

A strategy for optimization of cooperative platoon formation

Thanh-Son Dao*, Jan Paul Huissoon

Department of Mechanical and Mechatronics Engineering,
University of Waterloo,
Waterloo, ON N2L 3G1, Canada
E-mail: tsdao@uwaterloo.ca E-mail: jph@uwaterloo.ca
*Corresponding author

Christopher Michael Clark

Department of Computer Science,
California Polytechnic State University,
San Luis Obispo, CA 93407 USA
E-mail: cmclark@calpoly.edu

Abstract: This paper presents a direction for cooperative vehicle platoon formation. To enhance traffic safety, increase lane capacities and reduce fuel consumption, vehicles can be organized into platoons with the objective of maximizing the travel distance that platoons stay intact. Toward this end, this work evaluates a proposed strategy which assigns vehicles to platoons by solving an optimization problem. A linear model for assigning vehicles to appropriate platoons when they enter the highway is formulated. Simulation results demonstrate that lane capacity can be increased effectively when platooning operation is used.

Keywords: platoon; platoon formation; vehicle sorting; intelligent transportation; GPS; optimization; simplex algorithm; linear programming; cooperative architecture; vehicle network; autonomous driving; ad-hoc network.

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1 Introduction

Many transportation projects have been initiated to define the next generation of land transportation systems with the objective of improving road traffic efficiency and safety. Examples of these programs include: the California Partners



for Advanced Transit and Highway (PATH) program in the US, the Automobile of the 21st Century (AUTO21) project in Canada, as well as the Prometheus and DRIVE projects in Europe, and the Super-smart Vehicle Project in Japan. The goals of these programs are quite broad and include increased traffic throughput, less accidents, reduced fuel consumption and better driving experience. However, less research has been done on developing appropriate algorithms that allow cars to sense and intelligently affect the traffic flows that could result in more efficient use of highways.

This work targets the problem of traffic management using ‘platoon’ concept with the effort to develop scheduling and control techniques to support autonomous driving on urban multi-lane highways with multiple entry (on-ramp) and exit (off-ramp) points. The idea of platooning was first proposed by Shladover (1979). The concept behind platooning is to have vehicles in groups traveling in tight vehicle-string formations where the inter-vehicle spaces are on the order of 1-5 *m*. The group is controlled by a leader and multiple platoons would be separated by larger distances for a greater degree of safety (Varaiya, 1993). A prototype of this concept was demonstrated during Demo’97 in San Diego on a reserved 7-mile highway lane embedded with magnets to enable vehicle localization (Tan et al., 1993; Rajamani et al., 2000).

The idea of ‘platooning’ is to expand the limitation of capacity and safety that can be achieved by road vehicles. The effect of platooning on lane capacity, which relates the capacity C_{max} in *veh/lane/hr* to the steady state speed v in *km/hr*, the separation time between platoons t_h in seconds, the intra-platoon distance headway h in *m*, the average vehicle length s in *m*, and the maximum platoon size Υ is described by (see Appendix):

$$(1) \quad C_{max} = \frac{3600\Upsilon v}{3.6[(\Upsilon - 1)h + s] + t_h v}.$$

For example, the lane capacity can be increased up to 7600 vehicles per lane per hour when the maximum platoon size of 25 vehicles is used given that other parameters are: $h = 10$ *m*, $s = 4.5$ *m*, $v = 100$ *km/hr*, $t_h = 3$ seconds. With platooning, several-fold increase in roadway capacity can be achieved with minimal upgrades to infrastructure and relatively little public expense.

Under current highway driving conditions (without platooning), it is apparent that as the speed and density of vehicles increase, the likelihood and likely severity of crashes will increase. The limitations of drivers are the primary causes. Driver errors are responsible for 90% of crashes that occur today, and the limited ability of drivers to follow other vehicles produces the limitation on lane capacity. The limitation of drivers’ ability to perceive changes in vehicle spacing, relative motion, and acceleration and their limited speed and precision of response ensure that lane capacity cannot generally exceed 2,200 vehicles per hour under manual control (Ioannou, 1997). In order to increase lane capacity, it is necessary to organize vehicles in platoons where vehicles are at closer average spacing (for the same speed). The platoon mode of operation was conceived as a way of expanding the limitation of capacity and safety that can be achieved by road vehicles.

Another reason for platooning is reducing fuel consumption. It was proven by Browand and Michaelian (2000) that platooning operation can save fuel consumption by reducing aerodynamic drag exerted on the trailing vehicles. In this work,



the efforts to measure aerodynamic drag and fuel consumption on each vehicle in the platoon were conducted by Browand and Michaelian in both laboratory and real road tests as shown in Fig. 1. This study showed that at the 3-meter intra-platoon spacing and a travel speed of 96 km/hr , platooning could save between 5% and 12% in fuel, depending on whether the vehicle is platoon leader, trailing or interior vehicle. The interior vehicles had the least fuel consumption and thus benefited the most from close-following. Trailing vehicles were intermediate in benefit, and leading vehicles benefited least.



Figure 1 (a) Three-Lumina platoon in the Dryden wind tunnel at USC, and (b) platoon operation at 4-meter spacing to measure aerodynamic drag and fuel consumption (source: Browand and Michaelian, 2000).

