RFID technology is increasingly applied to a wide variety of applications such as payment of road toll tariffs. The vehicle is tagged and when it approaches the receiver, its information stored in the tag is read accurately. As such, a certain type of vehicle has a designated tariff that it must pay to be granted pass.

This technology can be applied to the identification of vehicles that require priority passage as in the case of a police car on a mission, ambulance, fire brigade, or VIP (very important person) that have to be granted immediate permission to pass. This method of vehicle identification is considered fast and safe because the information can be accessed by the RFID reader only. The tag is very cheap and therefore can be deployed cost-effectively in vehicles. All authorized vehicles will have to be identified and tagged for the smart and adaptive traffic lights to function optimally (Finkenzeller, 2010).

The RFID reader needs to be installed at a safe distance prior to the intersection depending on the conditions of the intersection, whether the intersection is busy or not. The distance of the RFID reader location to the intersection can be shorter if the intersection is not busy. However, it can be considerably long if the junction is usually busy. The lights turn green to the direction of the priority vehicle and red on the other sides including the pedestrian lights. The lights are reset to the previous status as soon as the vehicle with the priority pass passes the intersection. It is recommended to use active tags that can transmit signals for 500m or more to allow the reader to detect the presence of the priority case until it has completely exited the intersection. Figure 7 (Yeoman, 2014) illustrates the radio frequency identification system.

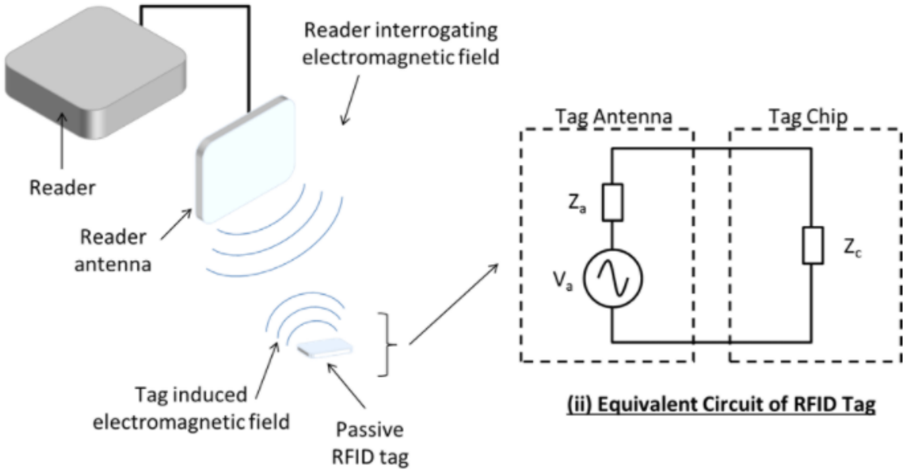


Figure 7 A radio frequency identification system (Yeoman, 2014)

3.3 Placement design

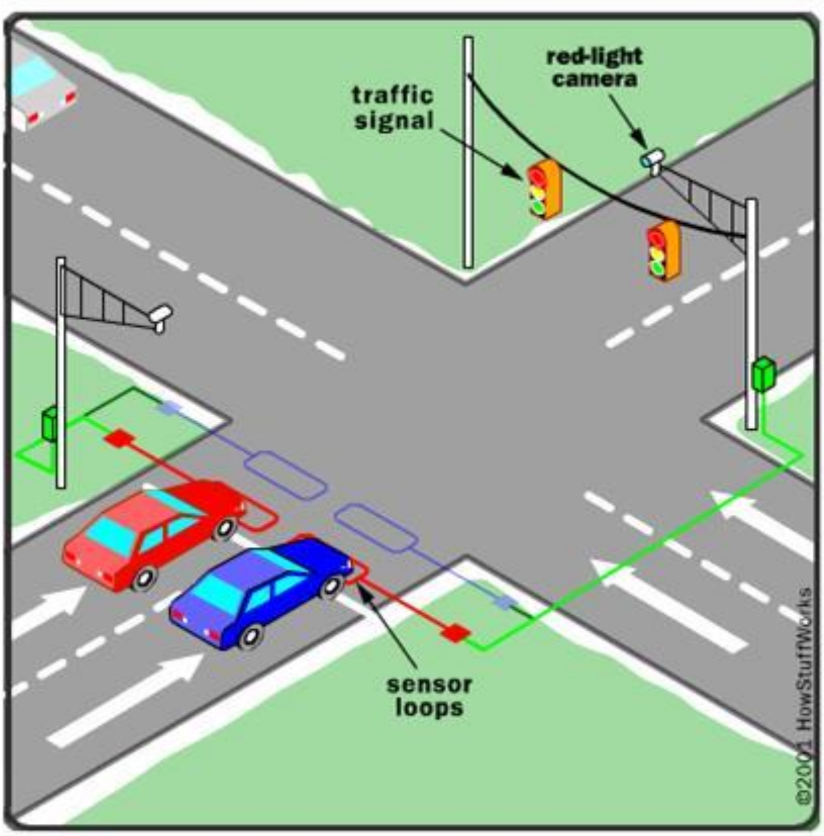


Figure 8 Placement of sensors viewed from a different angle (The Daily Scholar, 2013)

In an intersection especially a busy one, the placement of the services for smart traffic must be considered carefully for the best possible look and usage. For instance in Figure 8 (The Daily Scholar, 2013), the inductive loop sensor is installed under the road so the change after installation would be very challenging, also the video detection must be at the best angle conceivable for the best quality of image and exposure. The other agents in the system can be at flexible and adjustable areas since their functions would not be affected by the placement.

4 PROGRAM SPECIFICATION

The programmable logic controller is programmed with the suite of tools found within the Siemens TIA Portal (totally integrated automation). Specifically, TIA Portal is used to program the programmable controller. Programming in TIA Portal can be achieved in three different ways such as structured control language, ladder logic, and function block diagram. Statement list is accomplished through programming language similarly to the machine code. The programmer enters a program code into the coding environment. The ladder logic on the other hand uses circuit diagrams. Users who are familiar with the Boolean algebra logic boxes can also use the function block diagrams to implement programming. TIA Portal comprises a large library of components that are useful for a broad range of applications such as the conventional controls to mathematical functions, timers, counters, and flipflops. TIA Portal provides the users with different address tools such as function blocks, counters, bit memory, block, data, Input/ Output (I/O) signals, and timers. An address refers to the area and location of memory. Therefore, it is important to assign the I/O address areas correctly in both the hardware and specify in the address in Siemens TIA Portal.

Every input and output are assigned a default absolute address in accordance with the hardware structure. The absolute address can be assigned a selectable name. The different programming languages are assigned respective symbols, i.e. structured control language – SCL, ladder logic – LAD, and function block diagram – FBD.

The process of setting up the TIA Portal software for programming the programmable logic controller is moderately straight forward. The connection between the device and the software is accomplished through running the command file. The ladder diagram is created in the “Main [OB1]” to create a new project. Then the Main [OB1] is downloaded to the central processing unit to test if the program is operating correctly. Follow that are Normal and Busy Traffic [FC1], Pedestrian Crossing [FC2] and Priority Vehicle Pass [FC3].

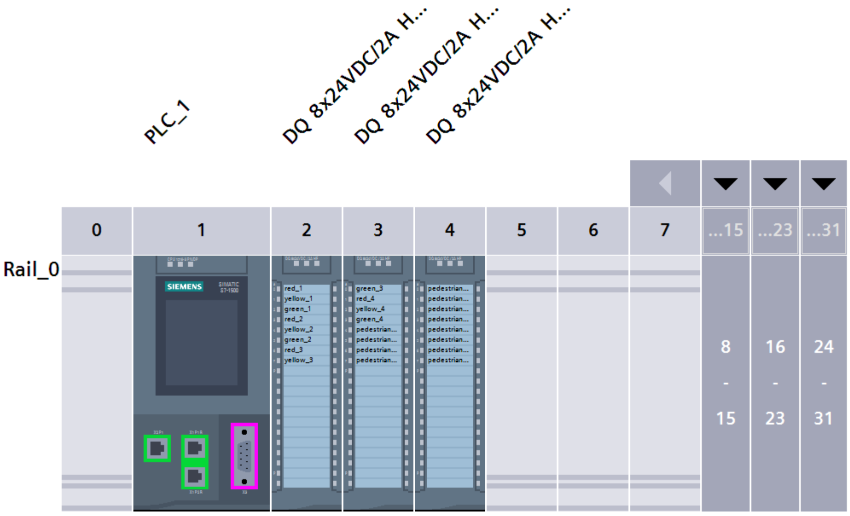


Figure 9 The PLC 1516-3 PN/DP of Siemens

4.1 Demand-actuated traffic light operation in an intersection

A traffic light control system that is run by actuators on demand at an intersection is auxiliary where the road experiences heavy traffic as well as very light traffic. By auxiliary it implies that the lights on the current roads are set to green by default and the supplementary roads are set to red. The sensors on the auxiliary road detect a vehicle approaching the intersection and the main street traffic lights turn to yellow and then to red as per the pre-programmed time. As lights on the active roads turn to red, the traffic lights on the auxiliary roads turn to green thereby allowing vehicles to pass the junction. The following is the summary of sequence of events timing of the operation:

1. All the lights are initially blinking yellow in Stop status.
2. Switching on Start button will kick off the traffic lighting system.
3. Therefore, switching on Start will put the light on Lane 1 and 3 on red and yellow while the auxiliary lanes will be set to red by default.
4. Pushing Stop activates the main road maintenance mode which allows yellow lights to blink in a 0.5s cycle.
5. When traffic light system is operation, traffic lights change is initiated by the end of the current activating traffic roads.
6. The system will initiate the change of light to red on the running roads after a 3 seconds delay when the last cycle of signals is off. The yellow light will remain on for 3 seconds before switching to green light. The switching to red traffic lights prompts a 3s time overlap where all the lights turn red for safety reasons.
7. The green lights on the auxiliary road are turned on after the 4 seconds red light overlap delay.
8. The auxiliary road yellow lights will remain on for 3 seconds to allow the vehicles to cross pass the junction.

9. The green lights will turn from yellow to red after the input time and those on the alternate roads will transition to yellow and then green from red.
10. The system ensures that all green lights are never turned on at the same time and a delay in red lights between cycles to avoid the possibility of vehicle collision.

4.2 System description and programming

In this system, a four-ways intersection with pedestrian crossing is taken into consideration. The input traffic data from adjacent intersections are used in the programmable logic controller. The system consists of a “start” operation push button, “stop” push button, and “pedestrian request” buttons. In addition, there are four switches for controlling the priority vehicle pass on each side of the junction, and another four switches for the vehicle density option. The system collectively is constituted by eleven inputs and fourteen outputs (eight green lights, eight red lights, and four yellow lights). The intersection has one green light and one red light on each side for pedestrian use. This traffic system was catered to the logic of Finnish traffic light law for the accuracy.

