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Green supply chain: Simulating road traffic congestion

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Abstract. With the increasing awareness of the consumers about environmental issues, businesses, households and governments increasingly want use green products and services which lead to green supply chain. This paper discusses a simulation study of a selected road traffic system that will contribute to the air pollution if in the congestion state. Road traffic congestion (RTC) can be caused by a temporary obstruction, a permanent capacity bottleneck in the network itself, and stochastic fluctuation in demand within a particular sector of the network, leading to spillback and queue propagation. A discrete-event simulation model is developed to represent the real traffic light control (TLC) system condition during peak hours. Certain performance measures such as average waiting time and queue length were measured using the simulation model. Existing system uses pre-set cycle time to control the light changes which is fixed time cycle. In this research, we test several other combination of pre-set cycle time with the objective to find the best system. In addition, we plan to use a combination of the pre-set cycle time and a proximity sensor which have the authority to manipulate the cycle time of the lights. The sensors work in such situation when the street seems to have less occupied vehicles, obviously it may not need a normal cycle for green light, and automatically change the cycle to street where vehicle is present.

1. Introduction

Road traffic congestion (RTC) can be caused by a temporary obstruction, a permanent capacity bottleneck in the network itself, and stochastic fluctuation in demand within a particular sector of the network, leading to spillback and queue propagation[1]–[3]. Sudden increase of vehicle on the road during peak hours also contributes to RTC [4], which leads to loss of time, missed opportunities and frustration[5]. Spending too much time in RTC can distract the emotion and this is not a good situation where it can trigger the act of irresponsible and violent among road user [6]. Respond from community care vehicles like ambulance, fire-fighter and police also being affected from the RTC. Obviously, air pollution became one of the big issue arises from RTC as it only brings harm to surrounding [7]. Additional impacts from this problem are the noises coming from the machine itself, honking by the unsatisfied drivers and annoying exhaust sound generated by the modified cars indirectly contribute to the noise pollution. Noise from road traffic give an affect to many people, and it becomes worsen in urban areas [8]–[10].

RTC can occur at anywhere and it can either be predictable or unpredictable. There is nothing can be done with unpredictable event as it happened outside the expectation if not for predicted event which occurs at the main road, and mostly controlled by traffic light system. Traffic light control (TLC) and optimization have received special attention in recent years. From the previous studies, most of RTC is closely related to weak traffic control system or more precisely an inefficient TLC system [1], [11]–[14]. Therefore, research in reducing RTC by manipulating TLC system is relevant to be studied where the focus of this study is at Changlun main road traffic system, Kedah.

Changlun is located between Jitra and Bukit Kayu Hitam (BKH). If we travel to the north from Changlun, BKH is the last destination of peninsular Malaysia (border between Malaysia and Thailand). While travelling to the south from Changlun is the rest of Malaysia territories all the way down to Johor Bahru. Starting from Malaysia-Thailand border where the BKH custom and immigration checkpoint is located, there is only one road which connects the BKH to Changlun and all the way down to Jitra and it is referred as the main road. As in Changlun, there is a main junction for this town which also the first junction travelled by the road user from BKH. High traffic density occurs at the junction as the result from the clash of these two regions traffic. Figure 1 illustrates the layout of the case study location.

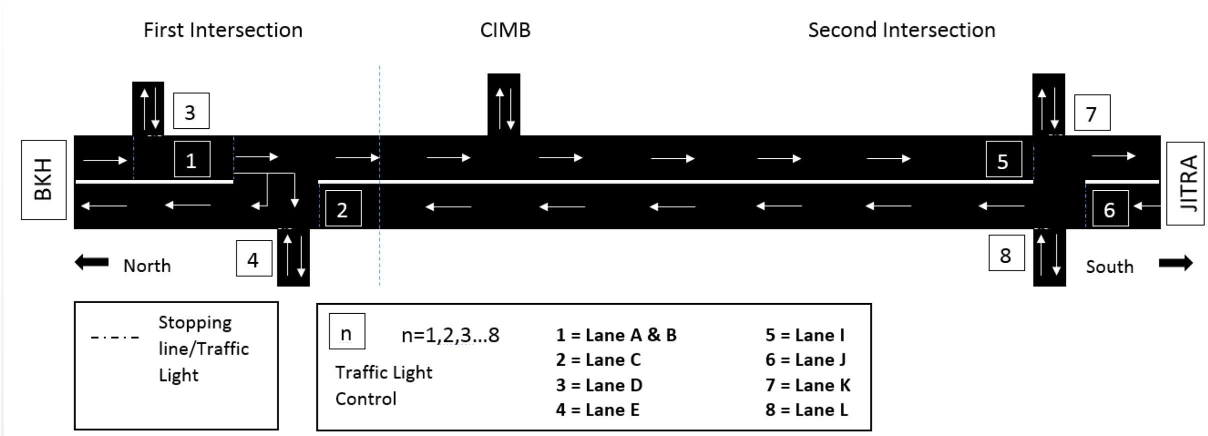

Figure 1. Changlun main road layout.

