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DISCRETE EVENT SIMULATION OF A ROAD INTERSECTION INTEGRATING V2V AND V2I FEATURES TO IMPROVE TRAFFIC FLOW

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ABSTRACT

Traffic congestion leads to waste of time and has tremendous impact on the environment. To reduce traffic congestion, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication have been explored and implemented. This paper focuses on integrating features of gap acceptance behavior proposed in V2V and road segment occupancy & intelligent traffic light phasing of V2I. Three separate simulation models have been presented in this study. A design of experiment generated thirty scenarios to capture the overall traffic flow performance in terms of total time and waiting time in the system, WIP and system efficiency. Results revealed that the proposed V2I simulation model in which routing was based on traffic light availability decreased the waiting time, total time and WIP significantly compared to baseline and smart traffic light vehicle flow model. The routing principle in the latter two models was based on space availability approach.

1 INTRODUCTION

Traffic congestion has been a problem in many developed cities around the world (Chattaraj, Bansal, and Chandra 2009). This phenomenon leads to a waste of time, fuel, and causes traffic related environmental and socio-economic problems (Hewage and Ruwanpura 2004) The traditional traffic control signals do not operate per current volume of traffic at the intersection, so they fail to control traffic effectively on busy intersections which leads to traffic congestion (Chattaraj, Bansal, and Chandra 2009). To avoid congestion, drivers need to anticipate other vehicle behavior, availability of gap to change a lane, and adjust their own acceleration and deceleration per traffic around them (Toledo, Koutsopoulos, and Ben-Akiva 2007).

A dynamic system is needed which can handle traffic smoothly and such a system is called Intelligent Traffic Control System (ITCS) (Sundar, Hebbar, and Golla 2015**.** The purpose of ITCS is to propagate emergency information to the drivers so that they can react to absence and presence of vehicles in a timely manner so that vehicle waiting time at intersections will decrease (Meneguette et al. 2016). The key features of an ITCS are Vehicle to Vehicle (V2V) interaction and Vehicle to Infrastructure (V2I) interaction. V2V interaction technology involves exchange of information such as road conditions, location, inter-vehicle distance, etc. between vehicles (Miller 2008). V2V works well in collision avoidance systems but in non-line of sight environments, performance of V2V is observed to be degraded significantly (Abbas et al. 2015, Chou et al. 2009). To this, V2I technology is essential to implement to manage traffic well (Milanes et al. 2012). V2I technology involves interaction with the infrastructure on road which forecasts vehicle queue length, vehicles arrival pattern in each lane, and therefore optimizes the signal even before a vehicle reaches the intersection (Priemer and Friedrich 2009). V2I technology informs drivers about traffic difficulties through a centralized system, which is a decision making control system for traffic signals and phasing

(Santa, Gómez-Skarmeta, and Sánchez-Artigas 2008). Since V2I are semi-autonomous systems, which require human and technology interactions, a strong understanding of driver decision making behavior is a key to success of these systems (Dia and Panwai 2014).

This study highlights the important features associated with V2V & V2I and integrating them into a discrete event simulation model. Two main factors were considered for this study – traffic flow model under which three simulation models were developed and inter-vehicle arrival time under which 10 levels were considered. An overall of 30 scenarios have been simulated to capture the effects of these factors on traffic performance indicators such as total time and waiting time in the system by a vehicle, total vehicles within the system after simulation run (WIP) and system efficiency.

2 LITERATURE REVIEW

2.1 Vehicle to Vehicle (V2V) Communication

Wang et al. (2014) designed a gap acceptance model based on the discrete choice theory to analyze gap acceptance behavior at an intersection. In their analysis, they incorporated variables such as lead gap, space gap, time gap, remained distance, and found that space gap has greater effect on driver's gap acceptance behavior than time gap due to speed variance. Naranjo et al. (2003) in his study pertaining to Inter-Vehicle Gap keeping observed that the instant where the gap among vehicles is insufficient, drivers deaccelerated their speed adequately. V2V technology allows Vehicle to Vehicle communication which results in one vehicle receiving information about its predecessor's vehicle speed, distance, space availability and location.

Greguric, Ivanjko, and Mandzuka (2014) studied traffic flow parameters such as speed, flow, and density and their relationship with each other at Zagreb bypass urban highway using a macroscopic simulator CTMSIM. They observed significant reduction in traffic density. Mir and Filali (2016) developed a geometry based V2V propagation model which captured information about things surrounding vehicles such as buildings and used GEMV2 (version 1.1) to simulate V2V propagation model over the selected area of Doha, Qatar. In their study, 1000 vehicles were involved in the simulation and moved randomly between selected origins and destinations. The simulation results showed that buildings and vehicle obstructions caused lower reliable communication range. The study found that V2V communication technology performance degraded in non-line of sight environment. Due to these challenges, the progression with ITS (Intelligent Traffic Systems) is needed to incorporate Vehicle to Infrastructure (V2I) communication technology.

