Sensor Integrated PLC Based Smart Traffic Control System for a Busy Single Lane Junction

Rifatul Islam Himel, Dr. Md. Aziz UlHuq

Abstract-Traffic congestion is one of the major stumbling blocks to socio-economic development of a country. The difficulty in road transportation system that people are continuously facing can be addressed successfully by implementing state-of-art technologies. In this paper, we are proposing a sensor integrated Programmable Logic Controller (PLC) based traffic control system by using Siemens S7 200 controller. This system needs a PLC controller, traffic signal lighting system and sensors. The key objective of this paper is to illustrate how to build an effective and efficient control method that harnesses traffic flow by detecting the presence or absence of automotive within certain range by manipulating mathematical functions. The controller of this system analyzes the queue and recognizes the blockade of the streets in a junction with the help of string of sensors deployed at each side of the street. The PLC system allocates more time for high congested section according to Ladder Logic Diagram (LLD) program. PLC controller checks sensors status, follows logical commands and turns ON or OFF the red, yellow or green light to instruct thoroughfare users. This unit prefers to resolve main street traffic congestion over sub-street gridlock as one of the specialty of this module is high occupancy vehicle or HOV priority treatment. When traffic density regains its normal flow, this traffic controller operates traffic control lighting system sequentially like a usual time constant traffic controller.

Index term- LLD, PLC, PLC based traffic control, Sensor integrated traffic control, Smart traffic control system, Siemens PLC controller, Traffic control system

1. INTRODUCTION

The sheer advancement of modern communication is one of the greatest achievements of human civilization. The results of the developments of this sector bring sophistication, comfort and efficient road transportation system into our life. But the management and control of traffic movements within the existing infrastructure are also getting harder than ever before because of higher rate of vehicle usage and unpredictability of traffic load at certain point of our day to day journey. Therefore, we have to mobilize ourselves into jam-packed, bustling, poorly managed city street which causes a significant waste of time, increases environmental vulnerability to global warming and hampers socio-economic growth of a country. Therefore, we need to implement an effective and smart control system to overcome all those inconveniences. Some of the research have been done to detect the congestion or management of traffic or addressing both by implementing different kind of technologies, like- inductive loop system, infrared spectrum study, visual camera implementation, image processing technique, RFID and GSM technology[4] etc. But neither of them used sensor integrated PLC based intelligent system to analyze the queue of a gridlock to do priority treatment, manage and control the traffic flow. In this paper we will demonstrate a way to develop a smart system in PLC platform by using Siemens S7 200 controller to get rid of traffic snarl-up of a single lane junction.

2. SMART TRAFFIC CONTROL SYSTEM

Smart traffic control system has the ability to sense the presence or absence of vehicles in the street by receiving detectors inputs, processing data of controller status and can compute timing accordingly to switch on correct signal for a particular load in an intersection. Implementation of certain mathematical and logical operation and utilization of cutting age electronic technology, traffic movements can be manipulated for gaining optimum service. Generally, an electronically interconnected smart traffic control system depends on (1) cycle length of traffic light controlling system[5] (2) signal phases for a track[5], (3) the system's response to interruption[5] and (4) HOV priority treatment[11] as complementary service.

Besides, the control system variables, like- flow rate, occupancy and density, vehicular presence, speed, queue length and headway[11] have also to be taken into consideration to design an efficient smart traffic control system unit. Smart traffic control system works in four modes: Peak time, Off time, Normal flow and Manual operation[5]. Peak time and Off time modes normally are relied on input feeds of a control system. The input depends on sensing unit of smart system. The integrated sensing units ensure intelligent controlling provision. Thus, the system with the help of valid LLD coding can decide for itself how and whom to serve in chronological order.

3. Advantage of Smart Traffic Control System

There are several advantages of smart traffic control system over conventional manually controlled system. Such as-

1. Smart traffic control system reduces congestion, average delay time of vehicles and improves traffic handling capacity[3] in a junction.

