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Dynamic ECO-Driving for Arterial Corridors

Matthew Barth[1,2], *Senior Member*, IEEE, Sindhura Mandava[1], Kanok Boriboonsomsin[2], and Haitao Xia[1]
[1]Department of Electrical Engineering, University of California Riverside
Riverside, CA 92507, USA, emails: barth@ee.ucr.edu, smand001@ucr.edu, and hxia001@ucr.edu
[2]College of Engineering – Center for Environmental Research and Technology, University of California Riverside
Riverside, CA 92507, USA, email: kanok@cert.ucr.edu

Abstract—**There are a variety of strategies that are now being considered to reduce fuel consumption and carbon dioxide (CO_2) emissions from the transportation sector. One strategy that is gaining interest worldwide is known as "eco-driving". Eco-driving typically consists of changing a person's driving behavior based on general (static) advice to the driver, such as accelerating slowly, driving smoothly, reducing high speeds, etc. Taking this one-step further, it is possible to provide real-time advice to drivers based on changing traffic and infrastructure conditions for even greater fuel and emission savings. This concept of *dynamic eco-driving* takes advantage of real-time traffic sensing and infrastructure information, which can then be communicated to a vehicle with a goal of reducing fuel consumption and emissions. In this paper, we consider dynamic eco-driving in an arterial corridor with traffic signals, where signal phase and timing information of a traffic light is provided to the vehicle. The vehicle can then adjust its velocity while traveling through a signalized corridor with the goal of minimizing fuel consumption and emissions. A dynamic eco-driving velocity planning algorithm has been developed and is described herein. This algorithm has then been tested in simulation, showing initial fuel economy and CO_2 improvements of around 12%.**

Keywords: traffic signal phase and timing;energy; emissions

I. INTRODUCTION

With pressure to reduce fuel consumption and carbon dioxide (CO_2) emissions from the transportation sector, policy makers are exploring a variety of strategies. Among these strategies is the concept of "eco-driving" which is garnering increased interest in recent years. Eco-driving is one of the conservation programs that can be very cost effective [1]. The core of these eco-driving programs is to provide drivers with a variety of advice and feedback to minimize fuel consumption and emissions while driving. The advice and feedback can be provided through various means including a website or brochure, class or training, and in-vehicle driving aids (e.g. eco-driving feedback systems on vehicle dashboard). Different eco-driving program evaluations in Europe have shown fuel economy improvements on the order of 5 to 15% [2].

There are a variety of practices a driver can do to save fuel and reduce emissions from his/her vehicle. Some of them simply have to do with the maintenance of the vehicle, for instance, check tire pressure and replace air filters regularly, remove excess weight from the vehicle, perform periodic engine tune-ups and use manufacturer-recommended motor oil, etc. Others have to do with how the vehicle is driven. The dependence of fuel consumption and emissions on how a vehicle is driven has been widely studied [3 - 8]. It is clear that in order reduce the fuel consumption and emissions, driving gently and reducing idling time are key factors.

Roadways such as freeways and highways are designed to have continuous traffic flow and therefore have little traffic control infrastructure. As a result, a vehicle traveling on uninterrupted roadway segments has no constraint on the time interval at which it reaches a particular point of the road. Therefore, it is relatively straightforward to design "dynamic eco-driving" systems where optimal speed advice (based on minimizing fuel consumption and emissions) can be communicated to the drivers (see, e.g., [8]).

However, for roadway segments that have traffic control infrastructure (e.g., traffic lights), traffic suffers from increased delays due to idling at the traffic signals on red and increased fuel consumption and emissions due to inherent accelerations/decelerations required at the signals. Many empirical studies have shown a positive relationship between vehicle emissions and fuel consumption with the delays at traffic signals [9, 10, 11]. To minimize delays (and therefore lowering fuel consumption and emissions), most of the research has been focused on infrastructure control, such as developing better traffic signal control algorithms that are both dynamic and adaptive, using information such as vehicle queue lengths (see, e.g., [12, 13, 14]).

However, with the recent advances in intelligent transportation system technology, it is now possible to put more of the control burden on the vehicles themselves with arterial eco-driving strategies. For example, a traffic controller's Signal Phase And Timing (SPAT) information can now be communicated directly to individual vehicles so that vehicles can adjust their speed as they travel through a signalized corridor, with the goal of minimizing idle time and acceleration events. Several researchers have developed and studied variable speed algorithms for arterial traffic (see, e.g., [9, 10, 15, 16, 17]). However, the majority are oriented towards providing optimal speed advice to the driver in order to improve *safety* by taking into consideration the current weather conditions, road grade, etc. Very few of these speed advice algorithms directly deal with minimizing emissions and fuel consumption while maintaining safety.