To maximize benefits of platooning, it is desirable to form platoons that are reasonably large (five or more vehicles), and it is also desirable to ensure that platoons remain intact for maximal distances as proposed by Hall and Chin (2002). In this work, the problem is approached by solving a linear model with an attempt to send vehicles entering the highway at entrances to appropriate platoons from highway upstream so that the vehicles stay with their host platoons until they exit the highway. This objective can be obtained by minimizing the total differences in destinations of platoon leaders and that of following vehicles.

This paper is organized as follows: First, a control diagram for platooning operation is presented in Section 3. Section 4 discusses a distributed control strategy for platooning formation and sorting at highway entrances. A linear model for the optimization problem is formulated in Section 5. Currently, by maximizing the distance that platoons stay intact and applying lane assignment to platoons, the system is able to send cars to appropriate platoons. Simulations to evaluate the algorithm are presented in Section 6, followed by some concluding remarks in Section 7.

2 Basic notations

C_{max} : maximum lane capacity [$veh/lane/hr$]

v : steady-state speed of vehicles [km/hr]

t_h : separation time between platoons [sec]

s : average vehicle length [m]

h : intra-platoon distance headway [m]

r : range of destinations in a platoon or the maximum difference in index between the nearest and furthest destinations of vehicles in a platoon

R : communication radius [m]

n_d : number of exits (off-ramps)

n_p : number of platoons within radius R

ε_p : current size of platoon p

Υ : maximum platoon size (the number of vehicles a platoon can accommodate)

$\alpha_{i,j}^p$: percentage of vehicles traveling from i to j that will join platoon p

$\chi_{i,j}^p$: number of vehicles at the entrance ramp traveling from i to j that will be sent to platoon p

$\chi_{i,j}$: number of vehicles traveling from i to j

$d_{i,j}$: distance traveled by a vehicle from entrance i to exit j [m]

$\delta_{i,p}^l$: distance traveled by the last vehicle in platoon p from entry i its destination [m]

des_p^f : destination index of the leader of platoon p

3 Platoon control diagram

The platoon assignment system in this work uses GPS as the only available sensor and form an ad-hoc network as the vehicles travel within communication range of each other. Each vehicle is assumed to be equipped with a GPS receiver and a processor to implement the lane-positioning algorithm and to communicate GPS data as well as other platoon information with other vehicles across the ad-hoc network. The proposed control diagram for platooning used in this work is shown in Fig. 2.

To support inter-vehicle communication (IVC), an IEEE 802.11p standard (see ASTM, 2003; Palazzi et al., 2007) - also referred to as Wireless Access for the Vehicular Environment (WAVE) - was developed and could guarantee a maximum communication range of up to 1000 m under optimal conditions, or around 300 m for cars traveling at 200 km/h . Moreover, a new family of standards, referred to as IEEE 1609 suite (Berger, 2007), specifically for IVC built on IEEE 802.11 chipset is now under development. Three of the standards (IEEE Std. 1609.1 for Resource Management, IEEE Std. 1609.2 for Security Services for Applications and Management Messages, and IEEE Std. 1609.4 for Multi-Channel Operation) in the suite have been approved for trial use, and one (IEEE Std. 1609.3 for Networking Services) is pending. Once widely adopted, these standards will ensure that cars will have a communication range of 300-500 m on highways.

The most crucial capability for a vehicle to operate in any collaborative driving system is to be able to guarantee the following of a vehicle ahead both longitudinally and laterally. Once this basic skill is achieved, higher order commands with the aid of IVC can be issued to the vehicle to space the vehicles in a single lane formation, or to enter/exit other platoons in other lanes. The lane positioning system introduced by Dao et al. (2007) works as a low-level input for platoon assignment.

It was also shown in (Dao et al., 2007) that relative GPS measurements (*i.e.*, relative distances between GPS measurements) can be utilized to obtain a higher position accuracy, making GPS a solid potential for platooning tasks where vehicles are equally spaced relative to each other. Dao et al. (2007) demonstrated that al-

though the 2-D positioning accuracy offered by a stand-alone standard GPS is 13 *m* (global average, 95%) and 36 *m* (worst site, 95%) due to several error sources such as satellite clock, ephemeris error, ionospheric effects, tropospheric effects, and the geometry of visible satellites (see Grewal et al., 2000); this set of errors from GPS is common for vehicles, making receivers that are relatively close to one another experience similar GPS error. These common errors therefore can be removed if we take into account the relative position between vehicles. This is similar to what happens with differential-GPS (D-GPS), where the GPS solution is improved by removing the common errors.

Other errors, which are local to the different receivers, include RF noise from the environment, receiver noise and resolution, multi-path, and receiver clock error. The effects of these errors can be reduced using a low-pass filter such as a combination of a particle filter fused with a low-pass Butterworth filter as demonstrated in a study of Dao et al. (2008) where the error of filtered relative GPS measurements is in the order of 0.1-0.3 *m* and, therefore, is adequate for platooning operation. Details about GPS were presented by Farrel and Barth (1999).