2. It minimizes environmental pollution caused by traffic, driver's frustration, road rage and collisions[3].

3. It ensures traffic's orderly movement[5]and fine-tuning of journey time.

4. It eradicates flaws of manual control and assigns proper amount of time according to traffic load.

5. It is a helpful system for traffic police as they will be able to put more focus on their other responsibilities.

6. It introduces more secured and sophisticated crossing system for pedestrian and vehicle.

4. Working Principle of Smart Traffic Control System

Sensor integrated PLC based smart traffic control system takes sensor input in PLC and allows more time for blocked area. It has three integral parts, e.g. - (1) PLC controller, (2) Hardware or traffic lighting system and (3) sensors. PLC controller controls the whole unit, the hardware acts according to the output provided by PLC and the sensors provide inputs to main controller.

The PLC controller can be further divided into two parts. One is it hardware and another is software[5]. The logical commands from software are integrated into hardware to make PLC controller a fully functioning system.

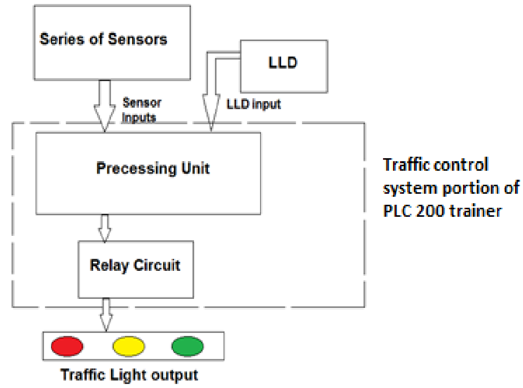


Fig 1: Working principle of smart traffic control system

PLC 200 trainer has its build in relay circuit to control traffic light output. Traffic light output consists of three kinds of LED signals- Red, Yellow and Green. A serious of sensors work as the input switches of this PLC controller. The series of sensors employed on the street can sense motor vehicle's presence and detect the size of queue of one side of an interconnection. PLC can analyze queue according to the LLD program set into processor by controller. The processor then process the input data and sends a signal according to the logic of the program to the output relay circuit. The signal timing of relay circuit alters according to command of LLD.

5. System Design

This paper illustrates a plan to design a smart traffic control system for single lane where the vehicles will move towards AC or BD (Fig. 2). This system ensures efficient AC and BD (Fig. 2) traffic movement. This will also do HOV priority treatment for AC traffic flow, because AC is considered to be Main Street and BD is sub-street in this paper. As Main Street contains more vehicles in peak hour and most of the cars, trucks, van etc. belong to important business dealings, it is necessary to put priority to major road than the sub roads. The sensors S1-S4 (Fig 2) in series at Main Street and S5-S8 (Fig 2) sensors at sub-street are to identify any blockage. They also do queue analysis. The programmed PLC system put priority for S1-S4 sensors. Red, yellow and green light will be illuminated according to the timing set in program. For each interruption of light path between transmitter and receiver of sensors, the time length of each phase of traffic lighting system will be extended. Hence, AC or BD (Fig 2) will have an opportunity to clear its own gridlock according to the density of traffic.