2.2 Vehicle to Infrastructure (V2I) Communication

Xiang and Chen (2016) developed an adaptive signal controller based on V2I communication technology which captured average delay time, queue length, travel time, and vehicle speed. The obtained information was given as input into a simulation model created using VISSIM (Xiang and Chen 2016). In another study Backfrieder, Ostermayer, and Mecklenbräuker (2017) developed a predictive congestion minimization algorithm (PCMA) which is based on current road condition. Current road condition was defined by road segment occupancy and if the level of occupancy exceeded a user defined threshold value then the predictive model would suggest rerouting strategies.

Priemer and Friedrich (2009) designed a phase based decentralized adaptive traffic signal control. The authors stressed that these detectors detect vehicles via V2I communication and based on this information the controller in five second time interval forecasts queue length the next 20 seconds' time optimization horizon. At beginning of each optimization horizon, a phasing sequence is generated and fed to the controller optimize phase sequence which results in queue length reduction.

In another study, Bento, Parafita, and Nunes (2012) developed a microscopic simulator (ISR-TFS) which involved roundabout intersection (RI) and crossroad intersection (CI), each involved inflow/outflow of traffic from four directions. The RI & CI intersections were imagined as three dimensional time space matrix, in which each cell is depicted by a physical space. The cell selection & speed profiling was governed by availability of the space itself. Based on the communication from ITMS, received via V2I, the flow of the vehicle was adjusted to avoid traffic congestion by using a path following controller.

Li et al. (2015) developed an intersection divided into n-by-n tiles, in which these segment of tiles can only be reserved based on availability. Based on this decision criteria, intersection controller processes reservation request from the vehicle and provides decision regarding location, speed, maximum acceleration rate, and update regarding the state of the tiles. The authors observed significant reduction in number of traffic stops at intersection in a microscopic traffic simulator VISSIM, and thus proved efficiency of proposed method.

2.3 Simulation Model Integrating V2V and V2I Features

Based on road segment availability, traffic light control system behavior, and arrival rate of the vehicles the overall queuing status of the specified system boundary changes every second. This can be captured in the discrete event simulation environment.

Salimifard and Ansari (2013) developed a discrete event simulation model of traffic intersection of an urban traffic signal intersection using ARENA (v.10). Their model provided an optimal duration for green phase signal in order to reduce the length of queue. In another study Abas et al. (2006) developed a discrete event simulation of a signalized intersection using JamSim software to analyze the green phase timing towards average waiting time in each lane. The authors proposed five different green light phases by observing real time traffic flow for low, medium, and high traffic volume. However, the traffic simulation model compromised with the real scenario because they assumed if either one of the links is executed in green phase, then other three links was automatically in red phase. Sumaryo, Halim, and Ramli (2013) designed a discrete event simulation model of traffic light control system on a single intersection in MATLAB using SIMULINK and SimEvent toolbox. By the application of model, improvement in traffic flow such as number of vehicles in queue and average waiting time were observed to be reduced. Cai, Wang, and Geers (2013) proposed a model to reduce vehicle's travel time through analyzing straightforward movement and turning movement along with various (uniform & varying) vehicle arrival rate combination. The results from the study of vehicle flow behavior such as speed, lane gap, and position showed substantial reduction in travel time.

Our proposed model takes under consideration of the various aspects of V2V & V2I such as vehicle to vehicle gap modelling & associated delay time, integration of logical phasing of traffic lights based on road segment state (busy or available), routing decision making based on human preference as well as preference by the traffic light availability(V2I model). Preference of routing in V2I model smart traffic light that changes phasing based on traffic volume in each direction as well as it includes least waiting time strategy.

3 METHODOLOGY

3.1 Conceptual Model

The intersection which was conceptualized in this simulation paper is based on West College Street and South 19th Avenue intersection in Bozeman, MT. Similar to its characteristics there are four entry points for arrival of cars and four exit. There are certain points where the road diverges into three lanes, one each for going left, straight, and right. In addition that, at certain points two or more lanes converge into a single lane. Figure 1 illustrates the intersection which has been considered for this study.

The illustrated road segmentation shown in the figure 2, resembles that of the intersection and the roads coming from four direction (east, west, north, and south). In figure 2, the road coming from the east side gets divided into three lanes (diverging point) and similarly the road going towards east gets merged into a single lane at a certain point (merging point).

