APPENDIX A

OPERATION OF BM1

The traffic light system illustrated in [109], performs the basic functionality of the traffic light systems and it consists of two entities, the traffic light controller (TLC) and the traffic light display entity (TLD). The traffic light controller performs a pre-timed switching among pre-set phases.

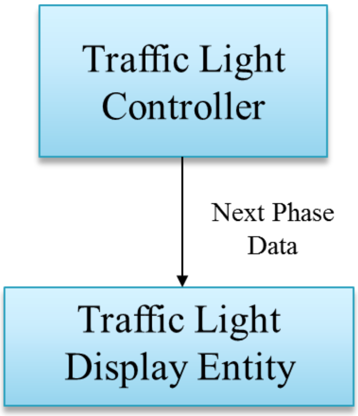

Figure A.1. Fixed Traffic Light Phase Plan System

The green time is distributed among all the intersection legs equally without taking in consideration the conditions of the approaches. This traffic light controller performs a fixed cycle of timed sequence as can be seen in Figure A.2.

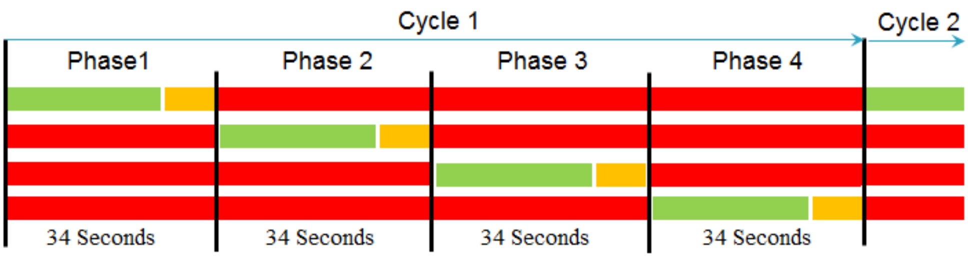

Figure A.2. BM1's Fixed (Pre-timed) Phasing Sequence

The phase time might be changed according to setting up company and the intersection's geometrical setup. The controller keeps repeating the same cycle timing and sequencing.

APPENDIX B

OPERATION OF BM2

The traffic light system illustrated in [110], performs added a modification to the basic functionality of the traffic light systems (illustrated in [109]) and it consists of three entities, the vehicle presence sensor, the traffic light controller (TLC) and the traffic light display entity (TLD). Just like BM1, the traffic light controller performs a pre-timed switching among pre-set phases with an added feature of skipping the phase which has no vehicles on.

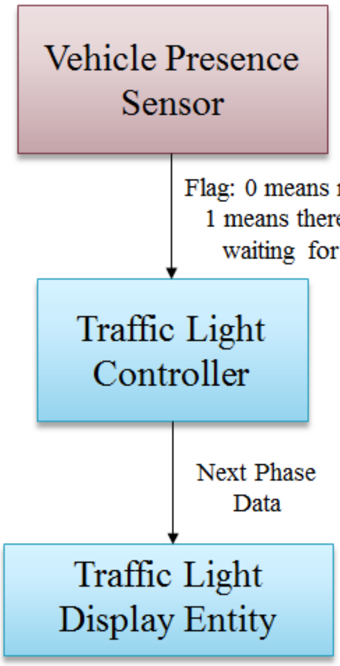

Figure B.1. Actuated Traffic Light System

The actuated traffic light behaves just like the fixed phase plan traffic light with one exception that is has the ability to detect the approaches with no vehicles on so it skips giving green time to that approach and continues with its cycle. Figure B.2 shows an example when phase two has no vehicles waiting for a green time, it will be skipped according to the rule of the actuated traffic light system.