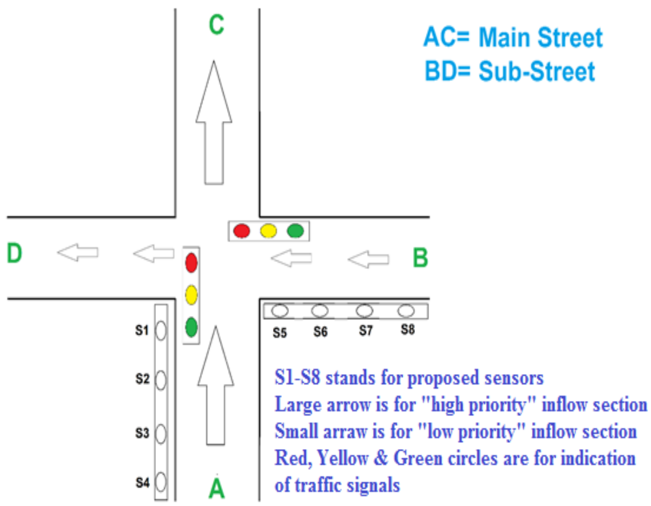
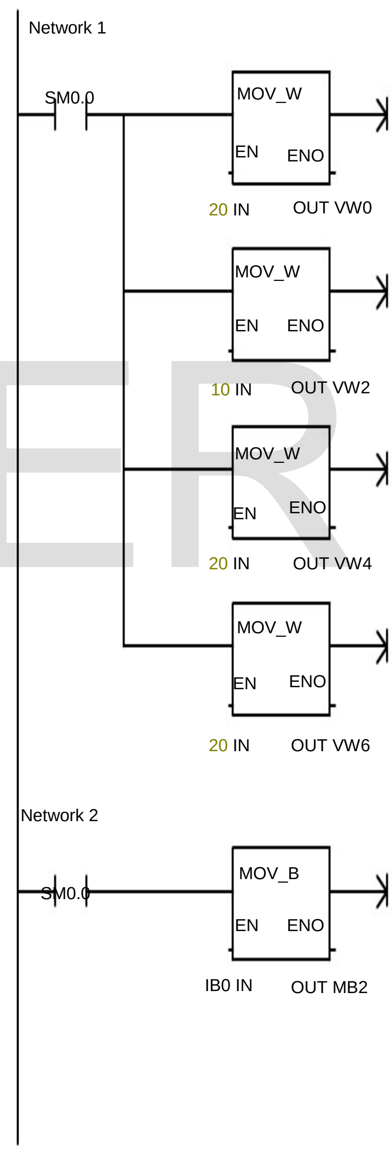