In this paper, we have developed a dynamic eco-driving system for signalized corridors that consists of an arterial velocity planning algorithm that attempts to minimize vehicle fuel consumption and emissions. In Section II, we briefly provide background on the key fuel consumption/emission factors associated with acceleration, idling, and steady-state velocity. In Section III, we provide the details of the arterial velocity planning algorithm, and then in Section IV, results are provided.

II. BACKGROUND

A. Velocity and Fuel Consumption/Emissions

The relationship between fuel consumption/emissions and vehicle velocity has been study extensively at a microscopic, physical level, a summary is provided in [18]. In general, when considering fuel and emissions normalized by distance traveled, the fuel-speed function takes on a general shape as shown in Fig. 1. At lower speeds, vehicles are spending a greater time on the roads and therefore have a high fuel/distance value. At higher speeds, the engine needs to work harder to overcome aerodynamic resistance, therefore the emissions are higher. In between these extremes, the fuel consumption and emissions are minimized, generally around 60 kph, depending on the vehicle type. As a result, in order to minimize overall fuel consumption and emissions while traveling down the road, it is best to maintain a steady-state velocity at these mid-range speeds.

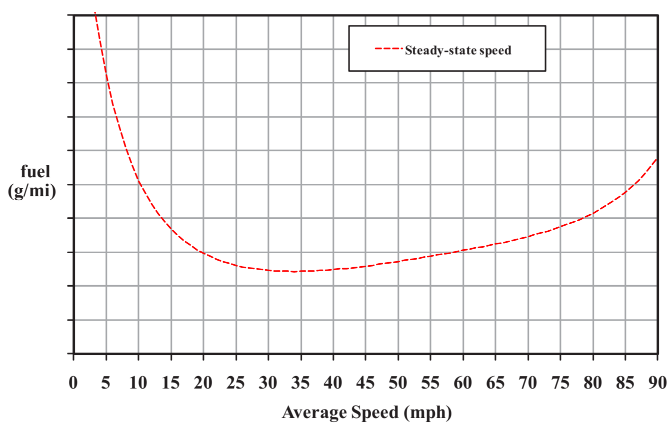

Figure 1. Fuel consumption versus average cruise speed generalized functional relationship.

B. Vehicle Trajectory Planning

We now consider the scenario of a single traffic light and its corresponding time-distance diagram as shown in Fig. 2. In this figure, the traffic light is at a fixed location and changes its phase with time, as shown with the green, yellow, and red lines. Also shown in this figure are several vehicle velocity trajectories that all have the initial velocity of $v_i(t)$ at point $d(t)$. At time t, signal phase and time information is received by the vehicle. We then consider the following cases:

Case 1: in this case, the vehicle increases its speed and manages to make it through the green light with no slowing or idling;

Case 2: in this case, the vehicle continues to drive at speed $v_i(t)$, and when the traffic light turn yellow then red, the vehicle slows down quickly and stops rather suddenly;

Case 3: in this case, the driver of the vehicle takes their foot off of the gas pedal and coasts to a stop at the intersection;

Case 4: in this case, the vehicle actively slows down (i.e., braking) and then travels at a lower speed until the traffic light turns green, after which the vehicle increases its speed, all without stopping.

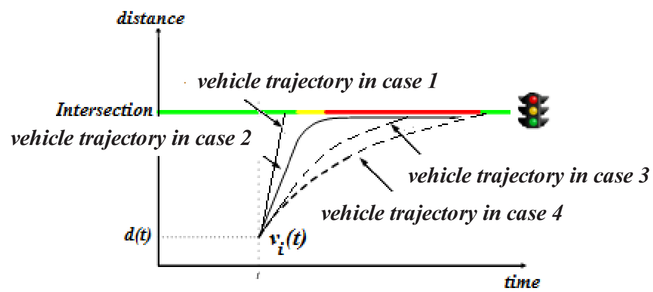

Figure 2. Time-space diagram representing different vehicle trajectories approaching an intersection.