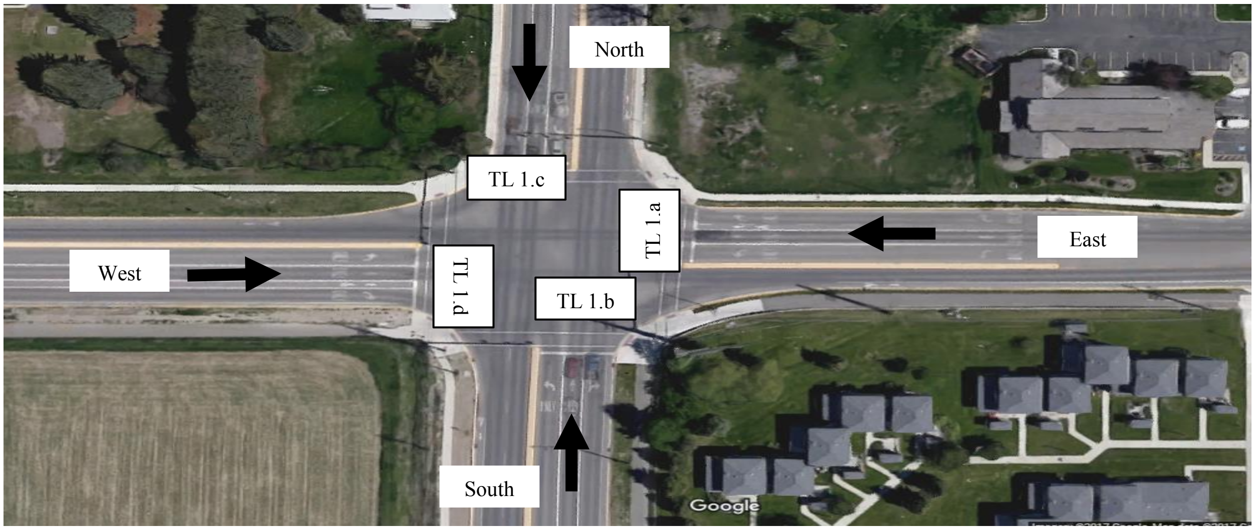

Figure 1: West College Street and South 19th Avenue intersection.

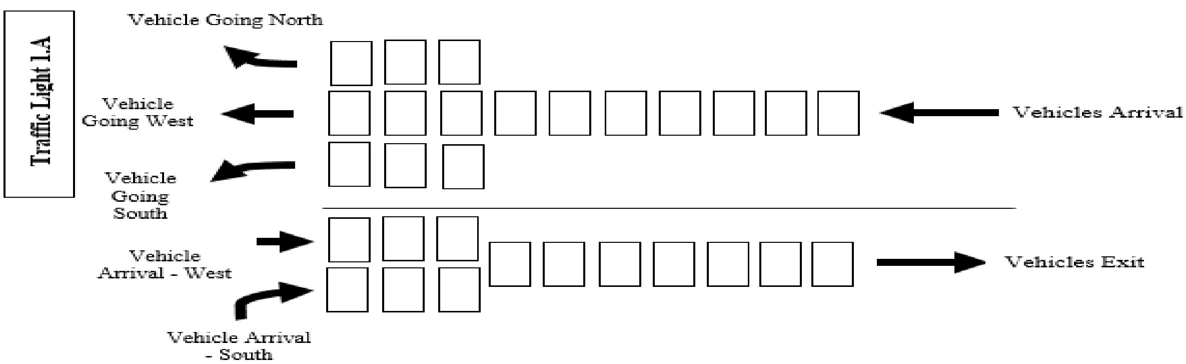

Figure 2: Segmenting East Side Road.

3.2 Model Assumption

While developing a simulation model based on the intersection illustrated above, the following assumptions were considered:

- A system boundary was considered, within which all the four roads are 10 road segments long. The diverging point is on the 7th road segment from the entry point and the merging point is the 3rd road segment from the intersection.
- The acceleration and deceleration of the vehicles were based on the gap between the entities occupying the road segments. The acceleration and deceleration were influenced by the delay time to pass the road segments.
- Each road segment was equal in size and can hold only one vehicle. There are no road segments considered in the intersection.
- The delay time associated in the traffic lights were considered to be (10,8,6) seconds by observing the signal phase time according to the volume of the traffic (high, medium, low). The phase time was decided based on the occupation status of the road segments at that instant in the simulation model.
- Cross paths of vehicles in the intersection were not considered. Situations such as unprotected left turns and cautious left turns in yellow lights were not considered

3.3 Simulation Model & Integrating V2V & V2I features

The conceptual model was transformed into a simulation model in ARENA (v.14.7). In the simulation model various basic modules were utilized to create traffic flow, constant-time based signal phasing and logical traffic volume based signal phasing, logical decision making regarding space selection and route selection.