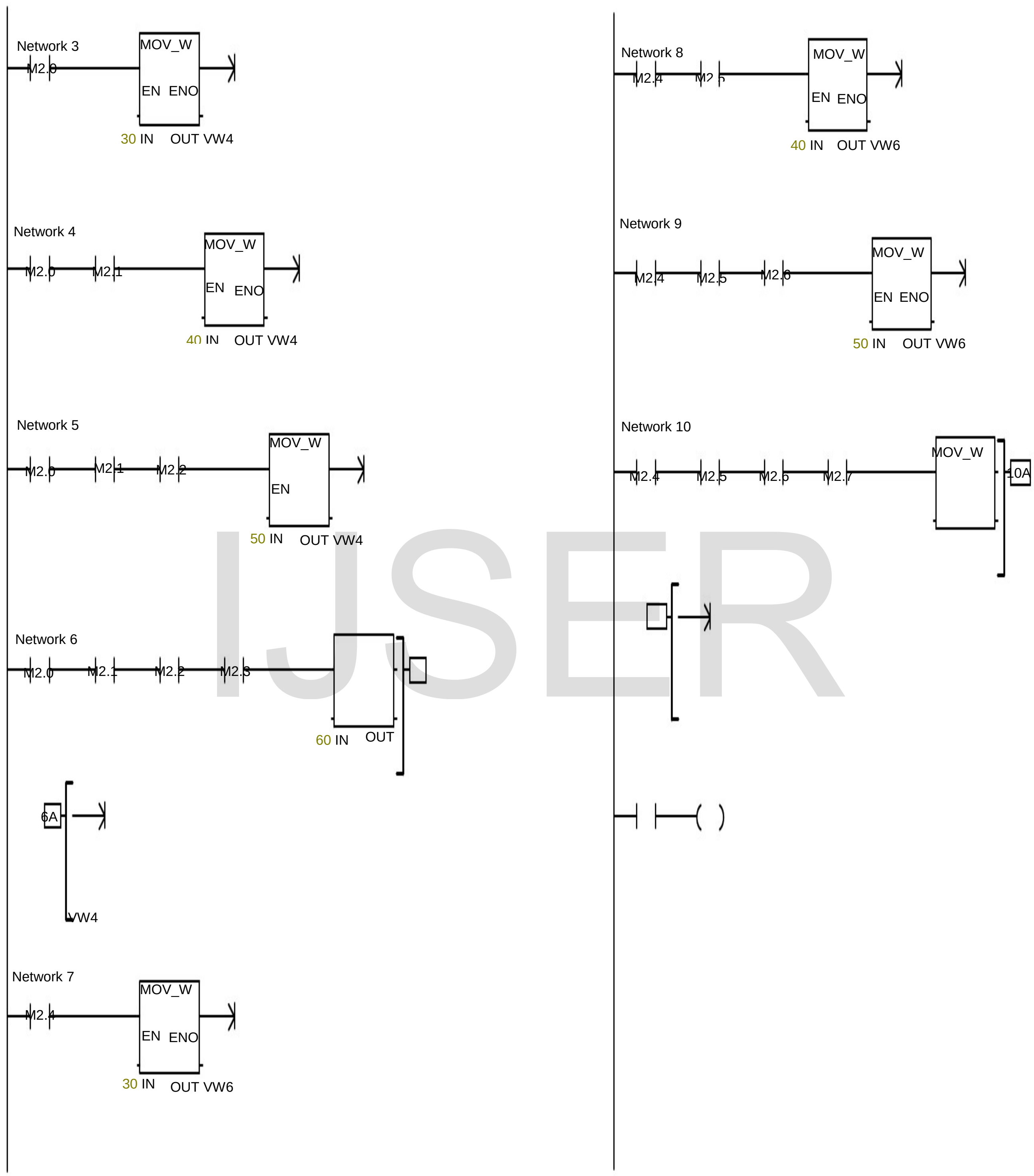