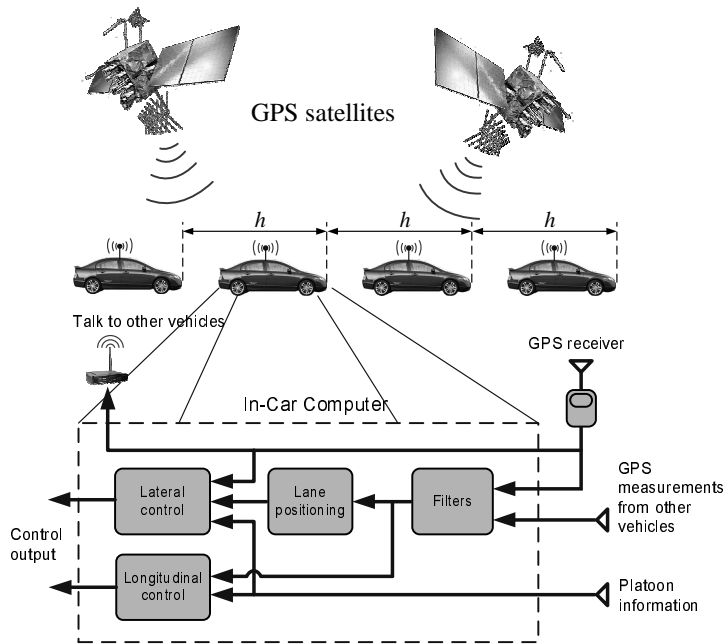


Figure 2 Control diagram for platooning operation.

The lateral controller is necessary for each vehicle in platoon for lane following and a longitudinal controller gives a vehicle in a platoon the capability of maintaining an intra-platoon distance h . When the vehicle is following another vehicle in the platoon, h is the separation between it and the vehicle just ahead. If the vehicle is a platoon leader, h is the distance between it and the next platoon. This topic has been extensively studied and demonstrated in the literature through the use of conventional control strategies to effectively achieve lateral control (Meier et al., 2004; Netto et al., 2004; Peng et al., 1992), longitudinal control (Swaroop

and Hedrick, 1994; Raza and Ioannou, 1996), and combined lateral and longitudinal control (Fritz, 1999; Rajamani et al., 2000).

Other platoon information a follower receives from other members includes: index numbers of platoon members, platoon split and platoon merge commands from the leader, platoon disband command from the leader, etc. For a platoon leader, the information includes: index numbers of platoon members, platoon merger and split requests from other members and free-agent vehicles, destinations of platoon members, etc. A platoon leader must also broadcast commands such as merge, split, and disband to the following vehicles in the group.

4 Strategy for platoon formation at entrances

In this section, a direction for forming platoons at highway entrances is proposed with an aim of increasing lane capacity and therefore enhancing traffic throughput. The platoon assignment will be formulated here as linear programming problems (see Cormen et al. (2001)) that can be solved using the simplex method invented by Dantzig (1959).

Let us consider a highway with n_e entrances (on-ramps) and n_d exits (off-ramps). The highway system used in this work is discretized into segments where each segment starts from an entrance i to the next entrance $i + 1$ as shown in Fig. 3.

The optimization problem is solved online in real-time everytime a vehicle hits a highway entry point. The system works as follows: (1) When a vehicle hits an entry point when it enters the highway, it communicates with all the existing platoons (coming from highway upstream) and incoming free-agent vehicles (vehicles, in the entrance ramp, not assigned to any platoon yet) within its communication range R . A platoon is considered to be within communication range if its leader is in the communication range. (2) The platoon assignment is executed and decides which incoming vehicles go to which platoons based on the sharing information among the platoons and vehicles in the communication group. (3) Vehicles, now no longer are free-agent, are maneuvered to assigned platoons leaving the entrance ramp for the next group of incoming free-agent vehicles. A vehicle, which has been assigned to a platoon, will not call its planner again even if it hits the entrance point. Fig. 3 depicts the concept of this communication group in which vehicles and platoons within R are shown in a dark color.

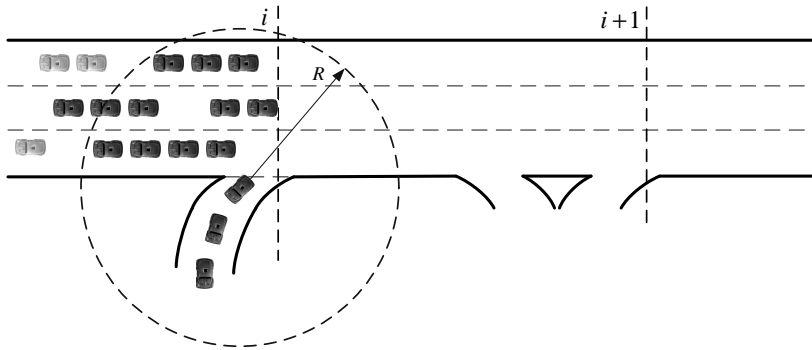


Figure 3 Platoon assignment strategy.