3.3.1 Road Segments and Delay Time Decision(DTS) Making

The roads were considered as an array of resources illustrated by seize modules. Once a vehicle seized a road segment (RS) resource, it could not be occupied by other vehicles. Thus, the traffic flow was depicted by a series of seize – delay – seize (next road segment) – release (previous road segment) (Benzaman, Al-Dhaheri, and Claudio 2016). However, the flow of vehicles was also governed by the gap between them. According to the gap-acceptance theory, the process of acceleration and deceleration of vehicles is captured in terms of delay time to cross the road segment. In this study, the delay time was associated with the gaps between vehicles – capturing a prime feature of V2V communication. In the simulation model, the decision to choose this delay time was logically connected by the availability of the road resources ahead. After a vehicle seizes a resource, it looks at the current state of the road resource state ahead of them, whether the resource had been taken (e.g. NR(Resource 1) = 1) or available (e.g. NR(Resource 1) = 0). Based on this logic, four delay times were formulized which was logically associated with the availability of the road resource. After a vehicle seized a resource it considered four decisions. The decisions were:

- Decide delay 1 - If the next four road segments were available – then it proceeded with delay time 0.75 seconds, if not go to decide delay 2
- Decide delay 2 – If the next three road segments were available – then it proceeded with delay time 1 second, if not go to decide delay 3
- Decide delay 3 – If the next two road segments were available – then it proceeded with delay time 1.25 seconds, if not go to decide delay 4
- Decide delay 4 – If the following road segment was available only – then it proceeded with delay time 1.5 seconds, if not the current resource was held until the next road segment was available.

3.3.2 Traffic Signal Phasing Associated with Road Resource State

Traffic lights at an intersections work in pairs (north-south or east-west) in a way that the paths of the vehicle do not cross. Apart from the assumption of unprotected left turns and cautious yellow left turns, only green and red light signal phases were considered. This signal phase changing was done in a cyclic manner with a logical entity which will also be discussed here. In discrete event simulation environment, the traffic signal phase changing was simulated by setting up several process modules (seize-delay-release option) and the logical part was integrated with decision modules. This study simulated the traffic signal phasing based on the vehicle in flow and the occupancy rate in the road segments. Two different traffic light signal phasing strategies were developed. They are as follows –

(1) constant time traffic signal (CTTS) phasing based on any occupancy rate, and
(2) smart traffic signal (STS) phasing based on specific occupancy rate.

CTTS phasing based on any occupancy rate was considered the baseline traffic simulation model in this study. It was seen that the traffic signal phases change according to the occupancy rate (at least one vehicle) and the delay time between each phase has been considered to be fixed (10 seconds). The steps are provided below:

- Step 1 – The simulation model checked the current state of the left road segment resources from east and west (before traffic light TL 1.a & TL 1.d) after the diverging point (primary logic 1 – D1). This is the protected left turn signal. If vehicles were found occupying the resources on both sides (at least one vehicle on each side), a left protected signal turn occurred (P1). After a certain fixed time window (10 seconds), the entity flowed through three more process modules which were represented by the traffic phases of (1) protected left turn and going straight for vehicles coming from east – P2, (2) protected left turn and going straight for vehicles coming from west – P3 & (3) going straight for vehicles coming from east & west – P4. If the primary logic1 failed at the initial state then the logical entity went to step 2.

- Step 2 – The simulation model checked the current state of the left road segment resources and the straight road segment resources (before traffic light TL 1.a) after the diverging point (primary logic2 – D2). If the logic was sustained a fixed 10 seconds time window was given to the vehicles to pass through (P2). After that the entity flowed through two more process modules which represented – (1) protected left turn and going straight for vehicles coming from west (P3) & (2) going straight for vehicles coming from east & west (P4). If the primary logic2 failed at the initial state then the logical entity went to step 3.
- Step 3 – The simulation model checked the current state of the left road segment resources and the straight road segment resources (before traffic light TL 1.d) after the diverging point (primary logic3 – D3). If the logic was sustained a fixed 10 seconds time window was given to the vehicles to pass through (P3). After that the entity flowed through the last process module which represented – going straight for vehicles coming from east & west (P4). If the primary logic3 failed at the initial state then the logical entity went to step 4.
- Step 4 – After failing the first three primary logics, the only signal that the vehicles were allowed to take was 'going straight' for vehicles coming from east & west (P4).