The operation control of demand-actuated traffic light system is implemented in Siemens CPU 1516-3 PN/DP. The general features of this programmable logic controller are:

1. It is a modular system that can be implemented for medium projects
2. It has different modules designed for various automation issues
3. The device is easy to reprogram such that it becomes easier to improve the process
4. The device can be connected easily to different communication networks such as Ethernet and message passing interface (MPI).
5. The device also has large programming capability

The system is designed such that two light signals of the opposite direction perform simultaneously. For example, the green light is activated by signal 1 and 3 or signal 2 and 4 at the same time. When the green light turns on, the vehicles can proceed further, and the pedestrian lights turn red (the pedestrians stop). The design of the junction is represented in Figure 10.

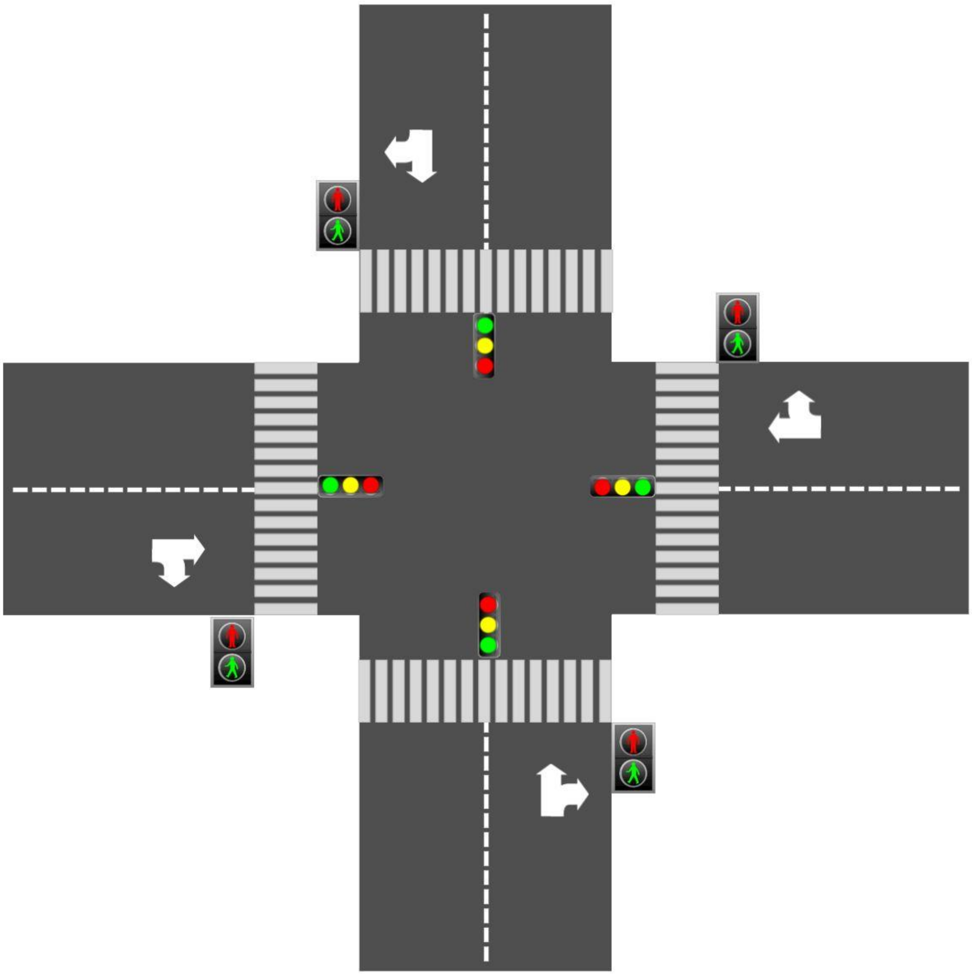


Figure 10 Design of an intersection traffic light system

The illustration in Figure 11 indicates 20 outputs. Four signals and four push buttons were used for the pedestrian function, thanks to the flexibility of the PLC. It shows how the physical system is built using the Figure 10 schematic. The four push buttons and four signals represent the four real buttons and respective signals. In the actual design, the pedestrian latches would be connected in separated with each pedestrian traffic outputs. This design helps in applying four pedestrian inputs for four output signals.

The inputs of the program while operating consist of:

1. Default signal time
2. Signal 1 to 4 busy cycle time
3. Pedestrian request 1 to 4 time
4. Yellow delay timer
5. Red delay timer

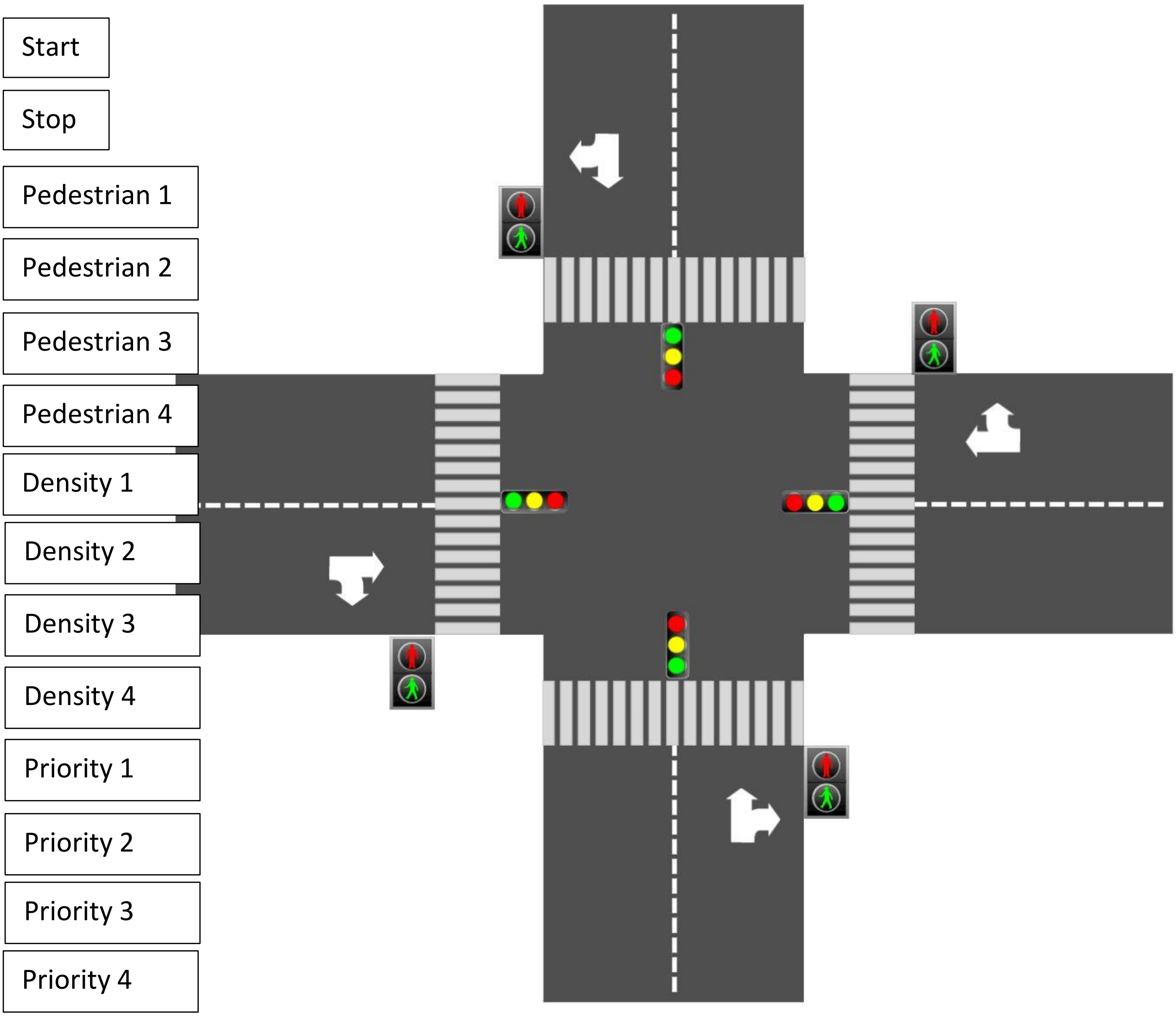


Figure 11 Physical buttons built for the intersection system

The four primary functions of this system include: normal flow, high-density flow, priority pass, and pedestrian crossing.

4.3 **Input data**

The Boolean algebra logic will be used for simulation of the sensors’ data. The inductive loop sensor provides the count of vehicles passing through the street portion and sent to the controller. In Boolean system, 1 implies that a vehicle has passed and 0 that a car has not passed. Thus, the data recorded by the RFID sensors will assume the 0, 1 type of integers with 0 for no priority and no busy vehicle pass present and 1 for priority vehicle pass present and heavy traffic occurs. This smart traffic and adaptive traffic lights thesis project is based on a four-way intersection with traffic lights in each direction. Therefore, the inductive loop sensors and the radio frequency identification readers will be placed in each direction. The data from these sensors will work in place of the programmable logic controller units, and the controller will use the developed program to obtain the needed outputs.

4.4 **Program functions**

4.4.1 Normal traffic

Figure 12 demonstrates a series of events during the normal traffic flow. During normal flow, signal 1 and signal 3 prompts red lights to turn on for 3 seconds, 3 seconds for yellow lights to signal the drivers and finally the green lights start for the time entered. Signal 1 and signal 3 work simultaneously until both goes on red to prompt the next cycle of traffic on the other lanes. When signal 1 and signal 3 are red, signal 2 and 4 will execute concurrently similar. The cycle then repeats itself in case of no interrupts such as pedestrian, busy mode or priority. The red lights are not assigned with timers, they stop when the yellow or green lights are on.