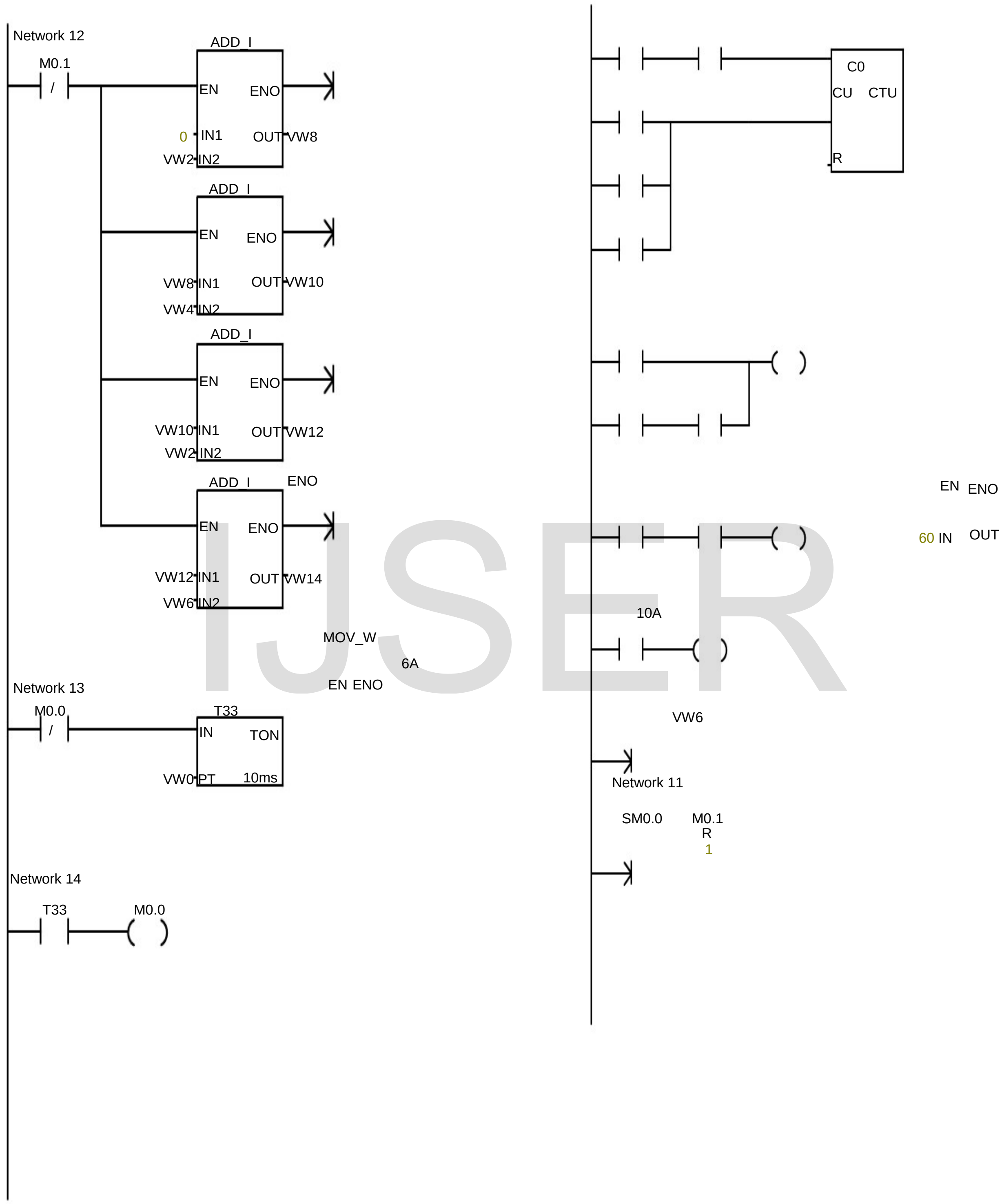
Fig 2: System plan

Smart traffic control LLD design consists of move word, move byte, add integer instructions, M2.0 to M2.7 input unit and a simple time constant traffic control system program. Special memory bits like- SM0.0, SM0.1 are read only components which provide a way of communication between computer's central processing unit and LLD program[2]. According to instruction manual, SM0.0 means that this bit provides always ON logic[2]. In this program, assigned variables for timing calculation of different stages are VW0, VW2, VW4, VW6, VW8, VW10, VW12 & VW14 (Fig 3). Move word (MOV_W) instruction is to shift numerical value from IN memory location to OUT location without changing the value. Here numbers are moved to variables registered in OUT memory unit. Each variable defines a memory unit which will store the value set for the program. Sensor output will be provided in M2.0 to M2.7 memory bit. When any of these memory bit turns on, the variables will add more time assigned to the program to prolong the duration of traffic light signal shifting to allow more traffic to flow for a particular lane. M0.1 is another bit used here to put logic for add integer instruction set. The command here for M0.1 shows that it is always closed in this program. Add integer (ADD_I) program will get the value from variables and will continue to add the two different variables always. If any of numerical value of a variable changes, the adder will also make the same type of modification to its output variable which allows the total system to adapt with the change of sensor input. A basic time constant traffic system is the base of this smart traffic control system. On-delay timer, up counter, positive transition and Q0.0 to Q0.2 bit are for clock, counting time for output signals, power flow to up counter and output respectively. I1.0 memory bits is set to manually control the traffic lighting system unit where SM0.1 is connected with the reset system of the up counter to ensure that first scan service is enabled. With the change of numerical value of VW8, VW10 and VW12, the outputs Q0.0, Q0.1 and Q0.2 starts functioning according to logical commands.