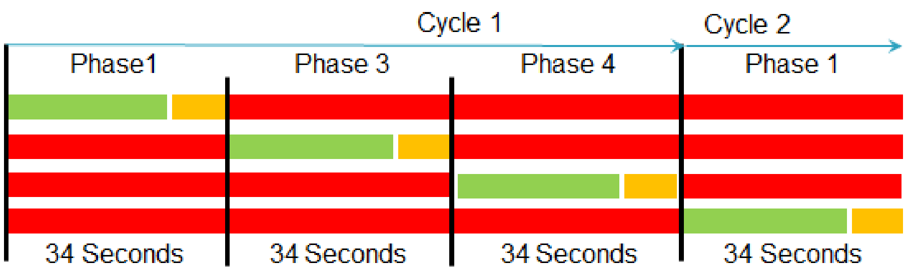

Figure B.2. BM2's Actuated Phasing Sequencing

The phase time might be changed according to setting up company and the intersection's geometrical setup. The controller keeps repeating the same cycle timing and sequencing with skipping the empty approaches.

APPENDIX C

OPERATION OF NM1

Referring to the work in [98], it introduced a new solution for the traffic congestion problem via using Fuzzy algorithm to run within the traffic light controller to make the phase decisions. The intersection model used in this work was a standard four legs intersection. Each approach consists of two lanes (through and left) as the right lane was assumed to be a slip lane. The arrival process was programed to be poison-randomly distributed arrival for each of the eight lanes.

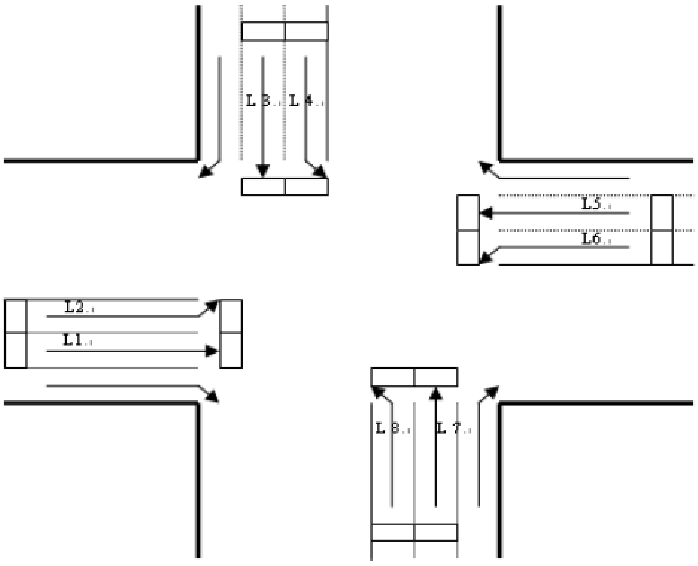

Figure C.1. Isolated Intersection Traffic Model

The controller was designed to make two decisions, the phase sequence priority and the green phase delay time. The phase priority was calculated by determining the Access queue and the Waiting queue, defined in Table C.1, summationsfor each of the twelve phases then sort them in descend order based on the Access queue values and choose the phase with the highest Access queue to be implemented next. While the green phase time was calculated by inserting both of the Access queue (N) and the Waiting Queue (W), as shown in Figure C.2, for the chosen phase to a fuzzy control algorithm to be evaluated. The two inputs membership functions are shown in Figure C.3 and C.4, while the output's membership function is shown in Figure C.5. The fuzzy control algorithm evaluates the two inputs via a set of rules shown in Table C.2.

Table C.1. Definitions for the Access Queue and the Waiting Queue

Phase	*Access queue*	*Waiting queue*
Phase 1	L8+L7	L1+L2+L3+L4+L5+L6
Phase 2	L8+L5	L1+L2+L3+L4+L6+L7
Phase 3	L8+L4	L1+L2+L3+L5+L6+L7
Phase 4	L7+L3	L1+L2+L4+L5+L6+L8
Phase 5	L7+L2	L1+L3+L4+L5+L6+L8
Phase 6	L6+L5	L1+L2+L3+L4+L7+L8
Phase 7	L6+L3	L1+L2+L4+L5+L7+L8
Phase 8	L6+L2	L1+L3+L4+L5+L7+L8
Phase 9	L5+L1	L2+L3+L4+L6+L7+L8
Phase 10	L4+L3	L1+L2+L5+L6+L7+L8
Phase 11	L4+L1	L2+L3+L5+L6+L7+L8
Phase 12	L2+L1	L3+L4+L5+L6+L7+L8