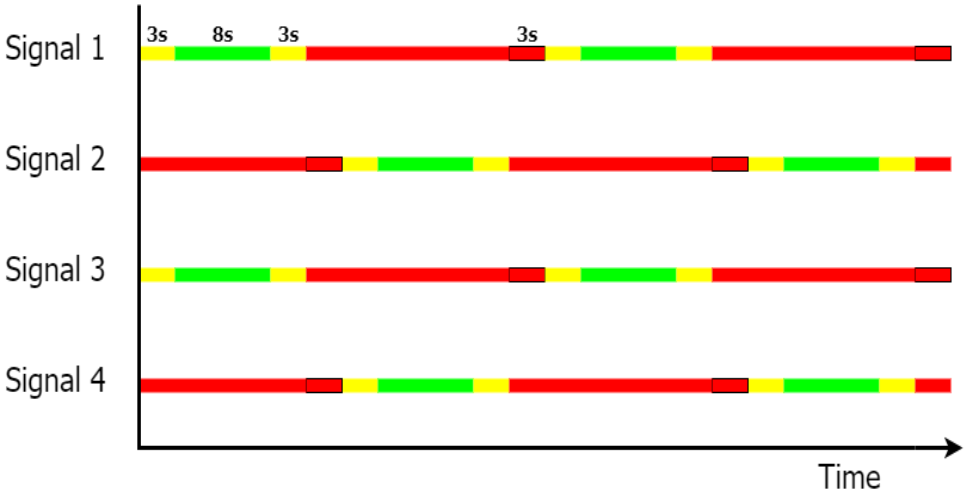


Figure 12 A schematic diagram of normal cycle timings

To put in another way, the end of the yellow light after the green light coincides with the beginning of the yellow light of the second Signal. This implies that the yellow lights can be synchronized to work at the same time, but due to the need to provide an allowance for a delay to avoid vehicle collisions at the intersection, this kind of synchronization is avoided. It can also be noticed that the red light does not have a timer because the driver is expected to stop whenever green or yellow lights are on. This cycle will continue repeating itself is no interruption is done due to the need for pedestrian or priority vehicle pass. In fact, the timing of the yellow and green lights is longer than 3 seconds and 8 seconds, respectively. The schedules shown above are for lab work only. Setting the timing can quickly be done through the simulation's perimeter according to the desired timings for an appropriate intersection. Of course, the schedule will depend on the intersection conditions, such as whether it is usually a busy junction or not.

4.4.2 Pedestrian pass

The incorporation of the pedestrian traffic light interrupts the normal flow cycle, as shown in Figure 13.

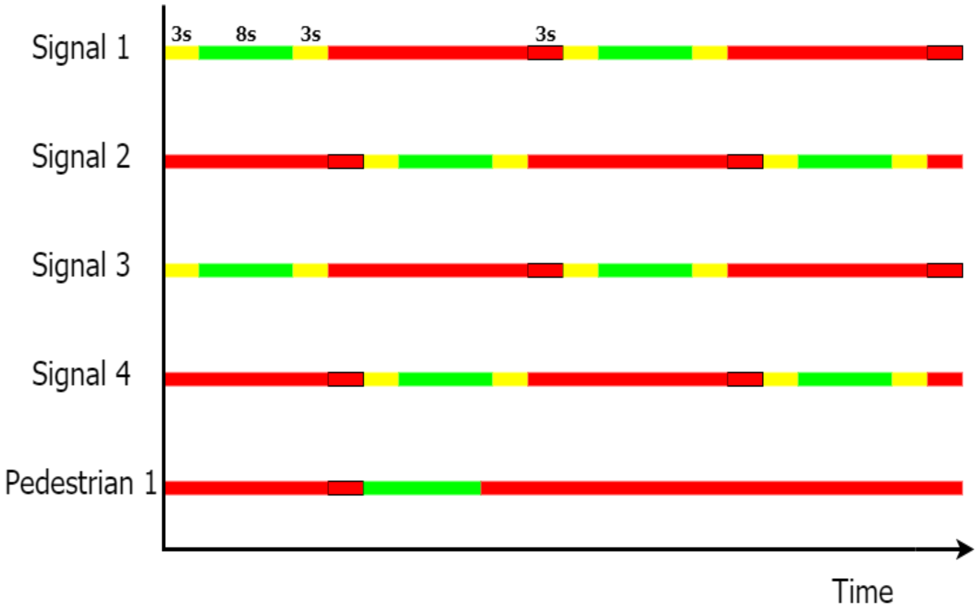


Figure 13 Incorporating pedestrian crossings

The pedestrian signal will have to wait until the end of Signal 1 to turn the pedestrian light 1 green before Signals 2 and 4 start. Note that the pedestrian signal does not have yellow lights, only green and red. Also, the duration of the pedestrian green light can be set by operator, as an example 10 seconds. As a matter of fact, the allocation for pedestrian crossing is more extended because the pedestrians take a lot longer to cross the road than a vehicle exiting a junction. At the end of the 6 seconds of yellow and red lights delay signaling the end of Signals 1 and 3, the pedestrian green light will set on for 10 seconds then change to red. Signals 2 and 4 can begin parallel with the pedestrian green light. A closer observation of the cycles shows that the pedestrian signal can start at the end of any pair of signals. For example, if the junction experiences heavy pedestrian crossing, the pedestrian light can begin at the end of each Signals cycle. Since the sequences are controlled by the programmable logic controller, it is easy to program the device to allow more frequent pedestrian crossings at the intersection.

4.4.3 Busy traffic

The road situation adjacent to the intersection can be either a dense traffic flow or a sparse one. As such, the computation in the PLC assumes the Boolean inputs of the Signal in which a set of decisions will take place as far as the duration of signals is concerned. Consequently, the period of the green light should increase on the side of the road that is experiencing high density, as shown in Figure 14.

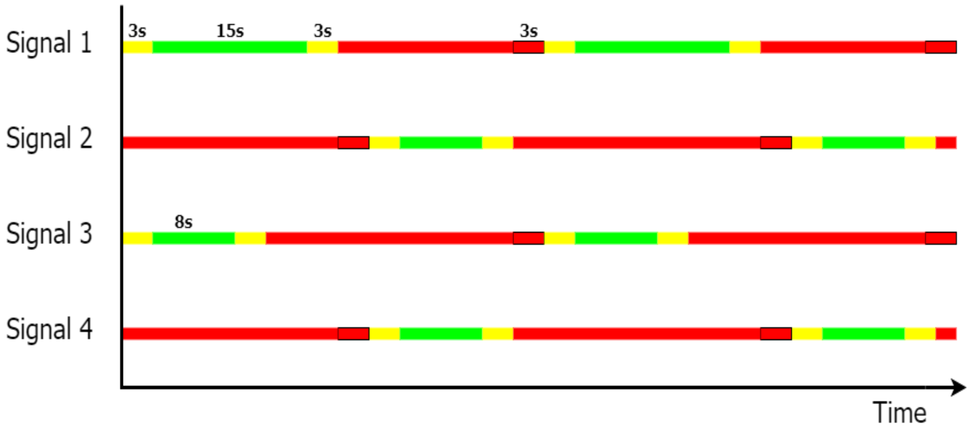


Figure 14 High-density traffic diagram

If there is a busy traffic flow associated with Signal 1 as shown in Figure 14, vehicles can pass the intersection a little longer, i.e., in 15 seconds instead of 8 seconds. As explained before, the inductive sensors placed on the road will provide the input signal in the real-life situation to determine the density of traffic associated with Signal 1. The time allocation, therefore, will vary depending on the density of traffic related to Signal 1.

4.4.4 Priority vehicle pass

Since a vehicle with a priority pass is allowed to pass the intersection at any moment, all signals are interrupted as both pedestrians, and other vehicles have to give way to the priority vehicle pass. Therefore, whenever such a case arises, the yellow light should be on for one second in all directions followed by a green light in the direction of the oncoming priority vehicle, but red lights for all the other routes to allow the priority vehicle to pass.

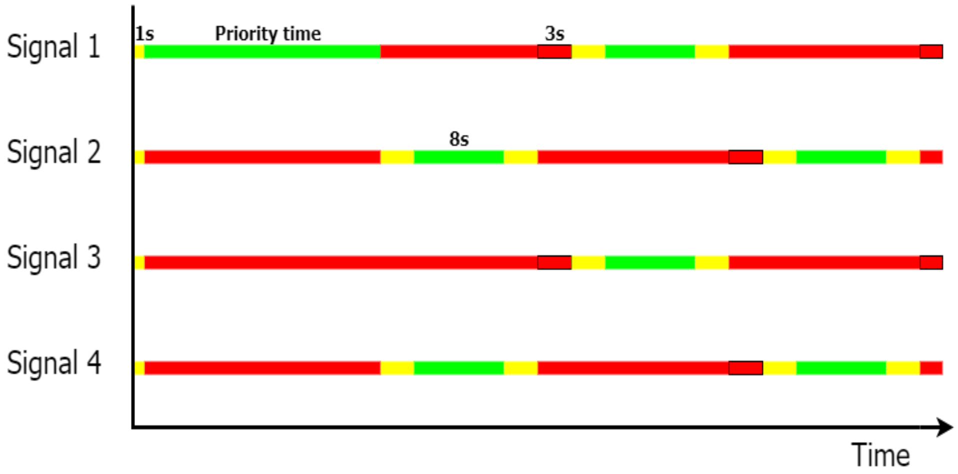


Figure 15 Demonstration of priority vehicle pass timing

Figure 15 demonstrates what happens when a priority vehicle approaches in the direction of Signal 1. The yellow traffic light signal set for one second in each direction to alert the other drivers at the intersection, and then the green traffic light for the direction of the priority vehicle will switch on while the lights in all the different routes, including the pedestrian lights will go red. What happens during the priority vehicle pass is that all the other lights pause and will continue from where they left as soon as the priority vehicle passes the intersection.

In another scenario, there may be more than one case of vehicle pass priority at the same time. The vehicle that triggers the Signal first will be allowed to pass before the priority circle begins for the second case to avoid vehicle collisions. In other words, only the priority cycle will be activated during the priority vehicle pass request scenario before the normal cycles resume.

4.4.5 Maintenance mode

As the traffic lights work continuously, the lights are featured with a maintenance option as the blinking yellow lights occurs. The yellow lights blink at a 1 second rate. Situations with lights broken down, road damage, late night traffic can be applied with the option to enhance the traffic flow.

5 SOFTWARE IMPLEMENTATION

This chapter presents the results of the Siemens TIA Portal v15.1 programming software. All the figures and texts below are concluded from operating the program under the thesis' requirements. The codes from the software are mainly easy to understand and integrated into a traffic control system.

5.1 Programming of normal traffic

The first step in programming the normal cycle is to latch the START button in FBD, as shown in Figure 16.