The LLD diagram of smart traffic control system is illustrated below:




Network 3
M2.0
MOV_W
EN ENO
30 IN OUT VW4
Network 4
M2.0
M2.1
MOV_W
EN ENO
40 IN OUT VW4
Network 5
M2.0
M2.1
M2.2
MOV_W
EN
50 IN OUT VW4
Network 6
M2.0
M2.1
M2.2
M2.3
60 IN OUT
6A
VW4
Network 7
M2.4
MOV_W
EN ENO
30 IN OUT VW6
Network 8
M2.4
MOV_W
EN ENO
40 IN OUT VW6
Network 9
M2.4
M2.5
M2.6
MOV_W
EN ENO
50 IN OUT VW6
Network 10
M2.4
M2.5
M2.6
M2.7
MOV_W
10A


Network 12
M0.1
ADD_I
EN ENO
0 IN1 OUT VW8
VW2 IN2
ADD_I
EN ENO
VW8 IN1 OUT VW10
VW4 IN2
ADD_I
EN ENO
VW10 IN1 OUT VW12
VW2 IN2
ADD_I ENO
EN ENO
VW12 IN1 OUT VW14
VW6 IN2
MOV_W
6A
EN ENO
Network 13
M0.0
T33
IN TON
VW0 PT 10ms
Network 14
T33
M0.0
C0
CU CTU
R
EN ENO
60 IN OUT
10A
VW6
Network 11
SM0.0
M0.1
R
1

Network 15
M0.0
P
SM0.1
C0 0 PV
>=I
VW14
I1.0

Network 16
C0 Q0.0
<=I
VW8
C0 C0
>I <=I
VW10 VW12

Network 17
C0 C0 Q0.1
<=I >I
VW10 VW8

Network 18
C0 Q0.2
>I
VW12

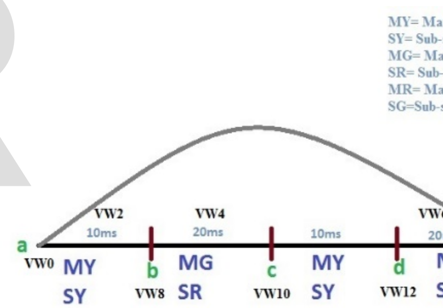


Fig 3: Time counting system analysis

6. Design Analysis

The amount of time is set carefully for the cycle of the program, for each of the interruption and for each of the light signal. MY (Fig 3) means Main street yellow light is on where SY (Fig 3) means sub street yellow light is on. When the signal from Main Street is Red (MR), then the sub-street will send a Green signal (SG) allowing traffic to flow in that portion. Likewise, when sub-street shows Red (SR), then Main Street permits traffic to move forward by providing green signal (MG).

The variables VW2 is set for 10ms. 20ms is assigned for each variable, VW4 and VW6. Main Street will indicate to stop traffic by Red light (VW6) and Main road green signal will appear for variable VW4. Subsequently, sub- street lighting system will provide signals for outflow.

From LLD diagram illustrated in this paper, in network 1, SM0.0 or always ON logic instigates to execute first line of LLD command provided in coding. Move word (MOV_W) instructions are enabled to move 20 to VW0, VW4 and VW6 memory and 10 to VW2. All the commands will be in parallel which means that Move word (MOV_W) instructions are to execute once at a time as parallel operation suggest OR operation to perform.

In network 2, SM0.0 always on bit is used to shift all input (IB0) to output (MB2). All the input data will be read and send to another memory bit in this operation. In network 3 to 6, M2.0, M2.1, M2.2 and M2.3 memory bits are added to get input from sensors. For each memory bit 10ms is included. So, if any of the bit in a row is on, the program will add 10ms to its phase and to the cycle. The output of these mathematical operation will be assigned to VW4 as it will shift or include the time of MG and SR portion. Like the same way, in network 7 to 10, M2.4, M2.5, M2.6 and M2.7 bits are added. These also increase 10ms to each of the lane and to the whole cycle. The execution of these operation will move to VW6 unit where time duration of MR and SG will be calculated.