After several observations, the road traffic at Changlun is in busiest condition at peak hour between 5 to 7 p.m. The TLC system used to control the traffic at the main road should be able to accommodate with the traffic capacity so that the RTC can be reduced or prevented at all. The operation of TLC should be relevant for time-efficiency to meet the suitable timing to comply with the traffic capacity.

However, current situation of TLC operation system at Changlun main road is inefficient in term of TLC time cycle. By using the current operation timing make the road traffic at junction 5 (Lane I) to be congested thus affected the rest of junctions at intersection 1.

2. Operation Procedure of the TLC

The operation of TLC at the junction starts from one TLC followed by the rest of TLC sequentially until one cycle is completed. Most junctions equipped with TLC undergo almost the same process and procedure.

At an intersection, there are four-way junctions. Each junction has its own TLC which give signals to the vehicles to move to specific direction, ready to stop, and last signal is for stop. The signal is given by the change of TLC's lights in 3 colors which are green, yellow, and red respectively. For each TLC, the operating time for the green and red signal lights are different.

The TLC operation starts from vehicles arrival at the respective junction. From there, all the vehicles should obey the signal given by the TLC. If by that time the signal shows green light, the vehicles are good to go to the specific directions. The yellow signal indicates the signal is about to turns red which strictly advisable for all the vehicles to stop and only pass through whenever it seems safe to go. Red light signal tells the vehicles from that intersection to stop and wait in a queue as the other junctions have its turn to go. When the last junction in the intersection turns red, it shows that the TLC system has completed one cycle and the process start again with the first junction turns green. Figure 2 below represent the conceptualization of TLC at the junction.

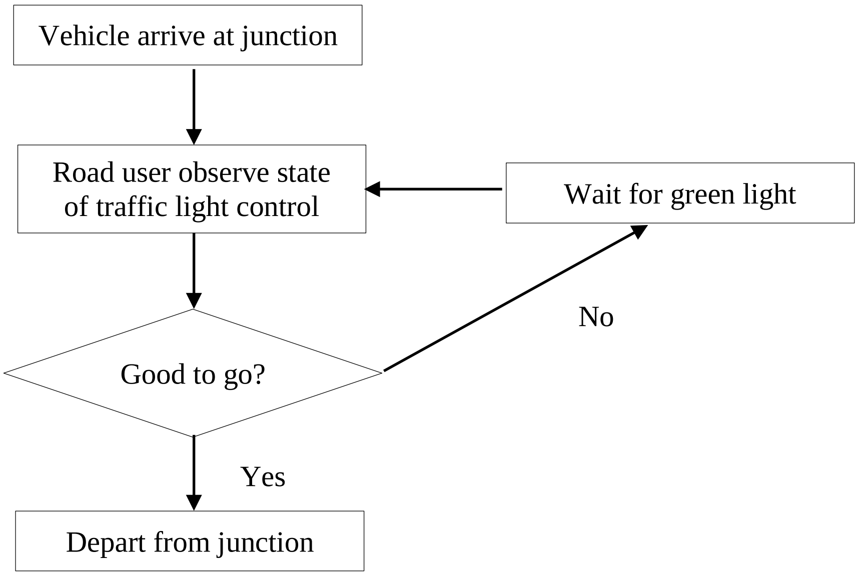

Figure 2. TLC conceptualization at each junction.

The TLC cycle at intersection 1 is explained as below.

0.00:	Vehicle from TLC 1 (Lane A and B) clear to go for all exit points while the rest of junction remain stop.
0.20:	Vehicle from TLC 1 that taking exit to the right or U-Turn (Lane B) have to stop. Vehicle from TLC 2 (Lane C) are clear to go. Vehicle from TLC 1 still clear to go but only for Lane A
2.00:	Vehicle from TLC 3 (Lane D) clear to go while the rest of the junction remain stop.
2.30:	Vehicle from TLC 4 (Lane E) clear to go while the rest of the junction remain stop.
3.05:	Vehicle from TLC 4 stop. End of one complete cycle.