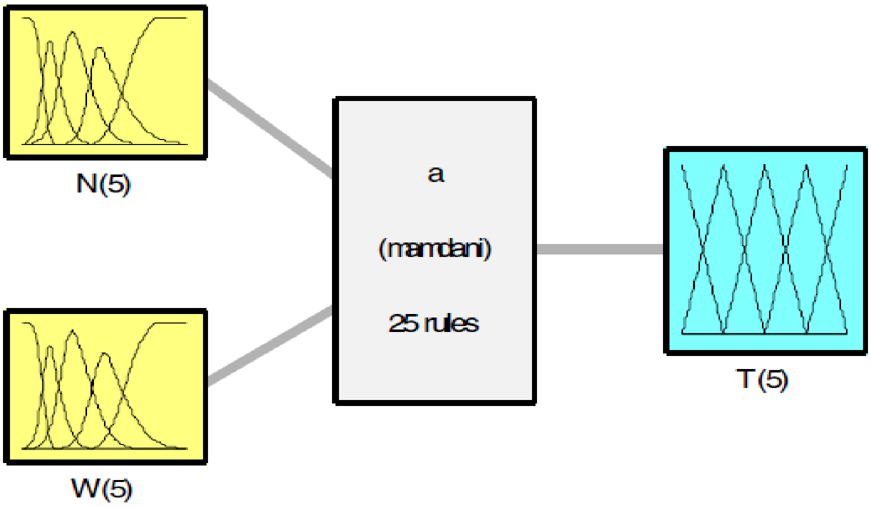

Figure C.2. The Fuzzy System Block Diagram for the Next Green Phase Time Decision Making

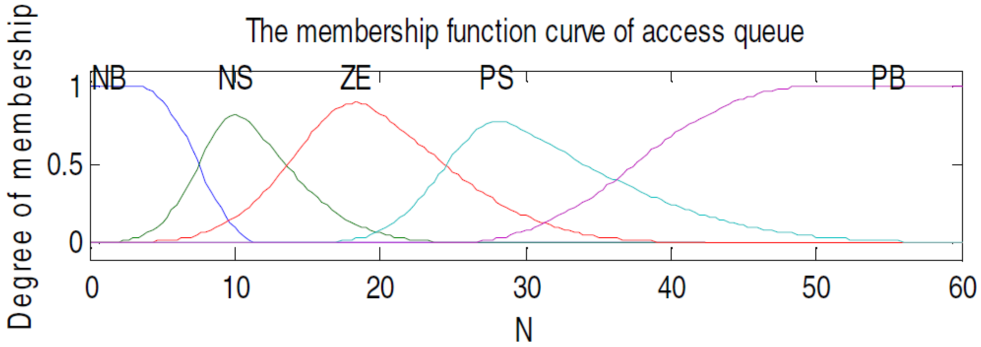

Figure C.2.The Input Membership Function for the Access Queue (N)

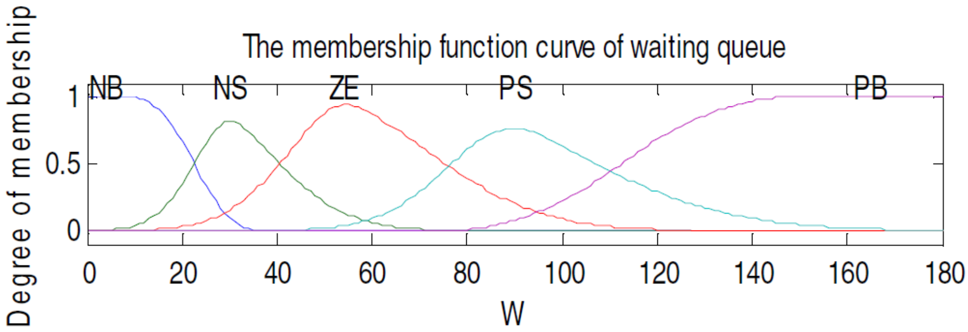

Figure C.3. The Input Membership Function for the Waiting Queue (W)