For these different trajectory cases, fuel consumption and emissions vary greatly. For case 1, even though the vehicle did not have to idle at the red light, the fuel consumption and emissions are high since the vehicle had to accelerate to make the green light. For case 2, fuel/emissions are also high due the fact that the vehicle had to hold the original velocity for a certain amount of time, and then had a long idle period. For case 3, the fuel/emissions are less, since very low fuel is being consumed as the vehicle coasts up to the intersection (case 2 and case 3 have been extensively compared in [11] with differences around 15%). Finally, case 4 has the lowest fuel consumption and emissions, due to the fact that its acceleration from the red light isn't from a dead stop, but rather from a moving velocity, therefore the energy required to accelerate back up to speed is significantly less.

Therefore, as a vehicle travels down a signalized corridor, it is best to travel at a mid-range speed when possible. As it approaches a signal, it is possible to dynamically adjust its velocity to minimize fuel consumption and emissions. The overall functional requirements of the vehicle are to: 1) try and maintain a steady state speed around the speed limit; 2) maintain safe headway distance to vehicles in front; 2) never cross the intersection on red; 3) minimize the idling time at the traffic signals; and 4) avoid sharp accelerations. An overall vehicle planning algorithm that takes all of these into account is described in greater detail in the next section.

III. VELOCITY PLANNING ALGORITHM

The overall block diagram of the arterial velocity planning algorithm is shown in Fig. 3.

The control logic for the velocity planner requires several input parameters:

v_h the target maximum speed on the roadway link that is dictated by the link speed limit and/or the car following logic, which typically has other input parameters such as headway distance (d_s), headway time (t_h), and current vehicle velocity (v_c).

d_{int} the distance from the vehicle to the intersection;

v_c the current vehicle velocity;

t_r, t_g the signal phase and timing information from the signal, where t_r is the time until the light changes to red, and t_g is the time until the light changes to green.

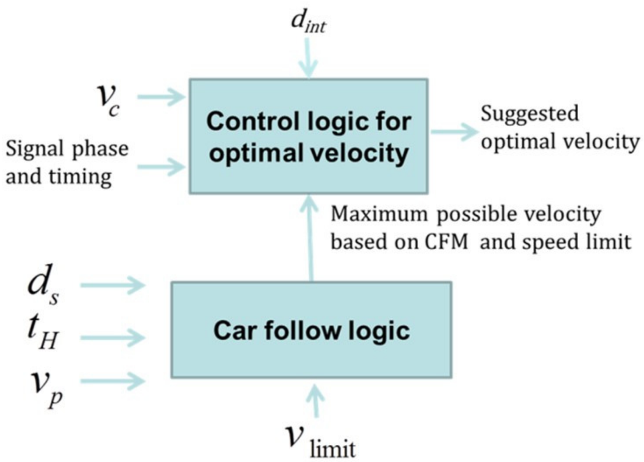

Figure 3. Block Diagram of the Arterial Velocity Planning Algorithm.

The control logic for the optimal velocity tries to minimize the fuel consumption by minimizing the total tractive power demand and the idling time while ensuring that the optimal velocity is less than or equal to v_{limit}. In order to avoid idling, the vehicle should reach the intersection during the green phase of the signal. Depending on the current phase of the signal, the travel time to the intersection is given as:

$$t \in \begin{cases} [0,t_r) \cup [t_g,t_{r1}) & if\ s = G \\ [t_g,t_r) & if\ s = R \end{cases} \tag{1}$$

Therefore, given the distance to the intersection d_{int}, the possible velocities of the vehicle fall into a range given by $v_{lo} = d_{int} / t_h$ and $v_{ho} = d_{int} / t_l$, where t_l and t_h are the low and high values respectively from the equation above. Figure 4 then represents the overall velocity selection algorithm. The acceleration and deceleration trajectory planning are described below.

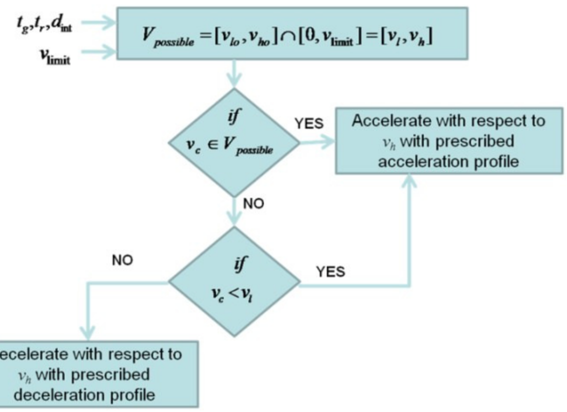

Figure 4. Block Diagram of the Arterial Velocity Planning Algorithm.