For assigning the incoming vehicles to appropriate platoons, the following policies are made to ensure the intactness of platoons:

1. Once a vehicle has been assigned a platoon, it stays with the hosted platoon for its entire trip until it exits the highway,
2. Platoons are constrained to have the maximum platoon size Υ ,
3. The difference in index between the nearest and the furthest destinations of vehicles in a platoon cannot exceed a maximum number r , called the ‘range of destinations’ of a platoon,
4. Vehicles in platoons are sorted front to back in the order non-increasing destination so that the rest of platoon members remain intact after some vehicles split off. The meaning of this policy is that in a platoon the leader has the furthest destination and the last vehicle in the group has the nearest destination. This allows the same vehicle to remain as platoon leader through the platoon’s lifetime, while the platoon ‘drops off’ vehicles that have closer destinations. This also gives a platoon the flexibility of having a greater range of destinations, as long as the range does not exceed r ,
5. If an incoming vehicle cannot find a feasible platoon to join (*i.e.*, satisfying the range r and the maximum platoon size Υ), it initiates a new platoon.

5 Problem formulation

This section develops a strategy for organizing vehicles arriving at entrance ramps into platoons, with the objective of maximizing the distance that platoons stay intact. Specifically, this involves grouping vehicles according to their destinations.

Vehicles are appended to existing platoons at the beginning of each road segment i on the basis of their destinations. A vehicle enters the highway, is adjoined to an existing platoon coming from highway upstream and remains intact until it reaches its destination. At this point, the vehicle separates from the host platoon and travels to its exit.

To derive the objective function for the optimization problem, denote the distance traveled by a vehicle from entrance i to exit j as $d_{i,j}$. Let the distance that the last vehicle of platoon p travel from entry i to its destination be $\delta_{i,p}^l$, respectively. To satisfy policy 4 and to maximize the distance a vehicle at an entrance stays intact with platoon p , the goal is to determine platoon p so that $\delta_{i,p}^l - d_{i,j} \geq 0$ is minimized. Let $\chi_{i,j}^p$ be the number of vehicles at the entrance ramp traveling from i to j that will be sent to platoon p , and n_p be the number of platoons within the range R . A candidate for the cost function to be minimized is:

$$(2) \quad \Theta_i = \sum_{p=1}^{n_p} \sum_{j=i+1}^{n_d} (\delta_{i,p}^l - d_{i,j}) \chi_{i,j}^p.$$

Denote $\alpha_{i,j}^p$ as the percentage of vehicles entering the highway and traveling from i to j that will join the platoon p . The factor $\alpha_{i,j}^p$ relates the number of vehicles

$\chi_{i,j}^p$ as $\chi_{i,j}^p = \chi_{i,j} \alpha_{i,j}^p$ where $\chi_{i,j}$ is the number of vehicles within R traveling from i to j . Equation (2) therefore can be rewritten as

$$(3) \quad \Theta_i = \sum_{p=1}^{n_p} \sum_{j=i+1}^{n_d} \chi_{i,j} (\delta_{i,p}^l - d_{i,j}) \alpha_{i,j}^p.$$

The minimization problem can be cast as a linear programming problem to solve for $\alpha_{i,j}^p$'s with the cost function in Eq. (3) subject to the following constraints:

1. Non-negativity: $\alpha_{i,j}^p \geq 0$,
2. Maximum platoon size: $\varepsilon_p + \sum_{j=i+1}^{n_d} \chi_{i,j} \alpha_{i,j}^p \leq \Upsilon$, where ε_p is the current size of platoon p , and Υ is the maximum platoon size (the number of vehicles a platoon can accommodate),
3. Percentages sum to 1: $\sum_{p=1}^{n_p} \alpha_{i,j}^p = 1$.

To satisfy policies 3 and 4, it is also required that $\alpha_{i,j}^p = 0$ (constraint 4) if either $des_p^f - j > r$ or $\delta_{i,p}^l - d_{i,j} < 0$ where des_p^f is the destination index of the leader of platoon p .

To summarize, the constrained minimization problem is of the form

$$\min \mathbf{c}^T \mathbf{x},$$

subject to

$$\mathbf{A}\mathbf{x} \leq \mathbf{b}, \quad \mathbf{A}_{eq}\mathbf{x} = \mathbf{b}_{eq}, \quad \text{and } \mathbf{x} \geq \mathbf{0}.$$

The vector $\mathbf{c} \in \Re^{n_p(n_d-i)}$ has the form

$$\mathbf{c} = \underbrace{[\chi_{i,i+1}(\delta_{i,1}^l - d_{i,i+1}) \dots \chi_{i,i+1}(\delta_{i,n_p}^l - d_{i,i+1}) \dots]}_{n_p \text{ components}} \dots \underbrace{[\chi_{i,n_d}(\delta_{i,1}^l - d_{i,n_d}) \dots \chi_{i,n_d}(\delta_{i,n_p}^l - d_{i,n_d})]}_{n_p \text{ components}}]^T,$$

vector $\mathbf{x} \in \Re^{n_p(n_d-i)}$ is

$$\mathbf{x} = \underbrace{[\alpha_{i,i+1}^1 \dots \alpha_{i,i+1}^{n_p}]}_{n_p} \dots \underbrace{[\alpha_{i,n_d}^1 \dots \alpha_{i,n_d}^{n_p}]}_{n_p}]^T,$$

matrix $\mathbf{A} \in \Re^{n_p \times n_p(n_d-i)}$ has the form

$$\mathbf{A} = [\mathbf{A}_{i,i+1} | \mathbf{A}_{i,i+2} | \dots | \mathbf{A}_{i,n_d}],$$

where a matrix $\mathbf{A}_{i,j} \in \Re^{n_p \times n_p}$ has the form

$$\mathbf{A}_{i,j} = \begin{bmatrix} \chi_{i,j} & & \\ & \ddots & \\ & & \chi_{i,j} \end{bmatrix},$$

and $\mathbf{A}_{eq} \in \mathfrak{R}^{(n_d-i) \times n_p(n_d-i)}$ is a band matrix

$$\mathbf{A}_{eq} = \begin{bmatrix} \overbrace{1 \ \dots \ 1}^{n_p} & & & \\ & \ddots & & \\ & & \ddots & \\ & & & \underbrace{1 \ \dots \ 1}_{n_p} \end{bmatrix}.$$