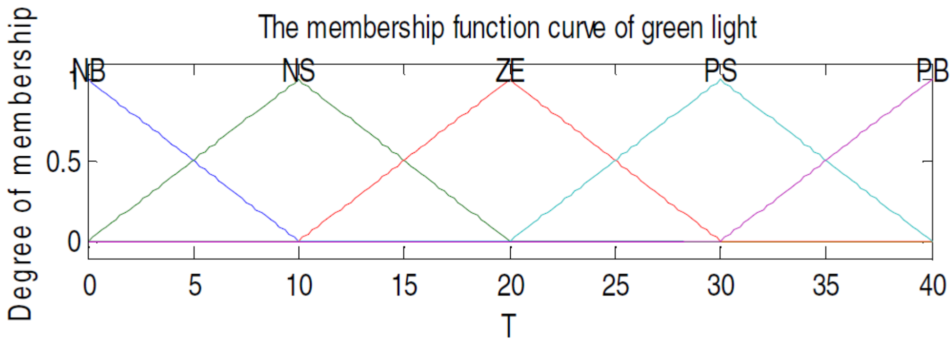

Figure C.4. The Output Membership Function for the Next Green Phase Time

Table C.2. Next Green Phase Time Decision Maker's List of Rules

N \ T \ W	***NB***	***NS***	***ZE***	***PS***	***PB***
NB	NB	NB	NB	NB	NB
NS	NS	NB	NB	NB	NB
ZE	ZE	NS	NS	NB	NB
PS	PS	ZE	ZE	NS	NB
PB	PB	PS	ZE	ZE	ZE

APPENDIX D

OPERATION OF NM1

Referring to the work in [112], it introduced a new solution for the traffic congestion problem via using Fuzzy algorithm to run within the traffic light controller to make the phase decisions. The intersection model used in this work was a standard four legs intersection. Each approach consists of two lanes (through and right) as the left lane was assumed to be a slip lane.The arrival process was programed to be poison-randomly distributed arrival for each of the eight lanes.

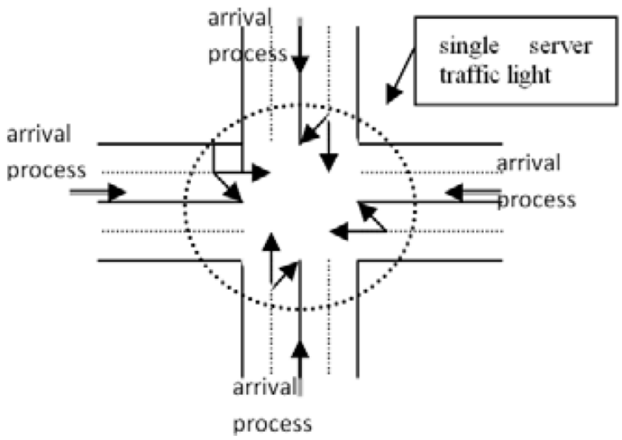

Figure D.1 Isolated Intersection Traffic Model

The controller was designed to make two decisions, the phase sequence and the phase green time extension. The phase sequence decision maker is a C language code which consists of a set of conditional rules to determine which approach has the highest priority to become green next phase. The phase sequence decision is being made per approach. In other words, the total number of phase’s possibilities is four phases which is can limit the system flexibility and accordingly the response accuracy. Another feature was added for the phase sequence block that it can skip a phase in case an approach has a zero number of vehicles in its queue. According to fuzzy membership functions, the maximum number of vehicles can be detected is 50 vehicles per approach which added another limitation to the systems as an approach with a 50 vehicles queue length would have the same priority as that one with a 1000 vehicles queue length.