In network 11 and 12, add integer operations and add cycle are programmed. SM0.0 always ON bit resets M0.1 bit after all operations done in network 12. So, after 1 cycle, it starts executing addition operation and also continues to place the summation of the calculation into different memory bit. The variable assigned for different memory bit are VW8, VW10, VW12 and VW14. Add integer (ADD_I) integer instruction are in parallel with one another while M0.1 is closed. In this program M0.1 is always closed and is reset when all addition of VW8, VW10, VW12 and VW14 are done once and for next cycle, it continues to complete this operation again. The operations are:

$$VW8 = VW0 + VW2 \quad (1)$$

$$VW10 = VW8 + VW4 \quad (2)$$

$$VW12 = VW10 + VW2 \quad (3)$$

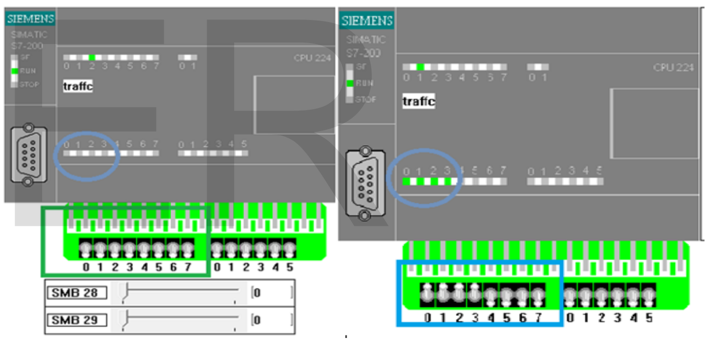
$$VW14 = VW12 + VW6 \quad (4)$$

In network 13-14, a clock is created for C0. PT is equal to VW0. When T33 ≥ PT (Present time)/ VW0, then the timer resets itself and TON of T33 triggers next circuit to ON state. For positive transition, C0 starts working. The length of full cycle is VW14. After the time span of VW14, it automatically resets C0 and the whole program then starts working again. I1.0 memory bit is available to provide a manual control service in case of any failure.

In network 16 to 18, a traffic control lighting system program has been created by assigning variables in time counting potion of the program. VW0 to VW8 and VW10 to VW12 time span in circuit make Q0.0 on. Q0.0 is for Yellow light. VW8 to VW10 time period is for "MG and SR" signal. These are generated when Q0.1 is ON within VW8 to VW10. The total time of VW12 to VW14 is assigned for "MR and SG". So, Q0.2 is ON within time length of VW12 to VW14. Thus, a logic or program is developed to sense the presence and absence of vehicle and to manipulate traffic control system according to the plan, time schedule and condition of traffic congestion in any junction.

7. System Test Result

S-7 200 simulator is a program which creates a virtual environment for testing any PLC program created in STEP 7-Micro/Win IDE Software[2]. Its LLD program testing arrangement is built in such a way that it can replace any laboratory test environment. It executes program with precision. It has 10 CPU configurations. It also provides virtual buttons to control input units. The program output can be checked on KOP screen and from virtual output units. Green signal determines the condition of input and output unit according to command and input interruption of the program.



(a) (b)

Fig 4: S-7 200 Simulator test- (a) without switching any input,(b) by switching main street side input

This program is done for CPU 224 system where there are 0-7 inputs and outputs. 8 inputs and 3 outputs are required to examine our program. When smart traffic program are loaded into this virtual system, it automatically generates KOP and OB1 which are resemble to the actual program's LLD and STL diagram respectively. When the program is running without putting any input unit, the program will act like a time constant traffic control system. The time spans for each signal to appear in screen are VW0 to VW8, VW10 to VW12, VW8 to VW10 and VW12 to VW14. In this simulator, output 0 or Q0.0 means actual yellow signal of both street ON. Output 1 or Q0.1 and 2 or Q0.2 are for "MG and SR" and "MR and SG" respectively.