Vector $\mathbf{b} \in \mathfrak{R}^{n_p}$ is

$$\mathbf{b} = \begin{bmatrix} \Upsilon - \varepsilon_1 \\ \vdots \\ \Upsilon - \varepsilon_{n_p} \end{bmatrix},$$

and vector $\mathbf{b}_{eq} \in \mathfrak{R}^{n_p(n_d-i)}$ is

$$\mathbf{b}_{eq} = \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix}.$$

The idea is to assign a vehicle to a platoon that has the closest destinations to that of the vehicle. To illustrate this concept, suppose that one platoon currently has destinations $\{4,3\}$, another currently has $\{6\}$ and destinations are equally spaced. Also, suppose that $r = 3$. If the newly arriving vehicle has destination 3, it is assigned to the first platoon, even though it would be feasible to assign it to the second.

6 Simulation results analysis

Simulations in VISSIM (2005) were used to evaluate the performance of the proposed platoon assignment algorithm. VISSIM is a microscopic, time step and behavior based simulator developed to analyze the full range of functionally classified roadways. It is capable of modeling traffic with various control measures in a 3D environment. VISSIM lets us communicate and control the behaviors of vehicles through a dynamic link library (DLL) file compiled from C/C++ code. Vehicle parameters from the external driver model DLL output function are stored within member variables of a designated vehicle class object. A detailed description about the software architecture used in this research is provided by Leung et al. (2006).

The four-lane highway used in the simulation has ten entrances from e_1 to e_{10} and ten exits from x_1 to x_{10} as shown in Fig. 4. The distance from one entry to the next exit downstream is 2 km. The highway starts with zero traffic and the vehicles are generated randomly by VISSIM.

Let the platoon ratio be the ratio of vehicle distances traveled to platoon distances traveled. To evaluate the proposed strategy, platoon sizes and platoon ratios at the road segment immediately after the third entrance are collected under different total input flows from the first three entrances and different destination ranges r . Eq. (1) was used to calculate the lane capacity based on the average platoon size. The parameters used in this equation are: $t_h = 3 \text{ sec}$, $v = 100 \text{ km/h}$, $h = 10 \text{ m}$, $s = 4.5 \text{ m}$, and $\Upsilon = 10 \text{ veh}$.

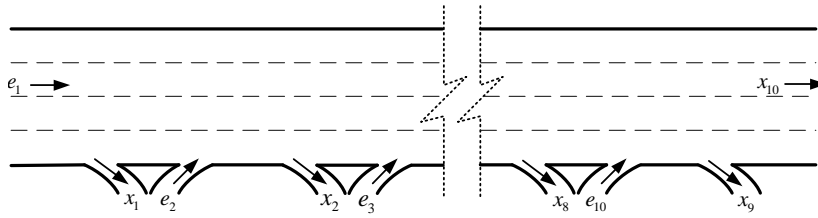


Figure 4 Highway used in simulations.

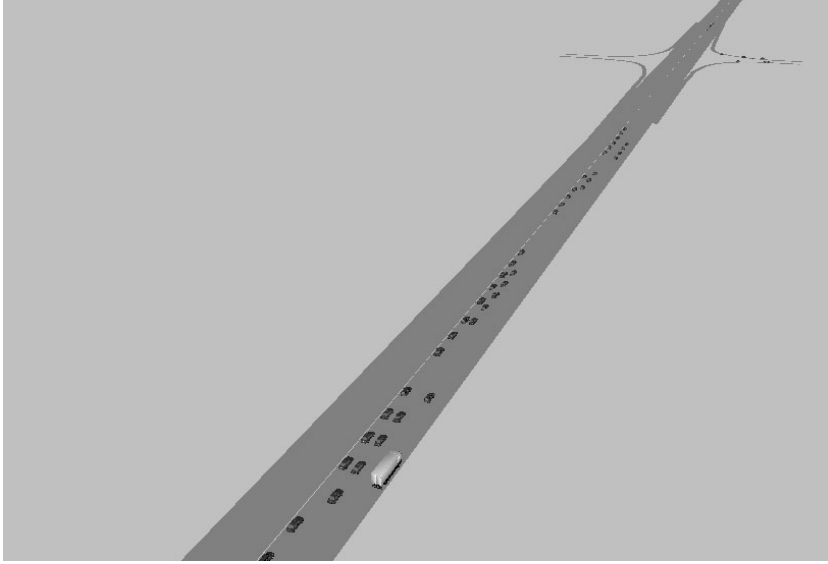


Figure 5 Screenshot of VISSIM simulation of platooning operation.