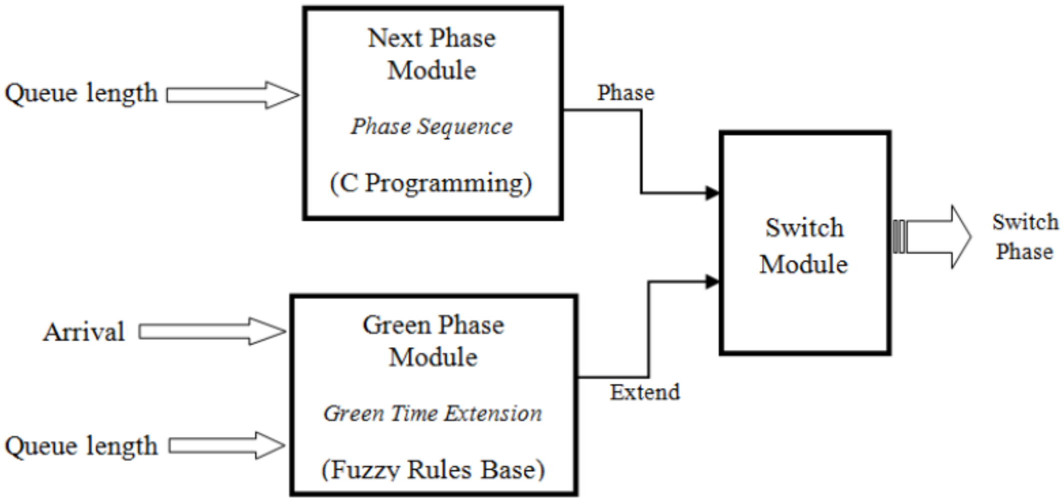

Figure D.2. Block Diagram of a Fuzzy Traffic Signal Controller

The other decision maker is the green time extension module which takes two input factors (queue length and the lane waiting time), and insert them to a fuzzy rules based algorithm, as shown in Figure D.3, to the determine the total time to be added to the next green phase. The input membership functions for the queue length and the waiting time can be seen in Figures D.4 and D.5.

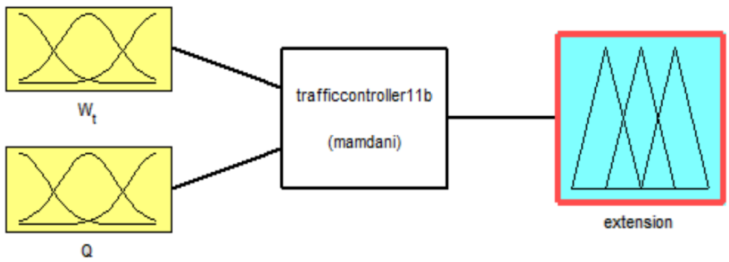

Figure D.3 Block Diagram for the Next Phase Green Time Extension Decision Maker

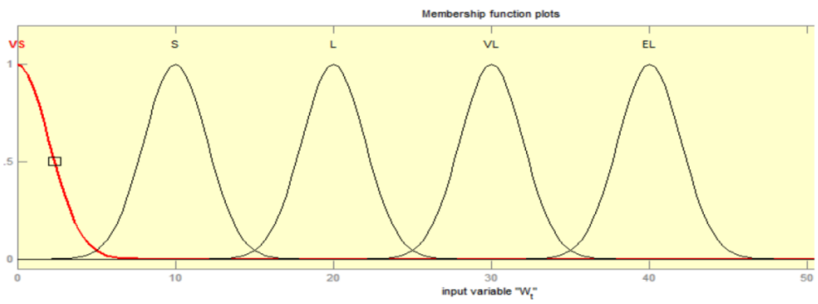

Figure D.4 Fuzzy System Input Membership function for the Vehicles Waiting Time (W_t)