In Fig. 4(b) unlike Fig 4(a), inputs have been provided by 0 to 3 input button. Four light indicator on display input unit 0 to 3 ensure that inputs are ON. This means the sensors of main road get interrupted virtually by vehicles. So, the time of "MG and SR" signal will be lengthened according to the program. In simulator test, after yielding 0 to 3 inputs, output display 1 blinks for longer time than other two. Similarly, for 4-7 input, the light flashing period for output display 2 prolonged and it is more for than the usual time constant traffic signal time.

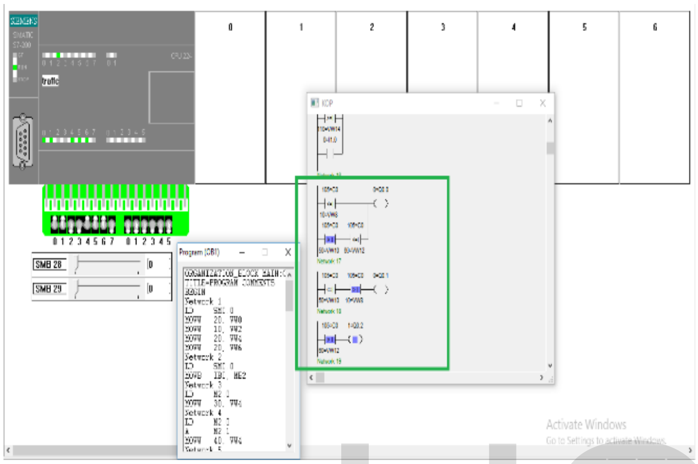


Fig 5: S-7 200 Simulator test result monitoring from KOP

In Fig. 5, KOP display facilitates to monitor outputs for each and every second of executed program. It shows the status of time count, output display unit and total time for a cycle. It is very useful tool to check exactly whether the addition of input changes the system or if Q0.0, Q0.1 and Q0.2 are working according to the developed LLD program.

In laboratory, all the necessary equipment like- PLC-200 trainer, PC for running program, USB cable to connect modular with PC or program, sensors for input to PLC modular and traffic control lighting system module to check outputs are used to run actual test. PC, sensors, PLC-200 trainer and traffic control lighting module are connected to AC power source. USB port from PC is connected with PLC module by USB cable. With the help of V4.0 STEP 7 MicroWIN SP9, the LLD program of smart traffic control system is loaded into PC. Traffic control lighting module and sensors then are connected with output and input units of module respectively for reexamining this system. When the program is run in normal condition, the output unit starts to act like a time constant traffic control system. It turns red, green and yellow lights after a certain time period defined by the program. When there are any obstacle in light transmission line between transmitter and receptors sensors, the module gets input. So, the program elongates time for a particular signal according to the program. We can check the time difference by comparing time taken to complete a certain phase and cycle before and after placing an obstruction.

8. Discussion and Further Development

In this paper, an intelligent traffic control system are developed where PLC tools and sensors are used. Implementation of this system requires high installation and maintenance charge. But this system will eliminate human errors and other traffic related problems. This smart system for single lane is much more sophisticated system than manually controlled system or time constant traffic control system. But like every other scientific unit, there are always a place for improvement. In this design, double lane junction was not considered. More sensors are needed to implement this system for double lane and the program also requires to be modified. More memory unit 3.0 to 3.7 also have to be used for other sensors and have to add mathematical functions in LLD accordingly. A theoretical plan has been made for the further development of this research. The plan is illustrated below:

Fig 6: Future plan for multiple lane

In this system, single side of a road will be divided into two segment. For each side of the road A, B, C and D, in flow will be 1 and out flow will be 2. In Fig 6, A1 is the inflow of the road A and the vehicle of A1 will pass by D2, C2 and B2. A1 is assigned in all of those street to clarify the current traffic movement showed in Fig 6. We can also do some research on power source of this smart unit. We can implement research of renewable energy to make it eco-friendly. In the future, some data acquisition and storage system will be studied for further development of this system to predict traffic condition of a junction in advance.

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