The probability distributions of platoon sizes versus destination range and total input flow are plotted in Fig. 6 and the associated means and standard deviations are plotted in Fig. 7. Fig. 8 shows the relationship between mean/standard deviation of platoon size, destination range and total input flow in three dimensional space. It can be seen that for each destination range, the average platoon size is small at low longitudinal input flow and grows as the volumes of vehicles at entries get higher. We can also see that no platoon exceeds the maximum platoon size of 10 vehicles when the input flow is 1000 *veh/hr* even at $r = 5$. The average platoon size is also larger when the destination range is large which increases lane capacity as shown in Fig. 9. This is reasonable since at high longitudinal flow, the chance of getting a feasible vehicle/platoon to join is higher.

Fig. 9 shows the lane capacities at 100 *km/hr* calculated from Eq. (1) based on the average platoon sizes. It is possible to draw several conclusions from this plot. Over the ranges of destinations tested, a larger range has greater benefit on lane capacity, but at the cost of reducing platoon ratio as shown in Fig. 10. The values for lane capacity are significant, at $r = 5$, the lane capacities range from 2360

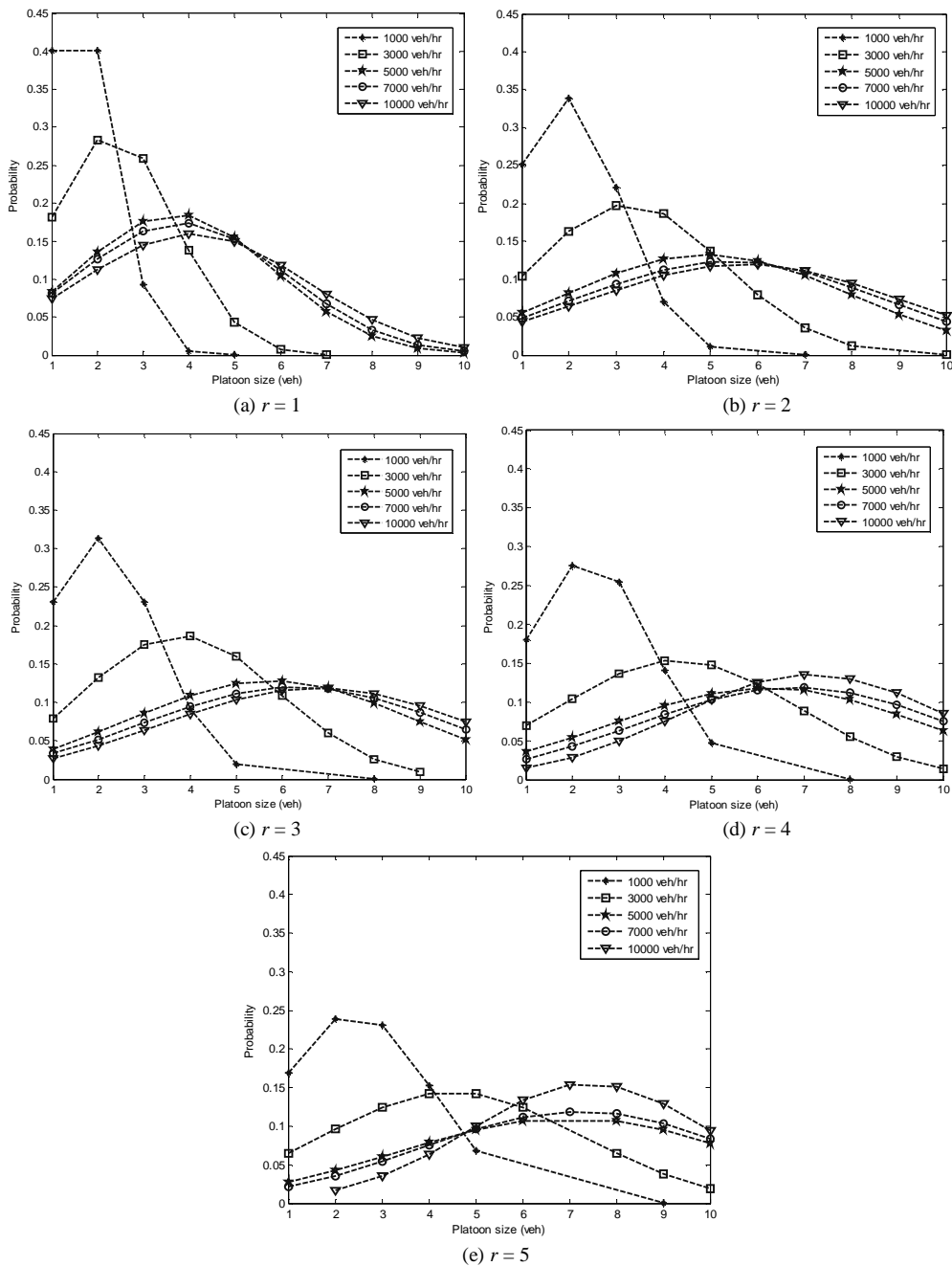


Figure 6 Platoon size probability distribution versus destination range r and input flow.