After passing through either of the four steps described above related with traffic light 1.a and 1.d, the logical entity would go through a completely similar four steps associated with traffic light 1.b and 1.c. The logical entity thus would process vehicles coming from north and south. Decision modules D4, D5 & D6 have logic embedded and process modules P5, P6, P7 & P8 have fixed delay (10 seconds) similar to TL 1.a & TL 1.d. After vehicles coming from north and south gets routed the logical entity cycles back to the steps associated with traffic light 1.a and 1.d.

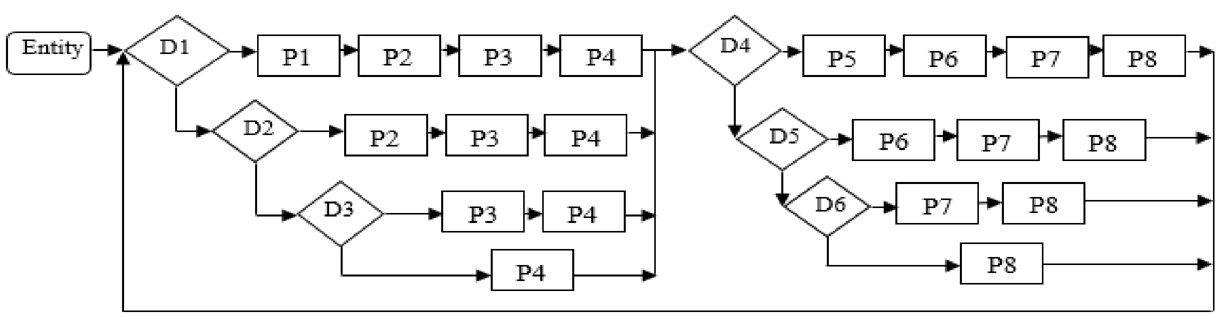

Figure 3: CTTS Traffic Light Phasing Simulation Model (Backward Portion: East-West Traffic Signal TL1.a & TL1.d, Forward Portion North-South Traffic Signal TL1.b & TL1.c).

STS phasing was based on specific occupancy rate. Instead of having a fixed time of 10 seconds during phase changes, the delay time was considered based on the traffic volume in the road segments after the diverging point. Three levels of traffic volume were considered and defined based on the logical delay time was formulated. For one of the traffic signal phases – simultaneous left protective turn for vehicles coming from east & west, the association between traffic volume and delay time is discussed below :

- High volume traffic occurred when at least 5 among 6 left turn road segments(on both east side and west side) became occupied. The combination could be 3 on the east side and 3 on the west side, 3 on the east side and 2 on the west side or 2 on the east side and 3 on the west side (S1). If any of these three combinations were found to be true, then the time delay (P1) for the left protective turn phasing would be 10 seconds.

- Medium volume traffic occurred when at least 3 among 6 left turn road segments (on both east side and west side) became occupied. The combinations could be (2,2), (2,1), (1,2), (3,0),(0,3). In cases of (3,0) and (0,3) combination even though there were not any vehicles occupying the logic for signal phase changing was generalized. This assumption could be easily relaxed with further decision modules. If any of these five combinations (S2) were found to be true, then the time delay (P2) for the left protective turn phasing would be 8 seconds.
- Low volume traffic occurred when at least 1 among 6 left turn road segments (on both east side and west side) became occupied. The combinations could be (1,1), (1,0), (0,1), (2,0),(0,2). If any of these five combinations (S3) were found to be true, then the time delay (P3) for the left protective turn phasing would be 6 seconds.

If the logic found a (0,0) combination then, the logical entity in the traffic signal phasing model was directed to check the traffic state for vehicles coming from north and south (N1) via P_{s1}(going straight for vehicles coming from east-west). The steps mentioned above was only for the left protective turn signals for east and west side traffic. The other steps in similar approach to the CTTS was also simulated such as (a) left protective turn and going straight for vehicles coming from east (b) left protective turn and going straight for vehicles coming from west & (c) going straight for vehicles coming from east and west. The logics for traffic volume were also the same in terms of traffic signal phase delay (P1, P2 & P3). After the east and north side vehicles were routed, the similar approach was taken in routing the vehicles from north and south side shown in figure 4 by segment d, e, f & g. Once vehicles are routed from north and south side, the entity is looped back.