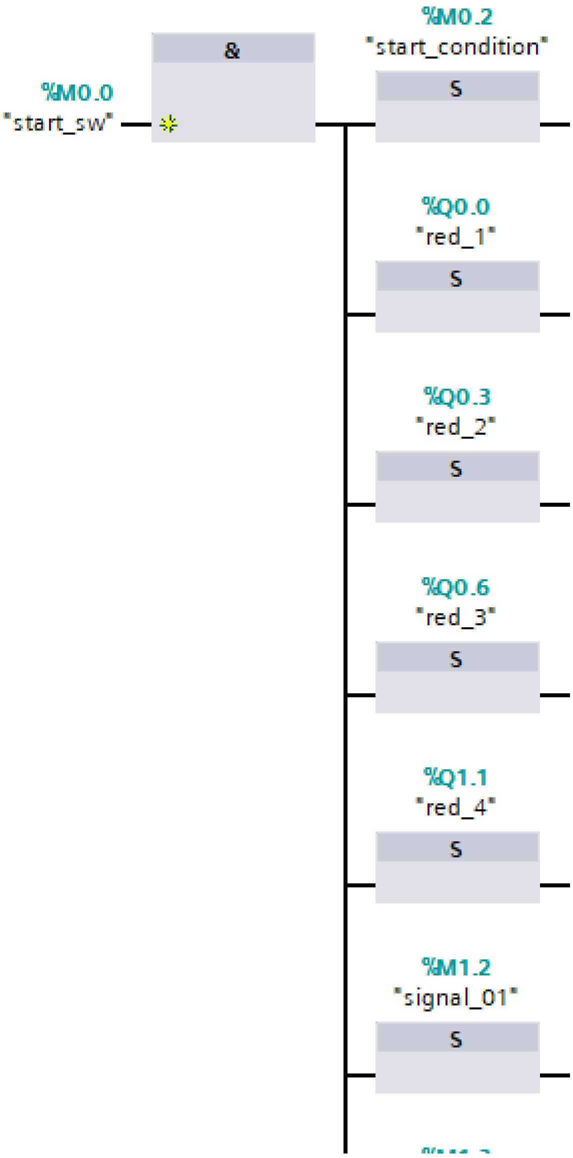


Figure 16 FBD logic for pressing the Start button

After the start button is initiated, the start condition’s value changes from 0 to 1, meaning the system is now prepared to work. Also, all the signal lights and switches of the intersection can now be adjusted. Since the normal traffic flow cycle is a series of events whereby the next outputs begin at the end of a preceding output cycle, the operation is controlled by the TON timer, which the input time can be change for the situation.

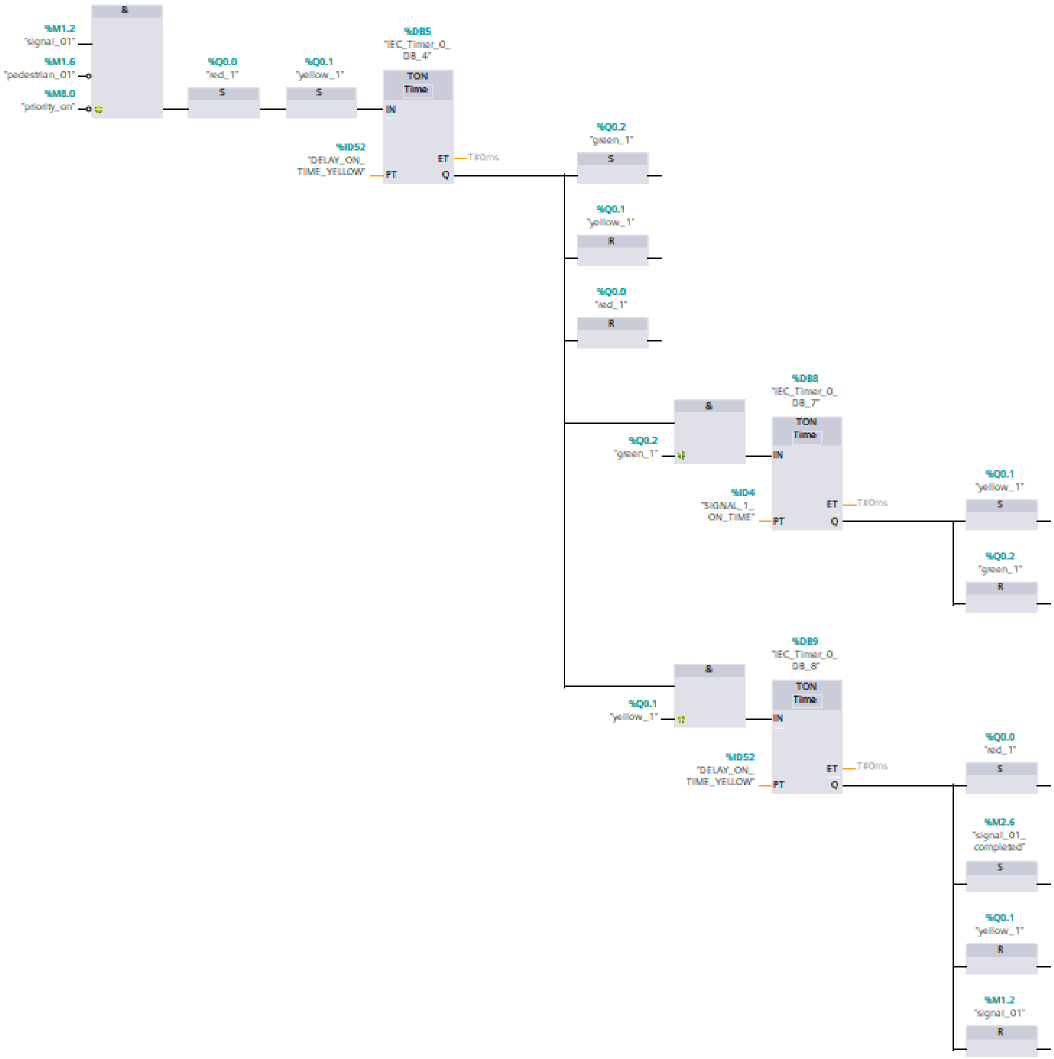


Figure 17 Signal 1 running logic

Pressing the start switch results to timer T1 as well as T2 and T3 getting energized in order. After 2 second, T1 goes to the next line of code, entering the green light stage. The T2 output (green 1) status will change to ON for the set time. T2 as well as green 1 get energized, and upon completion of T2 input time, green light stops and T3 get energized. The process continues with the pair of traffic cycles. 12 timers are used (T1-T12) due to presence of 12 timer events. The cycle will reset after every pair of cycles ends its runtime. The red light, the yellow light and the green light cannot all be on for the same signal.

5.2 Programming of pedestrian pass

The pedestrian traffic light system switches upon pushing the PED button on each post. The timer is set by the system operator, as previously described. First the pedestrian latched as shown below.

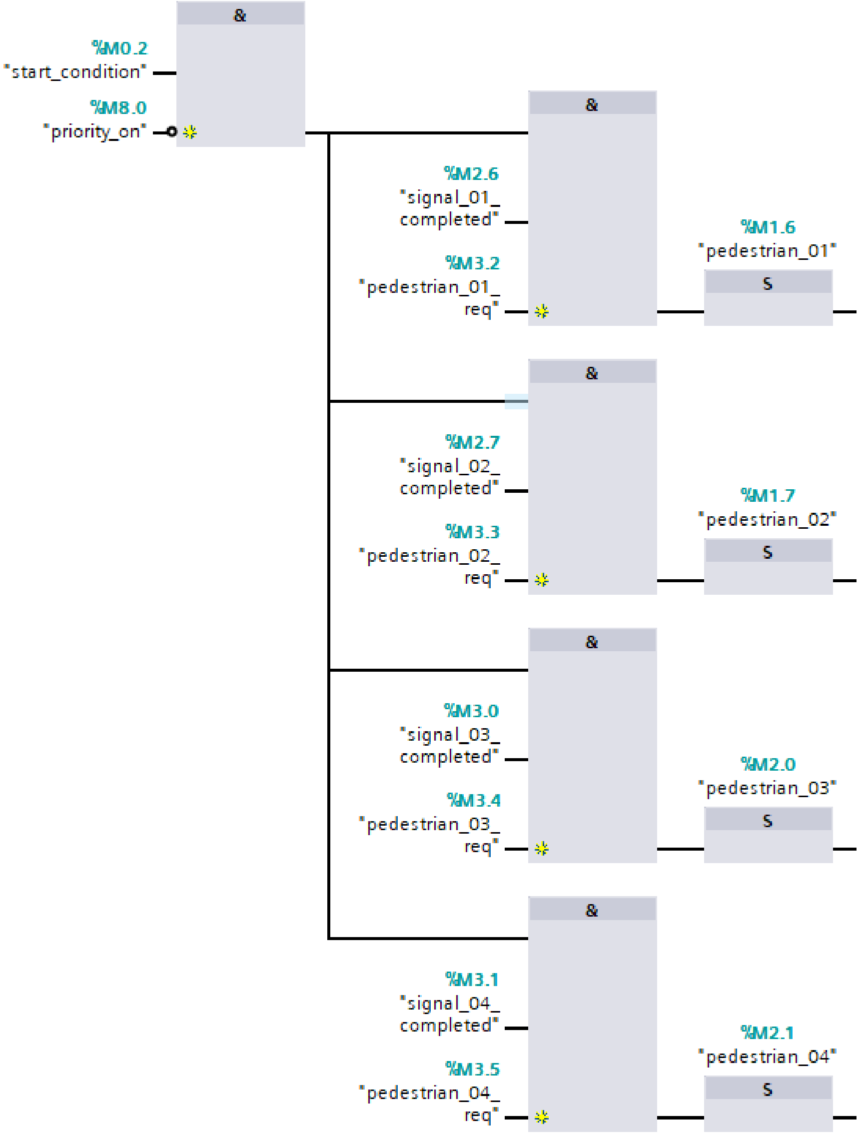


Figure 18 Conditions for each pedestrian request post to operate

The pedestrian requests are only activated when the start condition is on and the priority mode is off. The request for a specific road is activated when that road signal cycle is completed, for example the light on pedestrian walk 1 will work after the signals from road 1 are completed.

Through observation, the PED is a push button. The request is automatically turned off after the lights turn to red. There is a TON Timer for the input time of the operator. This implies the pedestrian latching will be stopped after set amount of time.