A. Acceleration Profile Design

In order to stay within the targeted range of velocity, or to achieve a velocity so the vehicle can reach the intersection at a specific time, the vehicle will need the ability to accelerate at specific times, as indicated in Fig. 4. There are an infinite number of ways to accelerate from one speed to another speed; several trajectory planning algorithms have been suggested in the literature including constant acceleration, linear-acceleration, and constant-throttle acceleration. However, we want to choose an acceleration profile that minimizes fuel consumption/emissions and is still comfortable to the passengers (i.e., low jerk). As shown in Fig. 5, we consider an acceleration from current vehicle velocity (v_c) to a velocity that will ensure that we are able to reach a point at a specific time. All possible trajectories need to reach a point (e.g., the intersection), therefore the area of region A must be equal to the area of regions B_1 and B_2 as shown in Fig. 5.

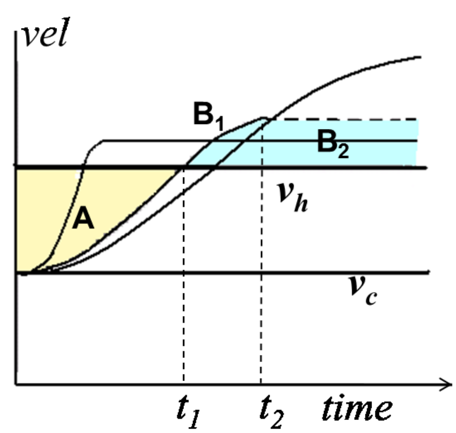

Figure 5. Different acceleration profiles for reaching a specific location at a specific time.

In order to ensure a smooth trajectory, we have chosen a family of velocity profiles with a trigonometric increase in velocity given by:

$$v = \begin{cases} v_h - v_d \cos(st) & for\ t = 0\ to \frac{\pi}{2s} \\ v_h - v_d * \frac{s}{a} * \cos a\left(t - \frac{\pi}{2s} + \frac{\pi}{2a}\right) & for\ t = \frac{\pi}{2s}\ to (\frac{\pi}{2a} + \frac{\pi}{2s}) \\ v_h + v_d * \frac{s}{a} & for\ t = (\frac{\pi}{2a} + \frac{\pi}{2s}) to \frac{d}{v_h} \end{cases} \quad (2)$$

where d is the target distance, v_h is the higher limit of the velocity range, and v_d is the difference between the current velocity of the vehicle and the higher limit of the velocity range (i.e., $v_d = v_h - v_c$). The parameters s and a define the family of velocity profiles. Different values of *(s,a)* correspond to different acceleration and jerk profiles. Parameter s controls the rate of change of acceleration in region A and parameter a controls the rate of change of acceleration in region B of Fig. 5. Given a value of s, the choice of a will depend on the requirement that the vehicle has to reach the target point at a specific time. An example of three velocity profiles with different values of (s,a) is shown in Fig. 6.

Among the family of velocity profiles for different values of (s,a), we choose the velocity profile that has minimum tractive power requirements, in order to minimize fuel consumption. The tractive power requirements of a vehicle depend on the velocity and the acceleration of the vehicle, given by:

$$P_{tract.} = Av + Bv^2 + Cv^3 + M(0.447a + gsin\theta)v * 0.447/1000 \quad (3)$$

where M is the vehicle mass with appropriate inertial correction for rotating and reciprocating parts (kg), v is speed (miles/hour or mph), a is acceleration (mph/second), g is the gravitational constant (9.81meters/s^2), and θ is the road grade angle in degrees. Here the coefficients $A, B,$ and C involve rolling resistance, speed-correction to rolling resistance, and air drag factors which can be determined empirically.