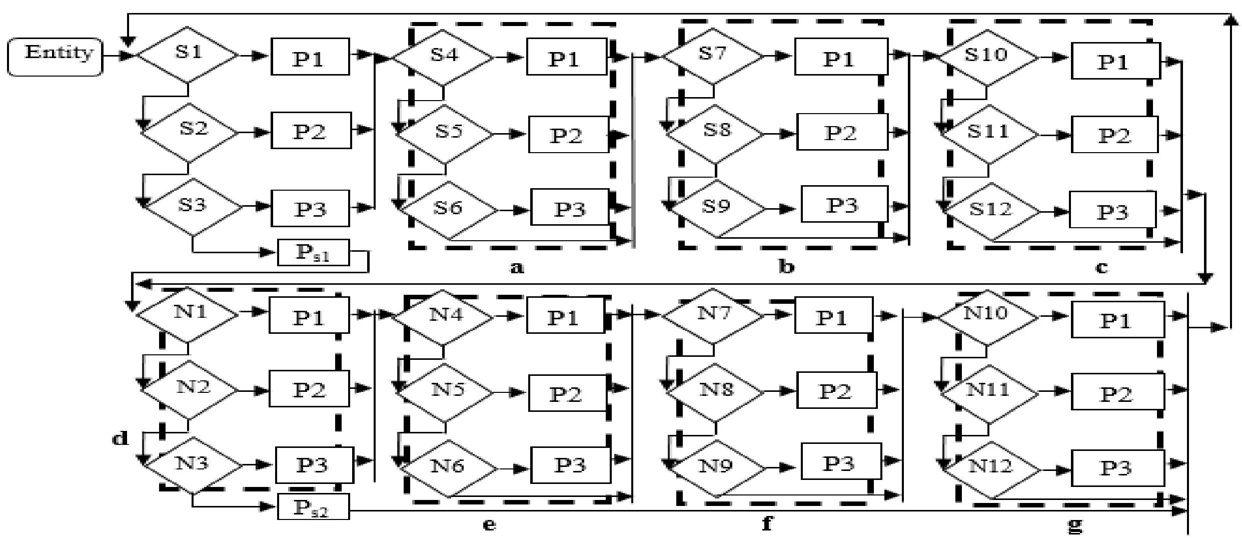

Figure 4: STS Traffic Light Phasing Simulation Model.

3.3.3 Logical Decisions with Space Selection and Route Selection

One of the important aspects of this simulation model, was to pre-decide on the preference on exiting points for the vehicles. This was realized by the humanistic choice whether the driver wishes to exit the intersection going straight, left or right. In the simulation model, this choice was made on the fourth road segment with equal decision percentages (33.33 % - left, 33.33% - straight and 33.33% - right). The vehicles were then attributed, which was checked just before the diverging point, only to separate them according to their preliminary choice. The space availability decision making was simplified in terms resource state as well.

Assuming that a decision was made on the fourth road segment that a vehicle would exit the intersection by going straight, the steps associated with its execution was modelled in the simulation as below:

- Step 1 – The vehicles checked the state of the resource for the road segment for going straight, if it was available then, it seized it. If this logic failed, the vehicles went to step 2.
- Step 2 – The vehicle checked the state of the resource for the road segment for going right, if it was available then it seized it. If this logic failed, the vehicle went to step 3.
- Step 3 – The vehicle checked the state of the resource for the road segment for going left, if it was available then it seized it. If this logic fails, the logical flow looped back.

Since in United States traffic signal phasing does not influence right side turns, the right side road segments usually did not build queues. So, in most cases when vehicles could not take a left turn or go straight due to the occupancy of roads, it took a right turn to exit the intersection. An illustration of the concept of space selection and the logical decisions are given below:

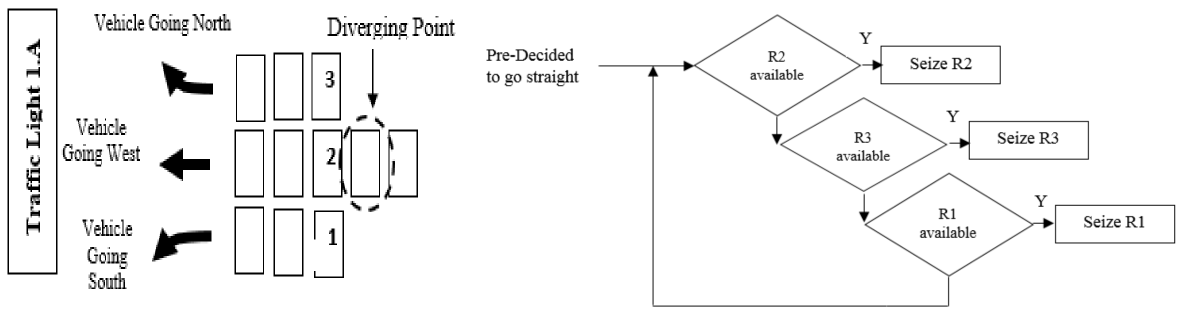

Figure 5: Space Selection Decision Making Criteria.