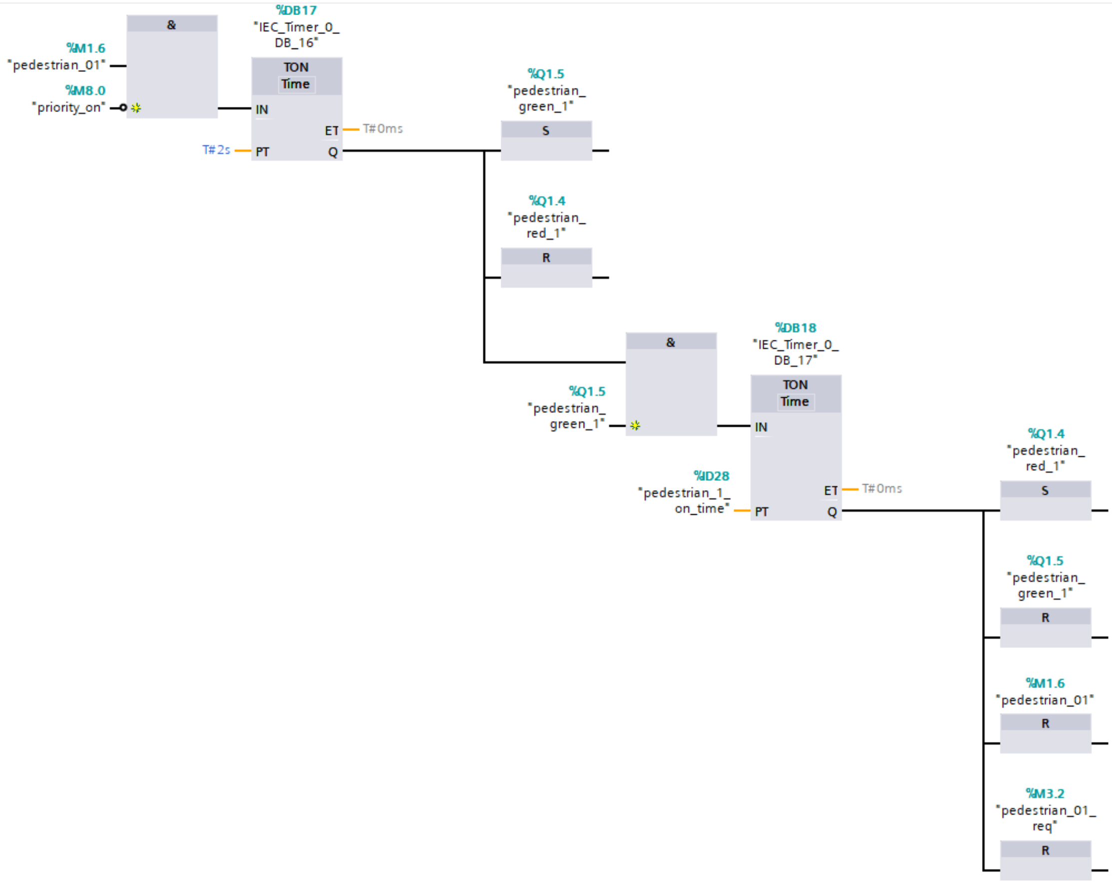


Figure 19 Logic for the start of pedestrian request 1

From the first line in Figure 19 we can observe that pressing the pedestrian crossing request will result on PED request 1 being triggered. There will be a 3 seconds delay between the phase of red light turning green. After the request is done, the normal cycle will start after all the conditions in PED request 1 has been turned off. A similar execution is utilized for signals 2, 3 and 4 of pedestrian crossing.

5.3 Programming of busy traffic

Programming busy traffic will necessitate an elongation of the green light duration to a higher value than in a normal flow situation. Figure 20 shows how the programming in high-density traffic flow situation is implemented. In case high-density traffic flow is not triggered, the green light duration is set to the normal cycle time. However, the allocation depends on the set time i.e. 15 seconds when high-density traffic flow is detected from the inductive loop sensors.

The MOVE block switches the timer in the signal coded for the normal cycle. The operation of this algorithm is based on the Boolean system as the input of the number of vehicles arises from vehicle count. The algorithm will thus depend on the number of vehicles present on the roads adjacent to an intersection.

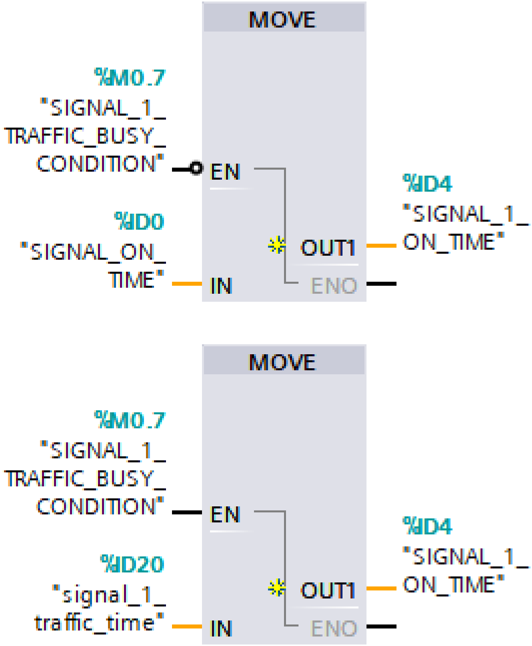


Figure 20 Change of time between two modes through the MOVE block

Presence of a busy traffic prompts an increase of the green light timer from e.g. 8 to 15 seconds through utilization of a MOVE block. The green light will be switched on for e.g. 30 seconds where the vehicles are >0≤20, 40 seconds if the number of vehicles is 21-40, and so forth. One thing that must be noted is that if the vehicle count is zero, it means that no vehicles are coming from that direction and so the amount of time allocated to the green light equals 0 seconds. Therefore, the signal will remain red that one may optimize road usage. In the real situation, programming in the PLC will allow for the desired amount of time for the green light under different road conditions. The green light will be on for time equal to time input to TON timer. Thus, this algorithm can be modified to suit the road conditions in real-life situations.

5.4 Programming of priority pass

The software will halt the execution of the normal traffic flow cycle and the pedestrian signals to avoid vehicle collisions. Instead of executing the normal vehicle flow and pedestrian pass, it will jump to the priority vehicle pass scenario.

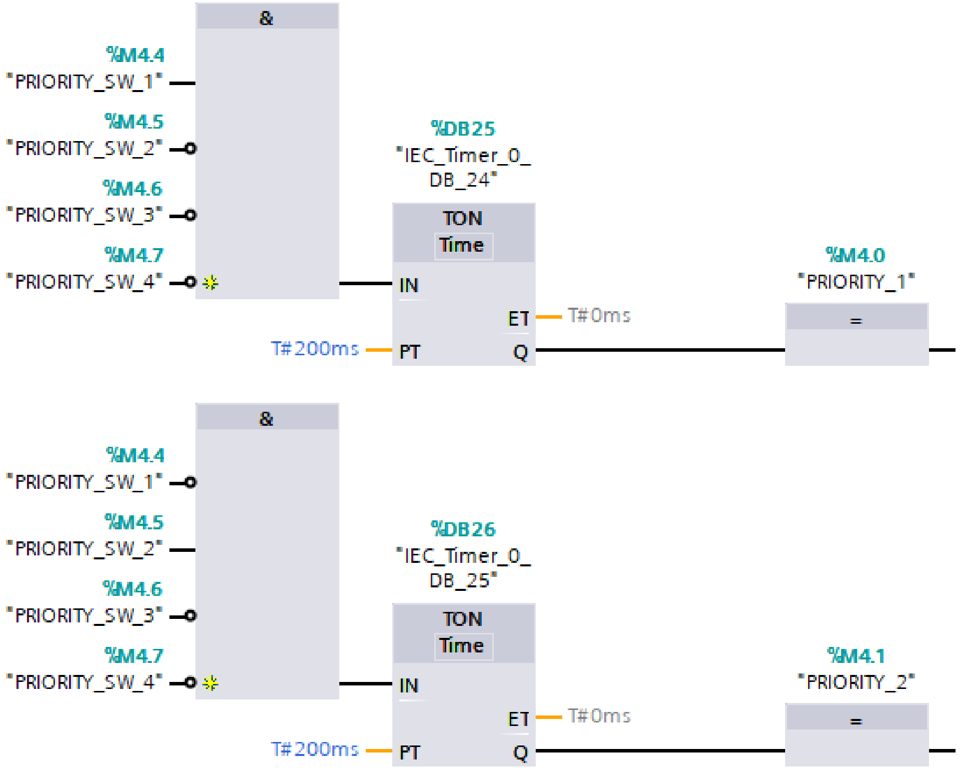


Figure 21 Conditions of priority switches

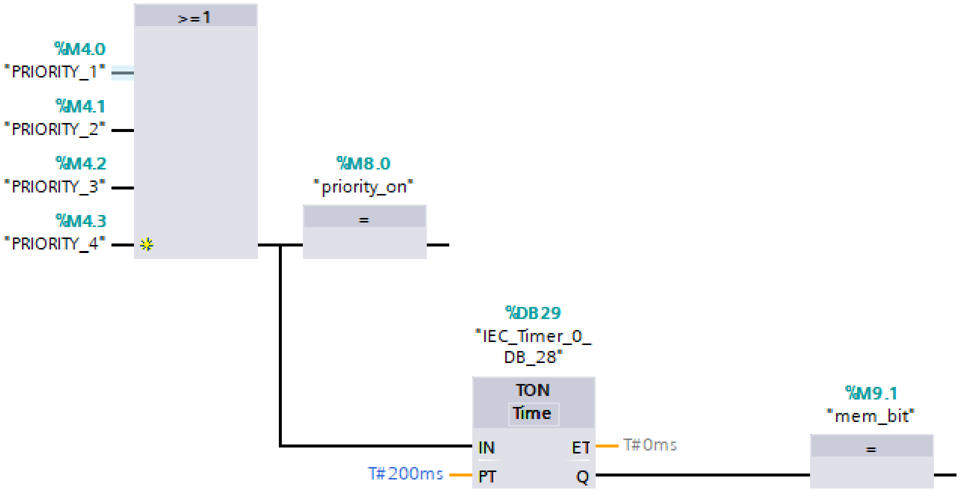


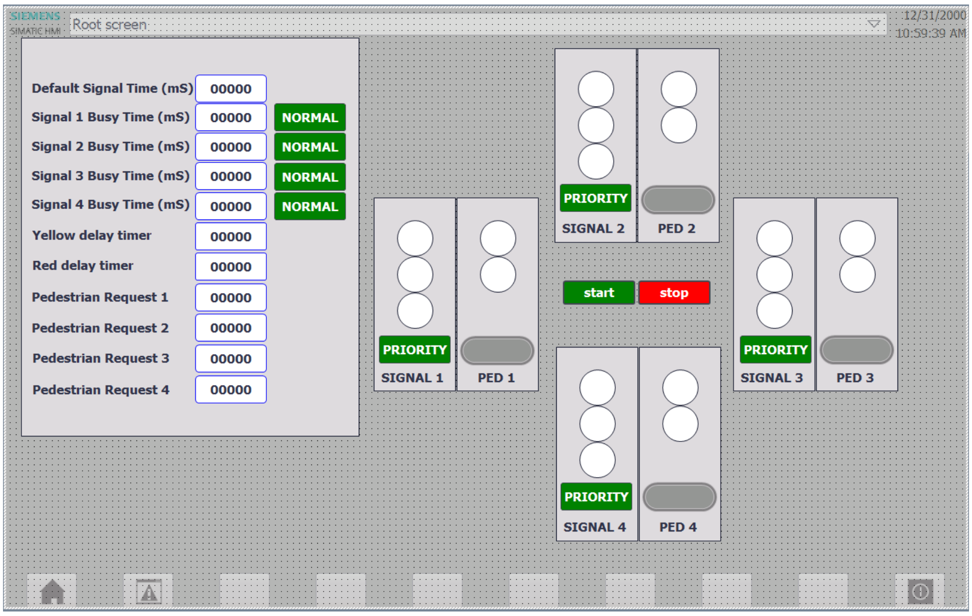
Figure 22 mem_bit trigger condition

Assuming that the priority pass signal is originating from the Signal 1 direction, the yellow lights in all directions will flash for 1 second. All priority switches usually are off and thus provide the guarantee that no other priority signal will be produced unless there is another priority signal. In this case, the mem_bit is used to close the switch for priority 1 and to start the green light in Priority 1 to allow the second priority vehicle to pass. Whenever any priority latch is activated, the request will begin with a 1-second flashlight, stop the yellow light, and activate Priority. Once it is activated, all the other functions are ended, to give the priority vehicle precedence. Presence of a priority on any direction, prompts the program from normal cycle execution and jumps to the priority network with a predefined label Priority mode. Yellow flash block turns on all yellow lights for 1 second when priority request is triggered. All the other lights are turned off.