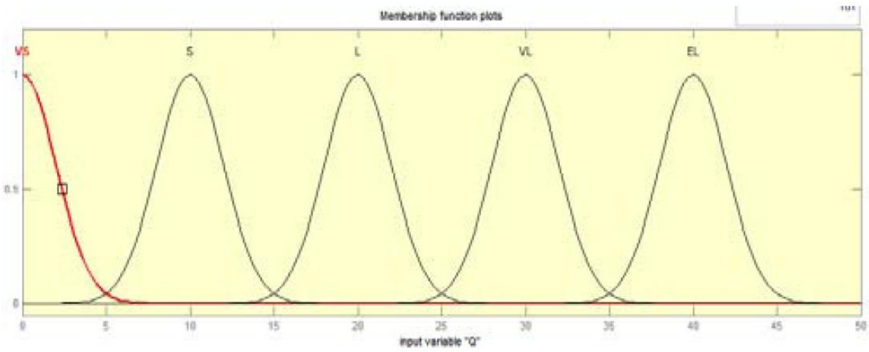

Figure D.5. Fuzzy System Input Membership function for the Approach Queue lengths (Q)

The green time extension decision maker would take the two inputs then evaluates them according to the Mamdani fuzzy logic rules those shown in Table D.1 and the final decision of the green time extension can be within the range shown in Figure D.6.

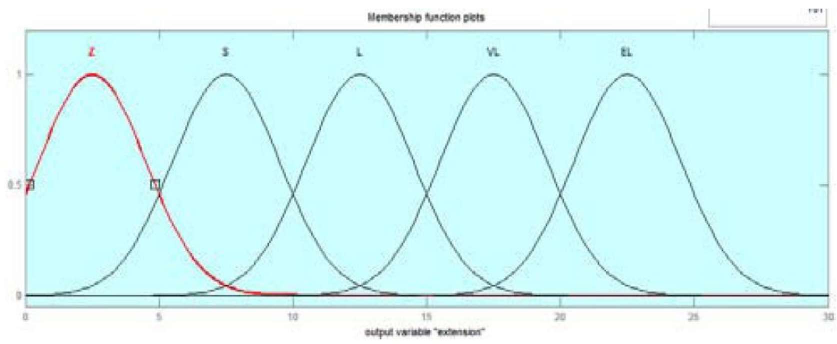

Figure D.6. Fuzzy System Output Membership function for the Phase time Extension

Table D.1. Green Phase Time Extension Decision Maker's Fuzzy Rules

Rules	Input 1(W_t)	Input 2(Q)	Output(extension)
1	VS	VS	Z
2	VS	S	Z
3	VS	L	S
4	VS	VL	S
5	VS	EL	L
6	S	VS	Z
7	S	S	S
8	S	L	S
9	S	VL	L
10	S	EL	L
11	L	VS	S
12	L	S	S
13	L	L	L
14	L	VL	L
15	L	EL	L
16	VL	VS	S
17	VL	S	S
18	VL	L	L
19	VL	VL	VL
20	VL	EL	EL
21	EL	VS	L
22	EL	S	L
23	EL	L	L
24	EL	VL	VL
25	EL	EL	EL

APPENDIX E

NEXT PHASE GREEN TIME CALCULATION EXAMPLES

In Figure E.1, the detailed calculation of the next phase green time is shown where the current green phase is (1-2), and it is the time for the phase to transit to become (4-5).

<u>Next Green Phase Time Algorithm</u>

1. **Initialization**
   - $V_C(1,T) = 0$, $V_C(2,T) = 0$, $V_C(4,T) =100$, $V_C(5,T) = 100$, $V_C(7,T) = 75$, $V_C(8,T) = 75$, $V_C(10,T) = 50$, $V_C(11,T) = 50$.
   - $C_{FVA}$for all the lanes are 1except $C_{FVA}(1,T)=0$ and $C_{FVA}(1,T)=0$.
   - $G_{C1}= 1$, $G_{C2}= 2$, $G_{N1}=4$, $G_{N2}=5$, and Full_Cycle_Time = 120

2. **DETERMINATION of** which direction's queues are confirmed to have arrived:
   - $V_C'(1,T) = 0$, $V_C'(2,T) = 0$, $V_C'(4,T) =100$, $V_C'(5,T) = 100$,
   - $V_C'(7,T) = 75$, $V_C'(8,T) = 75$, $V_C'(10,T) = 50$, $V_C'(11,T) = 50$.