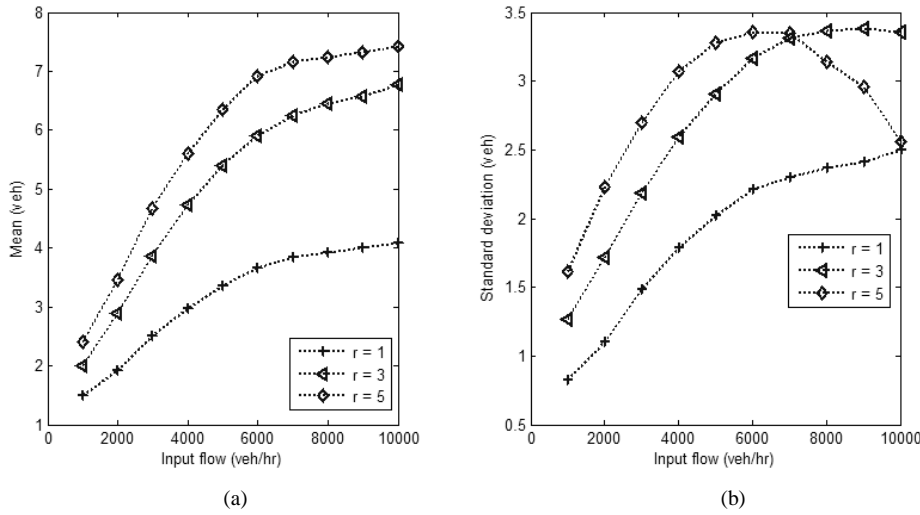


Figure 7 (a) Average and (b) standard deviation of platoon size versus destination range r and input flow.

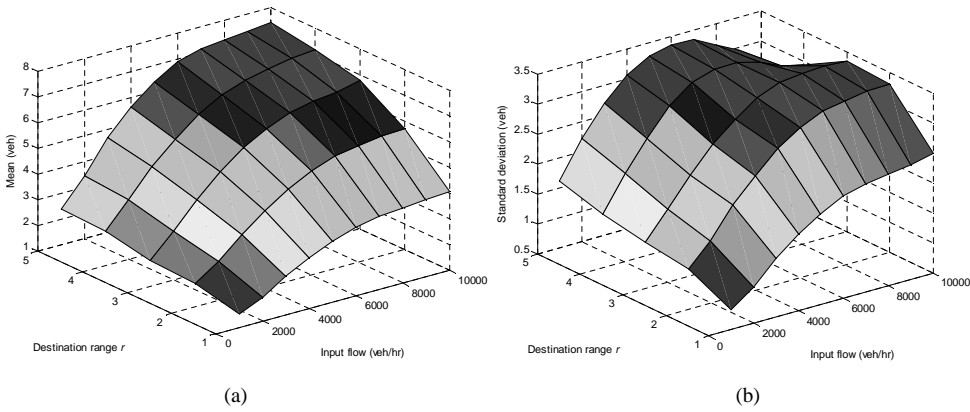


Figure 8 (a) Average and (b) standard deviation of platoon size versus destination range r and input flow.

veh/hr to 4880 *veh/hr* depending upon the total input flow. A higher longitudinal input flow results in a larger capacity.

On the other hand, there is no big improvement in terms of lane capacity for small destination range at low input flows. For example, the lane capacity is only 1610 *veh/hr* when the input flow is 1000 *veh/hr* and $r = 1$. A small destination range, however, means that most of the vehicles in a platoon have same destination and they can therefore exit the highway at the same time. Fig. 10 shows that at $r = 1$ the vehicles stay intact with the platoons up to 88% of the trip on average

while at $r = 5$ this number drops to 66%, 69% and 70% for the longitudinal flow of 1000 *veh/hr*, 5000 *veh/hr* and 10,000 *veh/hr*, respectively.

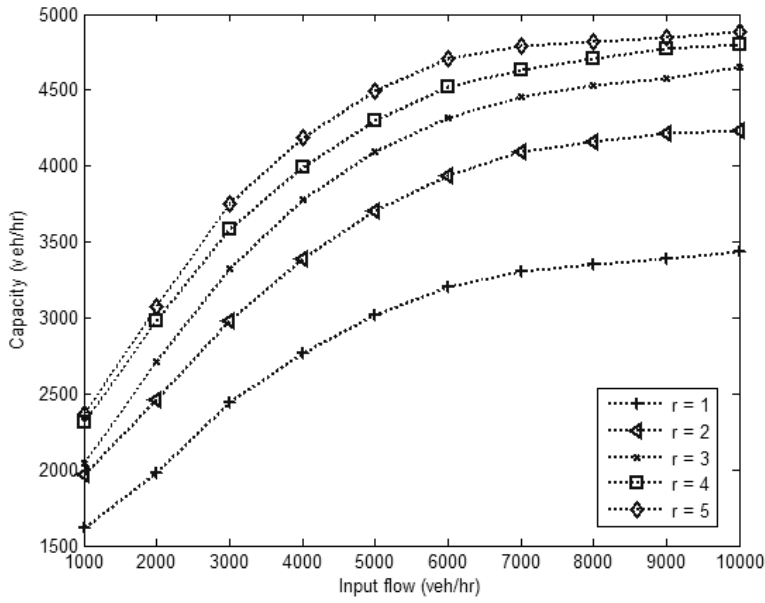


Figure 9 Lane capacity versus destination range r and input flow.