Route selection decision making was integrated into the model based on two criteria. (1) space availability – humanistic approach and (2) based on vehicle to infrastructure approach. Considering that a driver would not care if the selected route was not the same as the pre-decided route, space availability of humanistic approach prioritized road segment resource availability. On the other hand, the vehicle to infrastructure approach prioritized the traffic signal light availability. Considering a vehicle decided to go left, steps associated with the route selection in the vehicle to infrastructure approach are given below:

- Step 1 – If the traffic light phases associated with going left were available, then the vehicle picked that route. If the primary logic was not satisfied, the vehicle checked decisions at step 2.
- Step 2 – If the traffic light phases associated with going straight were available, then the vehicle picked that route. If the primary logic was not satisfied then the vehicle took the right turn.

4 DESIGN AND ANALYSIS OF EXPERIMENT

4.1 Scenario & Factors Construction

Using the simulation models, 30 scenarios were developed to study the effectiveness of models in reducing traffic congestion. The scenarios were ran for 24 hours for 20 replications. The design of experiment was constructed with two factors. The first factor was traffic flow model type which had three levels (1) baseline model , (2) smart traffic light model, and (3) vehicle to infrastructure (V2I) model. The second factor considered was inter arrival time with two distributions constant inter arrival time and Poisson inter arrival time, each had 5 levels. 4 response variables were considered - system efficiency, average total time, average waiting time, and total vehicles within the system after simulation run (WIP) was obtained. Created with JMP (v.13.1.0). Table 1 and table 2 shows the responses and factorial level considered correspondingly. Table 3 provides insights on traffic flow model and their relation to V2V and V2I features.

Table 1: Objectives of the DOE.

Response Name	Goal
System Efficiency	Maximize
Total Time	Minimize
Waiting Time	Minimize
WIP	Minimize

Table 2: Factors and Levels Associated with the Simulation Model.

Name	Values									
Traffic Flow Model	Baseline					Smart Traffic Light			V2I	
Inter-Arrival Time Distribution	Constant Distribution					Poisson Distribution				
Inter Arrival Time	5	10	15	30	60	8	10	15	30	60

Table 3: Features of the Traffic Flow Models.

Traffic Flow Model	Route Selection Preference	Traffic Light Signal Phasing	Features Embedded
Baseline	Humanistic Choice	CTTS	DTS(V2V)
Smart Traffic Light	Space Availability Choice	STS	DTS (V2V), Signal Phasing of STS(V2I)
V2I	Signal Availability Choice	STS	DTS (V2V), Signal Phasing of STS & Signal Based Route Selection (V2I)

5 RESULTS

5.1 Statistical Analysis

As per our hypothesis, the response variables were observed to be highest for V2I model followed by smart traffic light model. The significance of response variables total time, waiting time and WIP were considered with the minimization goal. As shown in Figure 6, Total time decreases from baseline to smart traffic light to V2I model and is minimum for V2I model. It shows a decreasing trend in Waiting time across three models and is minimum for V2I model. Similarly, WIP is minimum for V2I model.

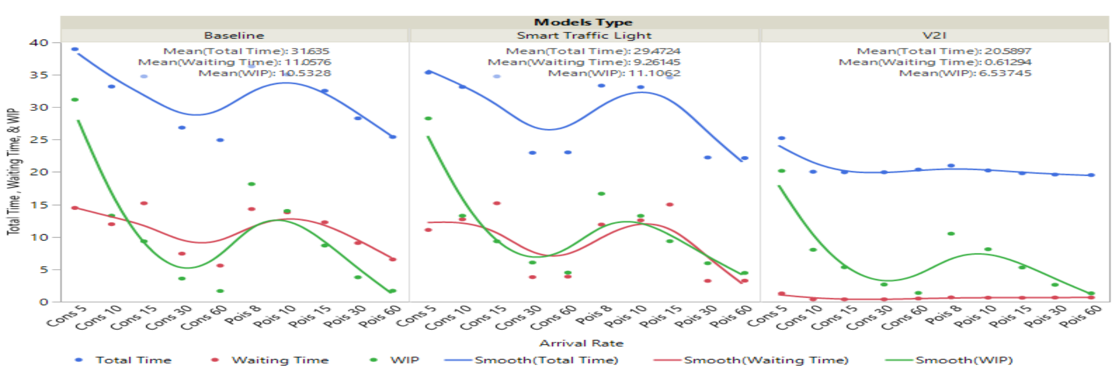

Figure 6. Inter-Arrival Time (Sec) Vs Baseline, Smart Traffic Light &V2I model.