3. **DETERMINATION** of VC''
   - $V_{C(4)}''(1,T) \leftarrow 0 * (1) * (0 \text{ and } 0) = 0$, $V_{C(4)}''(2,T)=0$, $V_{C(4)}''(4,T)=100$, $V_{C(4)}''(5,T)=0$, $V_{C(4)}''(7,T)=75$, $V_{C(4)}''(8,T)=0$, $V_{C(4)}''(10,T)=0$, $V_{C(4)}''(11,T)=50$
   - $V_{C(5)}''(1,T)=0$, $V_{C(5)}''(2,T)=0$, $V_{C(4)}''(4,T)= 0$, $V_{C(4)}''(5,T)=100$,$V_{C(5)}''(7,T)=75$, $V_{C(5)}''(8,T)=75$, $V_{C(5)}''(10,T)=50$, $V_{C(5)}''(11,T)=0$

4. **CALCULATE**, for each of the two directions, the summation of the results in step 3.
   $V_{CT}(4,T) = 0+0+100+0+75+0+0+50= 225$
   $V_{CT}(5,T) = 0+0+0+100+75+75+50+0 = 300$

5. **CALCULATE**, for each of the two directions, the division of the chosen direction's queue length over the total summation found for that direction in step 4.
   $VNR_4 = 100 / 225 = 0.445$
   $VNR_5 = 100 / 300 = 0.334$

6. **CALCULATE**, for each of the two directions, what percent of the full cycle time must be given to that direction.
   $G_{TN1} \leftarrow 0.445 * 120 = 53.4$
   $G_{TN2} \leftarrow 0.334 * 120 = 40.08$

7. **DETERMINE** the next phase time.
   Next_Phase_Time = Average(53.4 , 40.08) = 47 Seconds (rounded)

Figure E.1. Next Phase Green Time Calculation when phase transits from (1-2) to (4-5)

In Figure E.2, the detailed calculation of the next phase green time is shown where the current green phase is (1-2), and it is the time for the phase to transit to become (7-8).

Next Green Phase Time Algorithm

8. **Initialization**
   - $V_C(1,T) = 0$, $V_C(2,T) = 0$, $V_C(4,T) = 100$, $V_C(5,T) = 100$, $V_C(7,T) = 75$, $V_C(8,T) = 75$, $V_C(10,T) = 50$, $V_C(11,T) = 50$.
   - $C_{FVA}$for all the lanes are 1except $C_{FVA}(1,T)=0$ and $C_{FVA}(1,T)=0$.
   - $G_{C1}= 1$, $G_{C2}= 2$, $G_{N1}=7$, $G_{N2}=8$, and Full_Cycle_Time = 120

9. **DETERMINATION of** which direction's queues are confirmed to have arrived:
   - $V_C'(1,T) = 0$, $V_C'(2,T) = 0$, $V_C'(4,T) = 100$, $V_C'(5,T) = 100$,
   - $V_C'(7,T) = 75$, $V_C'(8,T) = 75$, $V_C'(10,T) = 50$, $V_C'(11,T) = 50$.

10. **DETERMINATION** of VC''
    - $V_{C(7)}''(1,T) \leftarrow 0 * (1) * (0 \text{ and } 0) = 0$, $V_{C(7)}''(2,T)=0$, $V_{C(7)}''(4,T)=100$, $V_{C(7)}''(5,T)=100$, $V_{C(7)}''(7,T)=75$, $V_{C(7)}''(8,T)=0$, $V_{C(7)}''(10,T)=0$, $V_{C(4)}''(11,T)=50$
    - $V_{C(8)}''(1,T)=0$, $V_{C(8)}''(2,T)=0$, $V_{C(8)}''(4,T)= 0$, $V_{C(8)}''(5,T)=100$,$V_{C(8)}''(7,T)=0$, $V_{C(8)}''(8,T)=75$, $V_{C(8)}''(10,T)=50$, $V_{C(5)}''(11,T)=50$

11. **CALCULATE**, for each of the two directions, the summation of the results in step 3.