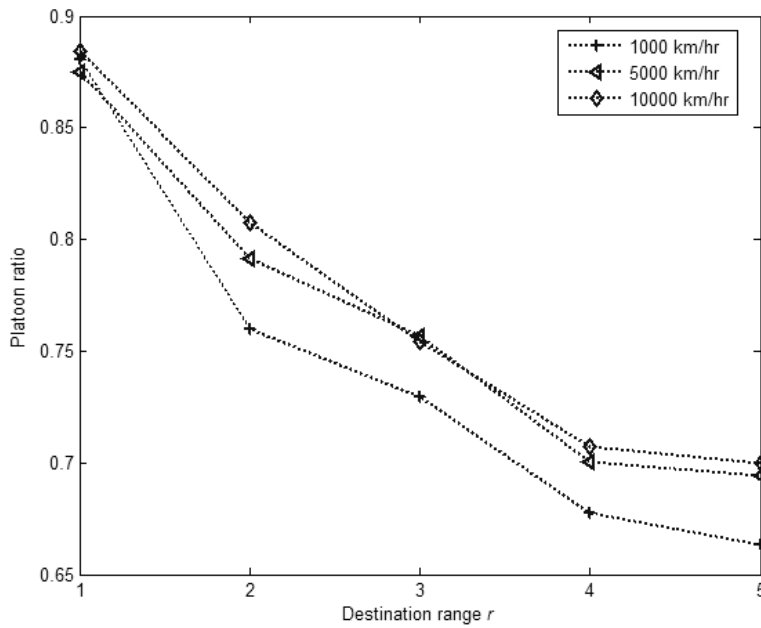


Figure 10 Platoon ratio versus destination range r and input flow.

7 Conclusions

To maximize highway throughput and reduce fuel consumption, it is desirable to create platoons that are large in size, and that remain intact over long distances. Sorting vehicles by destination at the entrance is one way to accomplish this objective. Toward this end, this work evaluated a proposed strategy which assigns vehicles to platoons by solving an optimization problem.

A linear model for effectively assigning vehicles to appropriate platoons when they enter the highway was formulated. The simplex algorithm was used to solve this optimization problem and simulation results in VISSIM were presented.

Simulation results demonstrated that lane capacity can be increased to between 2360 *veh/hr* and 4880 *veh/hr* when the destination range, representing the difference in index between the closest and the furthest exits for vehicles in the platoon, of 5 exits was used, depending on the total input traffic volume. Simulation results also suggested that while a smaller range of destination can lead to a lesser increase in lane capacity, it ensures that vehicles stay intact with the platoons for longer distances. For example, at the total input traffic volume is 5000 *veh/hr*, vehicles remain with their host platoons up to 88% when the destination range is 1 and only 69% when the destination range is 5. This results can be used to balance the tradeoff between highway capacity and distances platoons remain intact.

It should be highlighted that although lots of efforts have been put on lane assignment for single vehicles in the literature (Hall et al. (1999); Kim et al. (2005); Dao et al. (2007)), very little or no research has been done on lane assignment for multiple platoons. Compared to lane assignment for single vehicles, lane assignment for multiple platoons offers several advantages including a greater reduction in vehicle travel time and a significant increase in highway capacity together with many other known advantages of platooning such as smaller vehicle drag, less fuel consumption, and faster speed as pointed out by Browand and Michaelian (2000).

The platooning technology has some drawbacks, too. Platooning requires a more complicated controller and algorithm for vehicle longitudinal and lateral control. Another drawback is that lane assignment for platoons increases the frequency of lane changes and therefore might reduce the level of highway safety. However, this issue can be overcome with automatic control and is far outweighed by many other advantages of platooning.

A potential future direction for this work will be on quantifying the effect of platoon assignment on the reduction of fuel consumption. This can be done by using the field test results from the study of Browand and Michaelian (2000).

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Appendix

Let v be the steady state speed of the vehicles [km/hr], t_h be the separation time between platoons [seconds], s be the average length of vehicles [m], h be the intra-platoon distance headway [m], and Υ be the maximum platoon size (see Fig. 11). The total distance from the front bumper of a platoon leader to the rear bumper of the last vehicle in the following platoon is $(\Upsilon - 1)h + s + \frac{t_h v}{3.6}$ [m]. The total time in hr taking all the Υ vehicles to pass a given point is

$$(4) \quad \frac{3.6[(\Upsilon - 1)h + s] + t_h v}{3600v}.$$

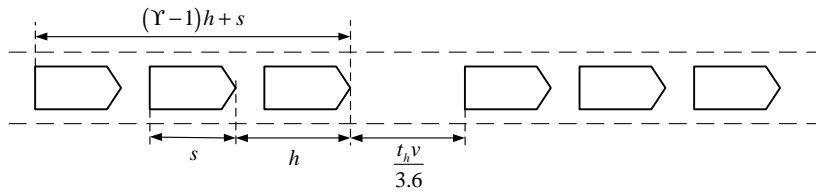


Figure 11 Lane capacity calculation.

Therefore the maximum capacity is

$$(5) \quad C_{max} = \frac{3600Yv}{3.6[(Y-1)h + s] + t_h v}.$$