Green light duration for TLC at intersection 1:

TLC 1 Lane A	: 120 seconds
TLC 1 Lane B	: 20 seconds
TLC 2 Lane C	: 100 seconds
TLC 3 Lane D	: 30 seconds
TLC 4 Lane E	: 35 seconds

The TLC cycle at intersection 2 explained below

0.00: Vehicle from TLC 5 (Lane I) clear to go for all exit points while the rest of junction remain stop.
0.57: Vehicle from TLC 6 (Lane J) clear to go while the rest of the junction remain stop.
1.57: Vehicle from TLC 7 (Lane K) clear to go while the rest of the junction remain stop.
2.47: Vehicle from TLC 8 (Lane L) clear to go while the rest of the junction remain stop.
3.32: Vehicle from TLC 8 stop. End of one complete cycle.

Green light duration for TLC at intersection 2:

TLC 5 (Lane I) : 57 seconds
TLC 6 (Lane J) : 60 seconds
TLC 7 (Lane K) : 50 seconds
TLC 8 (Lane L) : 45 seconds

Note that intersection 1 TLC's cycle starts from junction 1 while at that time, turn for green light at intersection 2 can be at anywhere between junction 5, 6, 7 and 8. It is assumed that at the beginning of simulation, both junction 1 and junction 5 start at the same time. For junction CIMB, there was no TLC.

3. Development of Simulation Model

The mentioned traffic network was simulated using ARENA software to represent the real activities for further analysis purpose. In the model, the moving vehicle are presented as the entity that moves throughout the system. There are two significant performance measures which are waiting times and number in queues.

3.1 Assumption of the modelled simulation

Simulation model is supposed to be the imitation of real situation. Due to unpredicted behavior of road user, the model has been developed based on the following assumption:

- **Entities Movement throughout the System**
  The movement of vehicles in a traffic network are unpredictable. At a moment, a specific vehicle could stay in a lane and suddenly switch to other lane at will. This situation occurs when the driver suddenly wants to change direction. For this study, all the vehicles will stay at the same lane as they had decided earlier and assumed no change in direction and no road rules are broken.
- **Synchronization of TLC timing at Intersection 1 and 2**
  The operation cycles for intersection number 1 and 2 are completely different. But at the beginning of the simulation, junction 1 will start with junction 5 at the same time.
- **Gap between Green-Red Signal Light**
  Between red light to green light, there is no inter-signal but not for green light to red light where yellow light appears as a warning light and all vehicles should take precaution to stop at all cost or clear to go if safe. In this study, when the TLC turns yellow, the vehicles are allowed to go and only stop completely when TLC shows red signal light. The time taken, which is the measurement used to record the time cycle for TLC only start as soon as the TLC turns green and end only when red signal light is given.

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3.2 Modules in ARENA

There are 8 different modules used to develop the model as stated in Table 1.

Table 1. List of modules.

Module	Function
Create	Arrival of vehicles in each junction
Decide	To decide the exit points, distribution on type of vehicle, TLC sequence and TLC timing
Separate	TLC sequence for lane A and lane B as both triggered at the same time
Dispose	Exit points
Assign	Assign type of vehicle either cars or lorries, TLC sequence logic
Seize	To seize the resource (road space to enter junction 5)
Release	Release the resource (road space) to allow next vehicle to enter junction 5.
Hold	Hold the vehicle at junctions and wait for signal, as the TLC
Signal	Send signal to the system to release vehicle at respective TLC
Station	Exit points
Route	Connect the exit points

4. Data Collection

For further data analysis purpose, input data must first to be collected or else simulation model cannot be developed. All data were collected between 5.00 pm to 7.00 pm during weekdays. In this study, there are several types of data which were collected:

i) Vehicle arrival at each junction – Collected from observation. The inter-arrival time between vehicles were recorded. Since the queue can be long, it was difficult to take the time only after the vehicle stop behind another vehicle. Arrival time for each vehicle was recorded at the time the vehicle pass the mark at certain junction.
ii) Vehicle departure – Upon departure from junction, different exit points involved and the total vehicle were recorded to get the distribution percentage. The average inter-departure between vehicles at junction also recorded.
iii) TLC sequence and timing – Collected also from observation, the cycle of TLC were taken for sequencing and timing.
iv) Junction 5 (Lane I) waiting time and number of vehicles in queue – Collected for validation purpose.