6 HMI VISUALIZATION AND SIMULATION

6.1 Program interface

For simulation purposes only junctions are visualized with the HMI KTP 1200 Basic PN as shown below. It has 14 push buttons which set bit while pressed. The buttons are the start button, stop push button, pedestrian request push buttons (PED), priority push buttons and the busy traffic push buttons. The interface can be interacted for the simulation of the intersection.



Default Signal Time (mS) 00000
Signal 1 Busy Time (mS) 00000
Signal 2 Busy Time (mS) 00000
Signal 3 Busy Time (mS) 00000
Signal 4 Busy Time (mS) 00000
Yellow delay timer 00000
Red delay timer 00000
Pedestrian Request 1 00000
Pedestrian Request 2 00000
Pedestrian Request 3 00000
Pedestrian Request 4 00000

Figure 23 The design of Human Machine Interface (HMI)

When started signals 1 and 3 will initiate first as the program is intended to be followed up by the pair of signals 2 and 4. the green normal button of each signal will turn red after switching to busy mode. If the system is stopped, it will make the yellow light blink for the function of maintenance. The HMI is designed to have the look and feel of an operating intersection in real life with the timer inputs depending on the given traffic situation. There is a parameter for adjustments of timing, since the simulated program only use theoretical numbers for condition of traffic.

6.2 Simulation

The system initiates and starts working by pressing the start push button and stops in the blinking state when the stop push button is pressed. The normal cycle executes normally unless interrupted by priority or busy or pedestrian requests being pressed. For time set example, the normal cycle works in order by turning on red light for 3 seconds, yellow light for 3 seconds, 8 seconds for green light, 3 seconds for yellow light and finally the red light starts again. The execution repeats itself unless an interruption occurs. On pressing the priority push button, the yellow light flashes for 1 second then the green light is turned on to give priority. On pressing the PED request push button, the green light turns on for i.e. 10 seconds after which the normal cycle execution resumes. The green light is turned on after signal being currently executed is completes its execution. On switching to busy push button, the green light is turned on for however long the user set it for the lane after which the normal cycles resume its execution when turning it off.

6.3 Utilization

Traffic congestion has been one of the biggest problems known to the modern society, developing, and developed countries included. In this case, the simulated program which was made for HAMK was to display the benefits of current adaptive traffic light systems that drivers and passengers could experience on the road. Less stoppage means less pollution on a bigger scale. This program indicates what can be implemented to the traffic system, with more manpower and hardware like cameras and sensors equipped for the project, the work could get more immersive.

More room for optimization of traffic lights and reduction in waiting time at intersections makes emergency services and public transports more efficient and safer. The smart traffic management system would give the emergency vehicles the priority through intersections thus helping with whatever the urgent situation. So, their outcome of being on the road would be less annoying to drivers and passengers. Also, the results of this project could be used as future documents for the HAMK campuses.

7 CONCLUSIONS

The main limitation in this thesis project was obtaining vehicle count data. Acquiring count data means doing real road modifications to install inductive loop sensors. The data could have been more reliable if actual vehicle count data had been obtained for the work. However, there is room for improvement of the project in the future. The input data for traffic density does not have to come from local inductive loop sensors. Advances in the global positioning system technology have helped in the development of accurate traffic data that can be used in the management of traffic at intersections. To sum it up, smart traffic controls are and will be adopted for future usage of modern traffic systems. Through the system with components such as sensors, communicators, and operators, the adaptive aspects of traffic system are currently implemented for better transport experience overall.

Nevertheless, the programming language used in this project manifested how it is possible to design and implement a smart and adaptive traffic light system for the intersections of city roads or in this case for HAMK. The deployment of inductive loops and RFID sensors on the road are sufficient to provide input signals for the management of traffic flow, priority vehicle pass, and pedestrian use of intersections.

The FBD language used in this project is simple to implement and quickly reproducible in different settings. The timing of the different cycles for different signals is easily set in the TIA Portal software. When the roads adjacent to the intersection are less busy, a shorter period is set for the green light or it remains red for as long as there are no vehicles on that stretch of the road. The duration for the green light for any road increases with the increasing number of vehicles on that road so that the adjacent road with the heaviest traffic is allocated the most time for the green traffic light.

The signal from the inductive loops is received as a count and the system allocates time depending on the number of counts. This makes it possible to give priority to the roads that have the heaviest traffic. The integration of the priority vehicle pass option in the management of the intersection traffic light system ensures that emergency services are provided with a minimal disruption in the traffic flow. The RFID sensor technology plays a critical role in enabling the identification of priority vehicles in good time to allow proper planning for time allocation.

The algorithms used in this thesis are sufficient for the design and operation of a smart traffic and adaptive traffic light system. Finally, the outcome of this program provides a better look at the traffic system from a logical standpoint, along with the demonstration of a PLC smart traffic system for HAMK for future reference.

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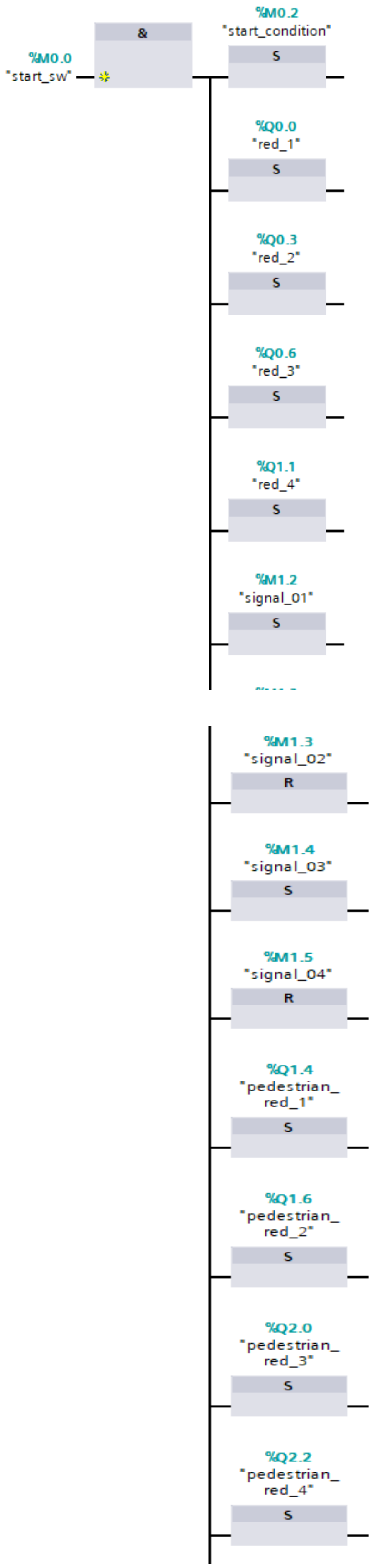
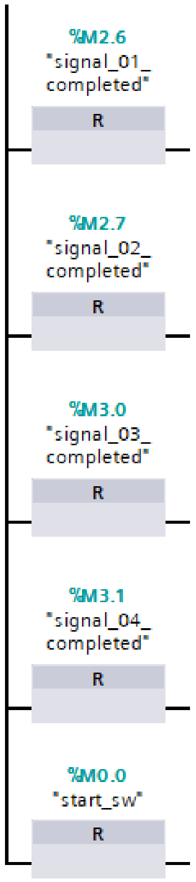
Appendix 1(1)

Coding segments of the program

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completed"
R
%M2.7
"signal_02_
completed"
R
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completed"
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%M3.1
"signal_04_
completed"
R
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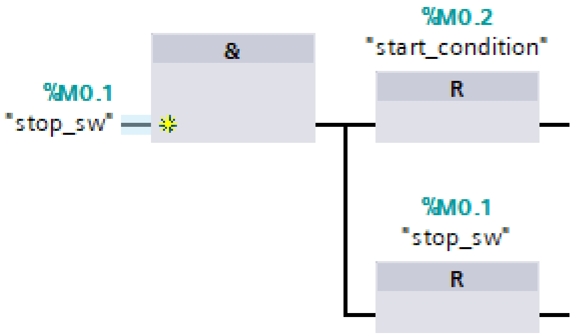
R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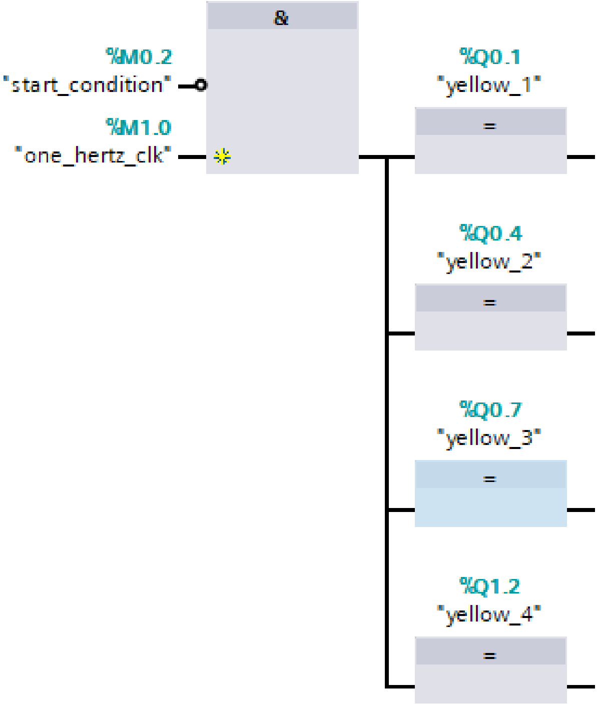
R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"yellow_2"
=
%Q0.7
"yellow_3"
=
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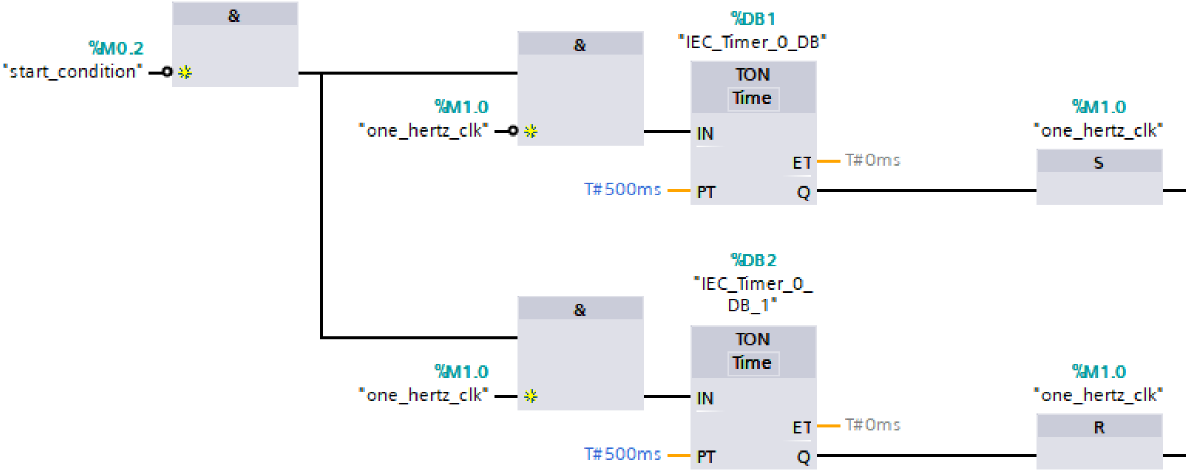
"yellow_4"
=