It is evident that among three models, V2I is the best model in terms of highest system efficiency and minimum total time, waiting time, and WIP. Figure 6 also showed comparison of baseline, smart traffic light and V2I model at different inter arrival time. From the graph, it is inferred that in every model, inter arrival time of poison 60 seconds provides us minimum total time, waiting time, and WIP. However, inter arrival time of vehicle cannot be controlled. If concepts from any of the 3 models are to be used, it is recommended that the logical decisions regarding traffic light phasing and the route selection decision in V2I should be considered.

The predictor profile shown in Figure 7 provides the comprehensive view of models, multiple inter arrival time for each model (x-axis) and theirs impact on response variable (Y-axis). The desirability column tells us that minimization is the goal for every response variable. From the desirability row for the models column, it is noticeable that V2I model leads in every aspect followed by smart traffic light, further followed by baseline model. The inter-arrival time of poison 60 seconds meets our desirability.

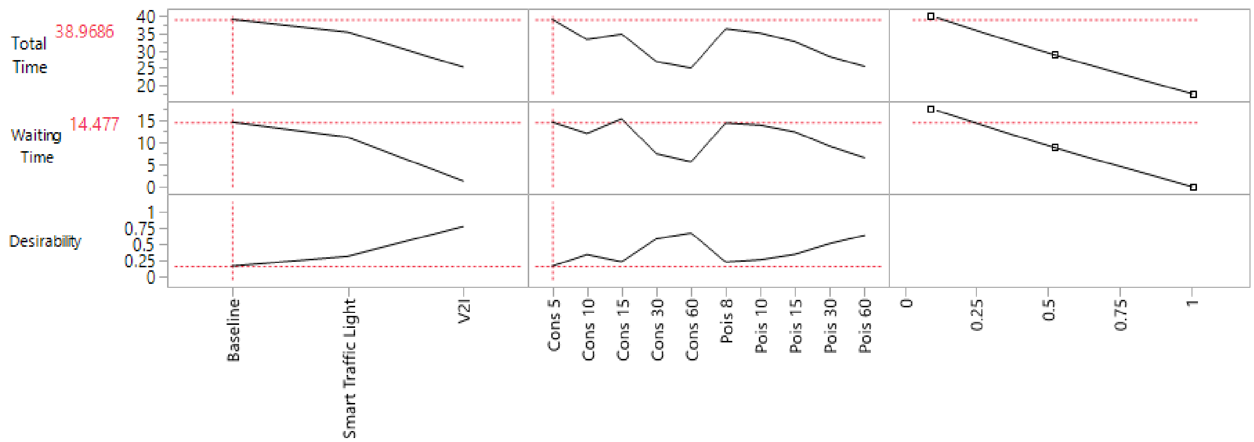

Figure 7: Predictor Profile for Response Variables.

The results shows that significance of intelligent traffic control systems such as V2I and smart traffic light control systems over traditional traffic control systems which are based on fixed time interval phase duration in reducing traffic congestion.

6 CONCLUSIONS AND FUTURE RESEARCH

This study has integrated the features of V2V and V2I into a simulation model to check the overall traffic flow performance on an intersection. In the process, three discrete event simulation models were built in ARENA (v.14.7) environment. 30 scenarios were generated based on 2 factors – traffic model and inter vehicle arrival time. It was found that when vehicles were routed to exit intersection based on the traffic light availability approach (V2I) was better than space availability approaches (baseline model and smart traffic light). Figure 8 provides a summary for the response variables.

Models Type	System Efficiency	Total Time	Waiting Time	WIP
Baseline	0.999564	31.63498	11.05759	10.53276
Smart Traffic Light	0.999437	29.47243	9.26145	11.10615
V2I	0.999698	20.58974	0.61294	6.53745

Figure 8: Summary of Main Responses from the Simulation Models.

Considering the generality of the conceptual model, precision can be brought to the inter-arrival time of the vehicles and the assumptions associated with the traffic light phasing time. This can open up more opportunities in the field of traffic simulation modelling in terms of utilizing road segment resources as a constraint. Future research should be directed towards the following points:

- The results obtained from the simulation model should be validated to prove the accuracy of the models. As the concepts of integrating V2V and V2I, are still in theoretical phase, validation techniques such as sensitivity analysis through parameter variability. The parameters which can be varied are delay time, traffic light phase change time & associated logical decisions and initial humanistic decision making percentage going left-straight-right.
- Unprotected left turns and yellow light phase should be included in the traffic signal phasing model and decisions related with proceeding during such situations should be captured.
- Integrate complex decision criteria associated with lane changing and space segmentation at the intersections. The assumption associated with driver's decision making with space selection or route selection, to increase intersection performance, can be further generalized by the aspect of foreknowledge. The foreknowledge can be of the intersection ahead, elapsed time of signal phases and congestion of other routes.

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