Tables 2 and 3 show the actual data collected for waiting time and number of vehicles in queue for lane I for validation purpose. It was difficult to collect these data for all lanes because there was too many vehicles and require lot of time and person to do so. Since Lane I was the critical one, which causing the bottleneck and affected the rest of TLC at intersection 1, Lane I was chosen.

Table 2. Data collected for Lane I.

Average waiting time (seconds)	Average number of vehicles in queue
168.55	92

Table 3. Data collected for number of vehicle arrival

Arrival	Total vehicle
Lane A	1778
Lane D	384
Lane E	519
Lane J	1611
Lane K	710
Lane L	510
CIMB	2213

For Lane B, Lane C and Lane I, the arrival of vehicle depend upon another junction's departure.

5. Analysis

The output of simulation is obtained after 5 simulation replications and discussed in terms of arrival rate, average waiting time, average number in queue, and validation in next section.

5.1 Arrival of Vehicle at each junction in the model

The data gathered was analyzed using Arena's input analyzer. Table 4 shows the data collected for vehicle arrival at respective junction.

Table 4. Vehicle arrival.

Arrival	Expression (s)	Replication					Average
		1	2	3	4	5	
Lane A	LOGN(4.47, 5.57)	1638	1655	1610	1514	1680	1620
Lane D	EXPO(18.8)	407	386	380	363	358	380
Lane E	WEIB(14.8, 1.22)	520	530	526	497	522	519
Lane J	LOGN(4.68, 5.31)	1548	1555	1551	1515	1616	1557
Lane K	EXPO(10.6)	628	697	687	704	680	679
Lane L	94 * BETA(0.645, 3.64)	487	521	478	520	497	500
CIMB	Constant (3)	2401	2401	2401	2401	2401	2401

For Lane B, Lane C and Lane I, the arrival of vehicle depend upon another junction's departure.

5.2 Average waiting time in the model

Table 5. Average waiting time.

Replication	1	2	3	4	5	Average
Queue A	120.4	136.9	110.00	24.65	126.53	103.7
Queue B	83.83	89.92	89.65	82.36	95.95	88.34
Queue C	23.16	23.16	27.10	25.6	25.12	24.83
Queue D	305.76	269.23	250.09	67.93	322.97	243
Queue E	713.53	510.84	460.11	68.03	821.17	514.74
Queue I	167.79	161.76	159.21	114.69	161.67	153.02
Queue J	66.99	65.53	64.23	66.84	67.35	66.19
Queue K	77.26	73.02	75.04	73.43	69.97	73.74
Queue L	75.55	71.49	75.93	75.35	77.97	75.26

The waiting time for CIMB junction was not taken as there was no TLC there.

5.3 Average number of vehicle in queues

Table 6. Average number of vehicle in queues.

Replication	1	2	3	4	5	Average
Queue A	26	34	23	5	29	23
Queue B	2	2	2	2	2	2
Queue C	2	2	3	3	3	3
Queue D	8	7	6	2	8	6
Queue E	43	31	30	4	50	32
Queue I	91	88	88	63	88	84
Queue J	14	14	14	14	15	14
Queue K	7	7	7	7	7	7
Queue L	5	5	5	6	5	5

The number of vehicle arrive for CIMB junction was not taken as there was no TLC and not interested for this study.

5.4 Validation of the model

Validation is a process to make sure the model that has been developed is correct. Table 7 below shows the comparison of actual data and simulated data obtained from the output.

Table 7. Comparison of actual and simulated value for arrival of vehicle.

Arrival of vehicle	Actual	Simulated	Difference Percentage (%)
Lane A	1778	1620	8.89
Lane D	384	380	1.04
Lane E	519	519	0.00
Lane J	1611	1557	3.35
Lane K	710	679	4.37
Lane L	510	500	2.00
Lane CIMB	2322	2401	3.4

Table 8. Comparison of actual and simulated for lane I.

	Actual	Simulated	Difference percentage (%)
Average waiting time (seconds)	168.55	153.02	9.21
Number of vehicles in queue	92	84	8.7

The table shows that, the difference between actual data and simulation output are less than 10% which is within standard 90% level of confidence. For a model to be accepted, the differences must be less than 10% [15].

6. Conclusion

The paper shows the results in the application of a simulation in a road traffic congestion modelling. The model can be used as a tool for making decisions of a traffic system. Investigations on planning and changes can be tried on the model without disturbing the existing operations.

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