&
%M0.2
"start_condition"
&
%M1.0
"one_hertz_clk"
%DB1
"IEC_Timer_0_DB"
TON
Time
IN
ET
T#0ms
T#500ms
PT
Q
%M1.0
"one_hertz_clk"
S
&
%M1.0
"one_hertz_clk"
%DB2
"IEC_Timer_0_DB_1"
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Time
IN
ET
T#0ms
T#500ms
PT
Q
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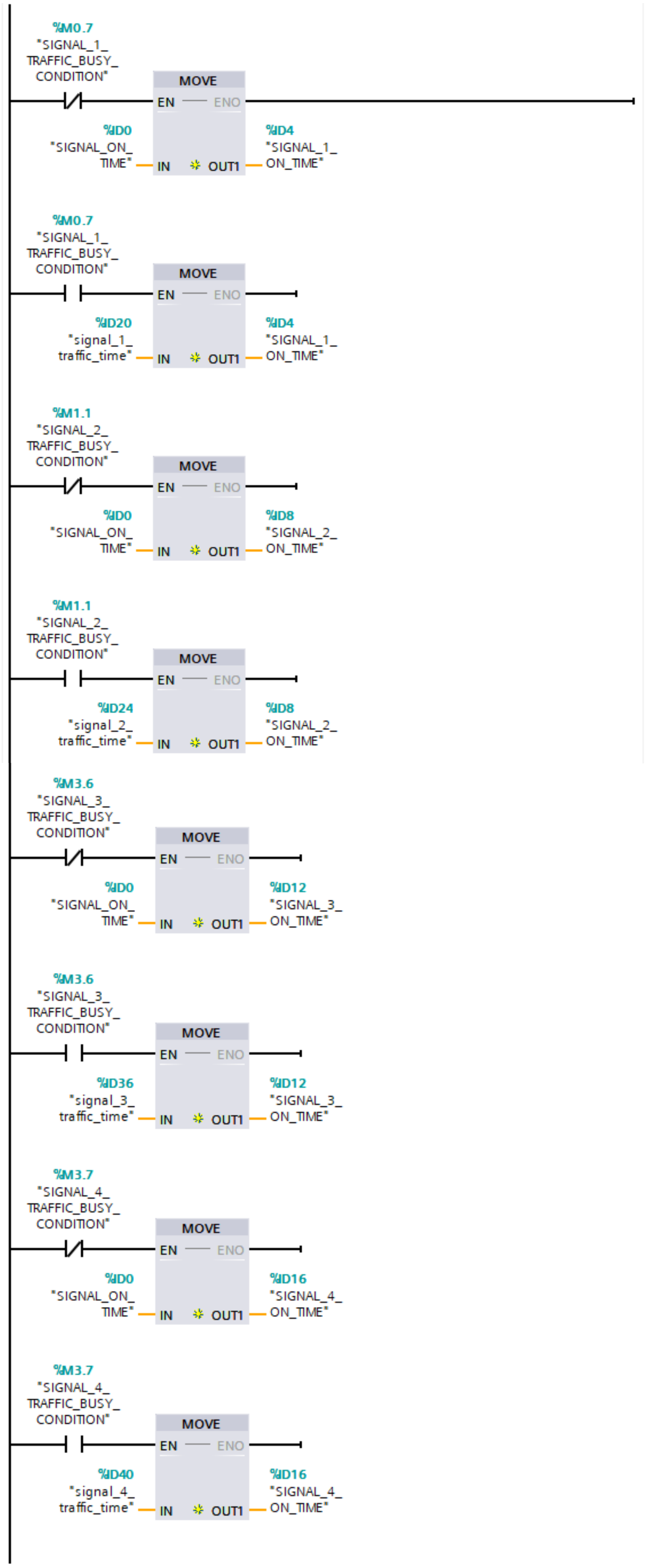
R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EN
ENO
%MD0
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IN
OUT1
%MD4
"SIGNAL_1_ON_TIME"
%M0.7
"SIGNAL_1_TRAFFIC_BUSY_CONDITION"
MOVE
EN
ENO
%MD20
"signal_1_traffic_time"
IN
OUT1
%MD4
"SIGNAL_1_ON_TIME"
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MOVE
EN
ENO
%MD0
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IN
OUT1
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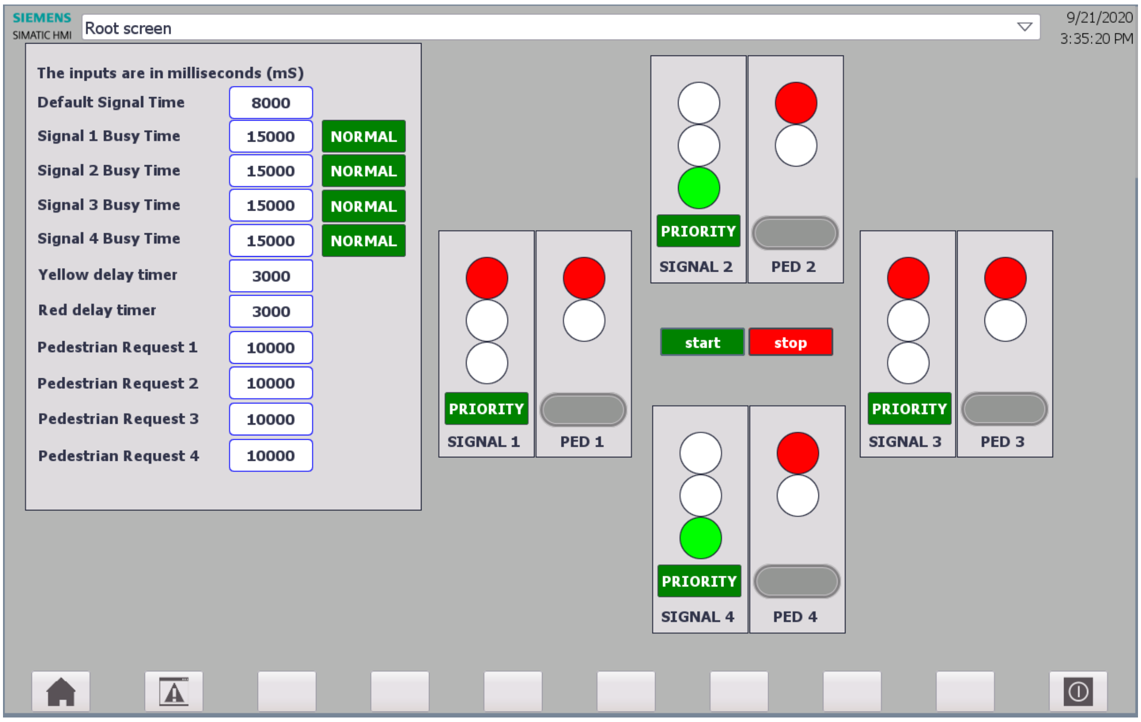
ENO
%MD0
"SIGNAL_ON_TIME"
IN
OUT1
%MD12
"SIGNAL_3_ON_TIME"
%M3.6
"SIGNAL_3_TRAFFIC_BUSY_CONDITION"
MOVE
EN
ENO
%MD36
"signal_3_traffic_time"
IN
OUT1
%MD12
"SIGNAL_3_ON_TIME"
%M3.7
"SIGNAL_4_TRAFFIC_BUSY_CONDITION"
MOVE
EN
ENO
%MD0
"SIGNAL_ON_TIME"
IN
OUT1
%MD16
"SIGNAL_4_ON_TIME"
%M3.7
"SIGNAL_4_TRAFFIC_BUSY_CONDITION"
MOVE
EN
ENO
%MD40
"signal_4_traffic_time"
IN
OUT1
%MD16
"SIGNAL_4_ON_TIME"

HMI working states

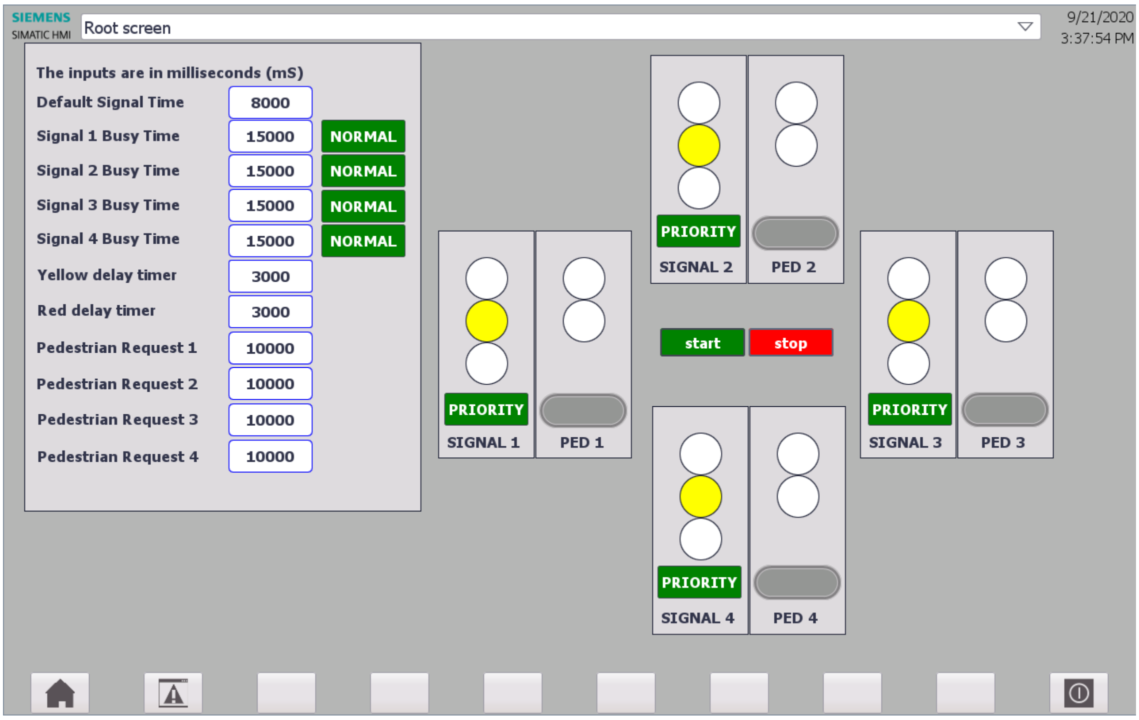


Root screen

9/21/2020
3:35:20 PM

The inputs are in milliseconds (mS)