    $V_{CT}(7,T) = 0+0+100+100+75+0+0+50= 325$

    $V_{CT}(8,T) = 0+0+0+100+0+75+50+50 = 275$

12. **CALCULATE**, for each of the two directions, the division of the chosen direction's queue length over the total summation found for that direction in step 4.

    $VNR_7 = 75 / 325 = 0.23$

    $VNR_8 = 75 / 275 = 0.273$

13. **CALCULATE**, for each of the two directions, what percent of the full cycle time must be given to that direction.

    $G_{TN1} \leftarrow 0.23 * 120 = 27.6$

    $G_{TN2} \leftarrow 0.275 * 120 = 33$

14. **DETERMINE** the next phase time.

    Next_Phase_Time = Average(27.6 , 33) = 30 Seconds (rounded)

Figure E.2. Next Phase Green Time Calculation when phase transits from (1-2) to (7-8)

In Figure E.3, the detailed calculation of the next phase green time is shown where the current green phase is (1-2), and it is the time for the phase to transit to become (10-11).

<u>Next Green Phase Time Algorithm</u>

15. **Initialization**
- $V_C(1,T) = 0$, $V_C(2,T) = 0$, $V_C(4,T) =100$, $V_C(5,T) = 100$, $V_C(7,T) = 75$, $V_C(8,T) = 75$, $V_C(10,T) = 50$, $V_C(11,T) = 50$.
- $C_{FVA}$for all the lanes are 1except $C_{FVA}(1,T)=0$ and $C_{FVA}(1,T)=0$.
- $G_{C1}= 1$, $G_{C2}= 2$, $G_{N1}=10$, $G_{N2}=11$, and Full_Cycle_Time = 120

16. **DETERMINATION of** which direction's queues are confirmed to have arrived:
- $V_C'(1,T) = 0$, $V_C'(2,T) = 0$, $V_C'(4,T) =100$, $V_C'(5,T) = 100$,
- $V_C'(7,T) = 75$, $V_C'(8,T) = 75$, $V_C'(10,T) = 50$, $V_C'(11,T) = 50$.

17. **DETERMINATION** of VC''
- $V_{C(10)}''(1,T) \leftarrow 0 * (1) * (0 \text{ and } 0) = 0$, $V_{C(10)}''(2,T)=0$, $V_{C(10)}''(4,T)=0$, $V_{C(10)}''(5,T)=100$, $V_{C(10)}''(7,T)=75$, $V_{C(10)}''(8,T)=75$, $V_{C(10)}''(10,T)=50$, $V_{C(10)}''(11,T)=0$
- $V_{C(11)}''(1,T)=0$, $V_{C(11)}''(2,T)=0$, $V_{C(11)}''(4,T)= 100$, $V_{C(11)}''(5,T)= 0$,$V_{C(11)}''(7,T)=0$, $V_{C(11)}''(8,T)=75$, $V_{C(11)}''(10,T)=0$, $V_{C(11)}''(11,T)=50$

18. **CALCULATE**, for each of the two directions, the summation of the results in step 3.

$V_{CT}(4,T) = 0+0+0+100+75+75+50+0= 300$

$V_{CT}(5,T) = 0+0+100+0+0+75+0+50 = 225$

19. **CALCULATE**, for each of the two directions, the division of the chosen direction's queue length over the total summation found for that direction in step 4.

$VNR_7 = 50 / 300 = 0.167$

$VNR_8 = 50 / 225 = 0.223$

20. **CALCULATE**, for each of the two directions, what percent of the full cycle time must be given to that direction.

$G_{TN1} \leftarrow 0.167 *120 = 20.04$

$G_{TN2} \leftarrow 0.223 * 120 = 26.76$

21. **DETERMINE** the next phase time.

Next_Phase_Time = Average(20.04 , 26.76) = 23 Seconds (rounded)

Figure E.3. Next Phase Green Time Calculation when phase transits from (1-2) to (10-11)