Default Signal Time	8000	
Signal 1 Busy Time	15000	NORMAL
Signal 2 Busy Time	15000	NORMAL
Signal 3 Busy Time	15000	NORMAL
Signal 4 Busy Time	15000	NORMAL
Yellow delay timer	3000	
Red delay timer	3000	
Pedestrian Request 1	10000	
Pedestrian Request 2	10000	
Pedestrian Request 3	10000	
Pedestrian Request 4	10000	



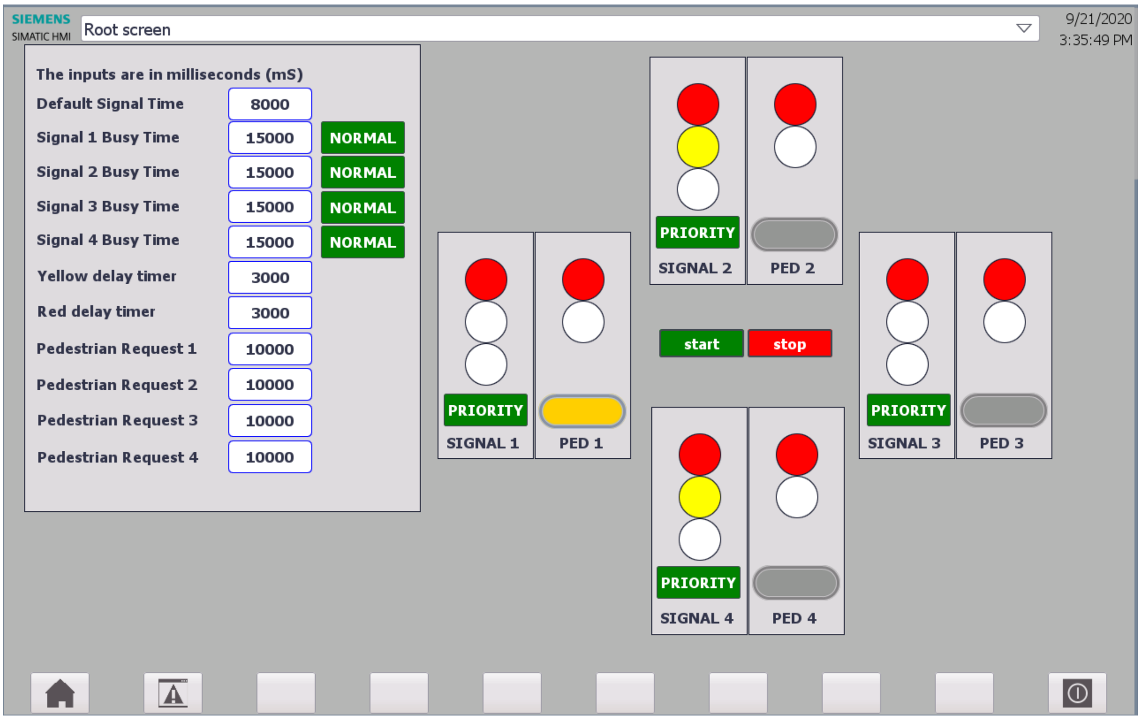
Root screen

9/21/2020
3:37:54 PM

The inputs are in milliseconds (mS)

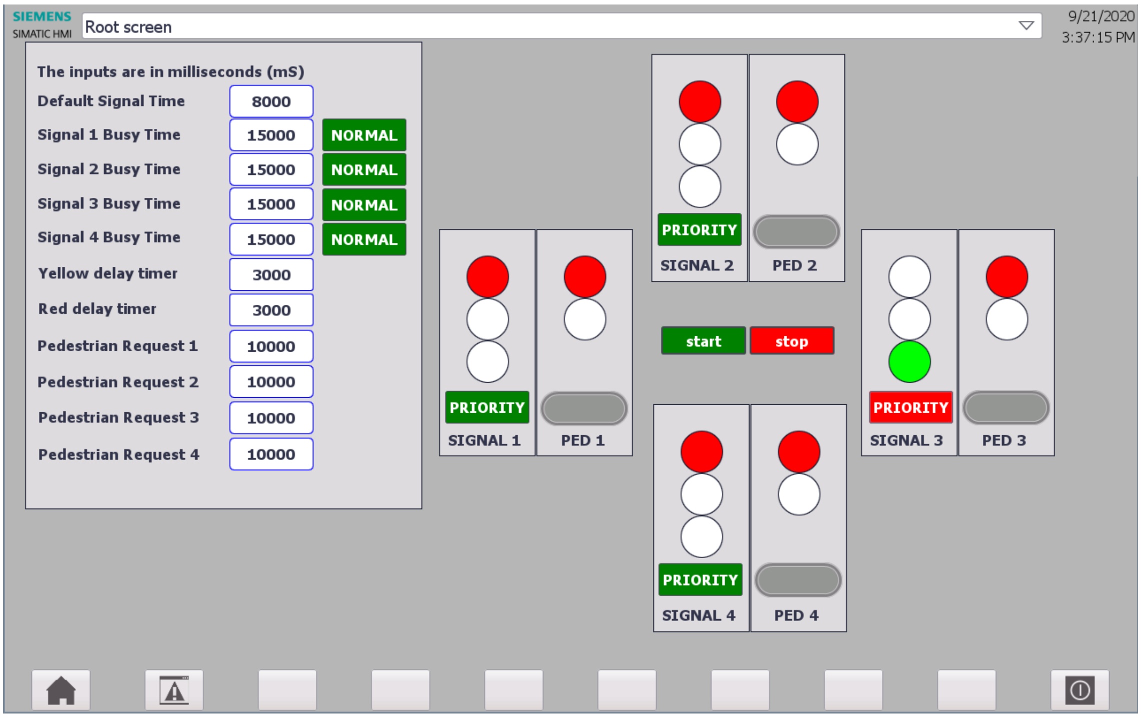
Default Signal Time	8000	
Signal 1 Busy Time	15000	NORMAL
Signal 2 Busy Time	15000	NORMAL
Signal 3 Busy Time	15000	NORMAL
Signal 4 Busy Time	15000	NORMAL
Yellow delay timer	3000	
Red delay timer	3000	
Pedestrian Request 1	10000	
Pedestrian Request 2	10000	
Pedestrian Request 3	10000	
Pedestrian Request 4	10000	

Appendix 2(2)



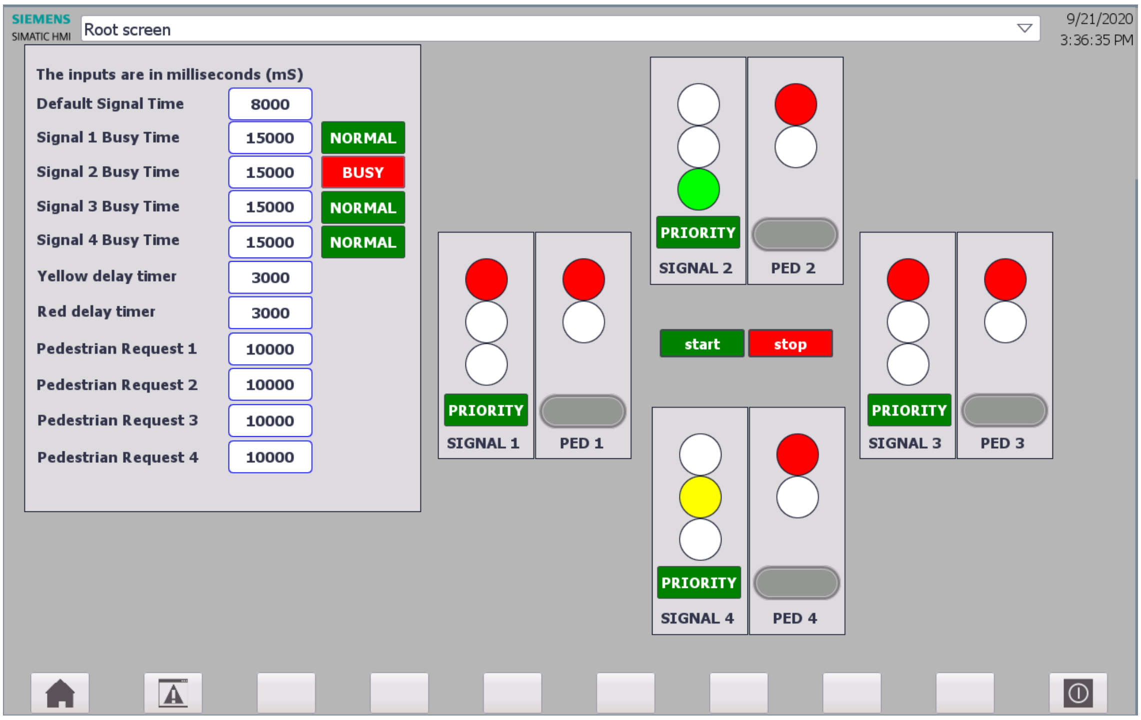
The inputs are in milliseconds (mS)

Default Signal Time	8000	
Signal 1 Busy Time	15000	NORMAL
Signal 2 Busy Time	15000	NORMAL
Signal 3 Busy Time	15000	NORMAL
Signal 4 Busy Time	15000	NORMAL
Yellow delay timer	3000	
Red delay timer	3000	
Pedestrian Request 1	10000	
Pedestrian Request 2	10000	
Pedestrian Request 3	10000	
Pedestrian Request 4	10000	



The inputs are in milliseconds (mS)

Default Signal Time	8000	
Signal 1 Busy Time	15000	NORMAL
Signal 2 Busy Time	15000	NORMAL
Signal 3 Busy Time	15000	NORMAL
Signal 4 Busy Time	15000	NORMAL
Yellow delay timer	3000	
Red delay timer	3000	
Pedestrian Request 1	10000	
Pedestrian Request 2	10000	
Pedestrian Request 3	10000	
Pedestrian Request 4	10000	



The inputs are in milliseconds (mS)

Default Signal Time	8000	
Signal 1 Busy Time	15000	NORMAL
Signal 2 Busy Time	15000	BUSY
Signal 3 Busy Time	15000	NORMAL
Signal 4 Busy Time	15000	NORMAL
Yellow delay timer	3000	
Red delay timer	3000	
Pedestrian Request 1	10000	
Pedestrian Request 2	10000	
Pedestrian Request 3	10000	
Pedestrian Request 4	10000	