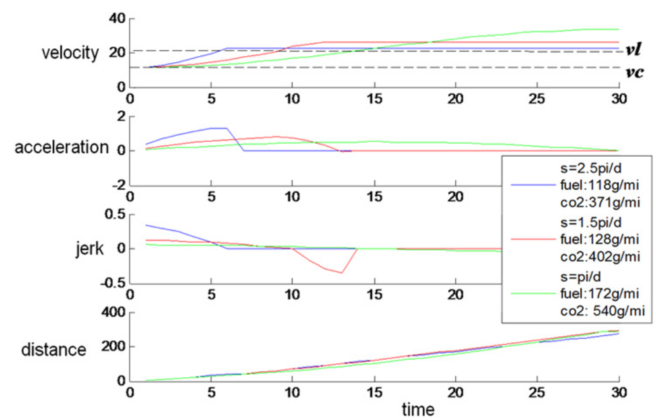

Figure 6. Different velocity profiles for different values of *(s,a)* and their corresponding fuel consumption & emissions.

Given Eqn. 2 and the constraint that the vehicle reaches the target point at a specific time, we can specify that the area A must be equal to the total area of B_1 and B_2, as illustrated in Fig. 5.

With this constraint, we can write eqn. (4):

$$\int_0^{\frac{\pi}{2s}} (v_h - v_d \cos(st))dt - \int_0^{\frac{\pi}{2s}} v_h dt = \int_{\frac{\pi}{2s}}^{\frac{\pi}{2s}+\frac{\pi}{2a}} \left(v_h - v_d s \frac{\cos a\left(t - \frac{\pi}{2s} + \frac{\pi}{2a}\right)}{a}\right) dt + \int_{\frac{\pi}{2s}+\frac{\pi}{2a}}^{\frac{d}{v_h}} \left(v_h + v_d \frac{s}{a}\right) dt - \int_{\frac{\pi}{2s}}^{d/v_h} v_h dt \quad (4)$$

Solving the above equation gives the following equation relating s and a:

$$a^2 + s\left(\frac{\pi}{2} - Ts\right)a + s^2\left(\frac{\pi}{2} - 1\right) = 0 \quad (5)$$

The above equation is quadratic in a, for a value of s. The above equation has real roots only if $s \geq 3.08/T\ or\ 0 \leq s \leq 0.06/T$. For a value of s , a can take the positive value:

$$\frac{1}{2}\left(-s\left(\frac{\pi}{2} - Ts\right) + \sqrt{s^2\left(\frac{\pi}{2} - Ts\right)^2 - 4s^2\left(\frac{\pi}{2} - 1\right)}\right) \quad (6)$$

At this point, s can take any value within the range $\left[\frac{3.08}{T}, \infty\right)$, where $T = \frac{d}{v_h}$, i.e., the time required to reach the target distance. The larger the value of s, the sharper the acceleration will be. The limit of s will be dictated by the power of the vehicle, safety, and the ride pleasure (i.e., constrained jerk). When combined with the total integrated tractive power of the trajectory, it can be seen that to minimize fuel consumption for the total acceleration maneuver, we should choose s as large as possible. This is counter-intuitive to the standard eco-driving advice that says that we should always accelerate slowly. When given a time and distance constraint, the best trajectory will accelerate quickly, reach a target velocity, then remain at a constant velocity until the position is reached.

The maximum jerk is a function of:

$$jerk_{max} = -v_d sa \quad (7)$$

By taking into consideration the ride pleasure, previous research results [19] has shown that a driver can tolerate up to a maximum acceleration of 2.5m/s^2 with a gradually increasing jerk profile. Therefore we choose a constraint on the maximum s value given by:

$$|jerk_{max}| = v_d sa \leq 10\ and\ |a_{max}| \leq 2.5m/s^2 \quad (8)$$

B. Deceleration Profile Design

The approach to designing a fuel efficient deceleration profile is carried out in a very similar fashion to the acceleration profile design. When a vehicle has to decelerate to a known speed at a known point (e.g., stopping at an intersection), there are an infinite number of ways of performing this deceleration as shown in Fig. 7.

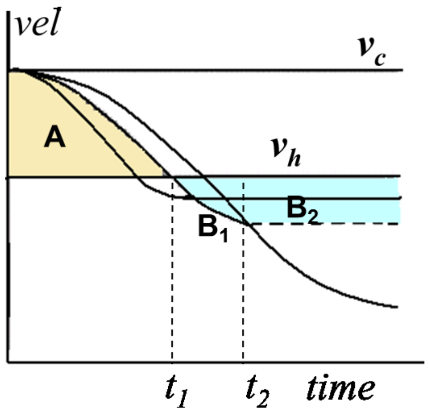

Figure 7. Different deceleration profiles for reaching a specific location at a specific time.

We again choose a trigonometric family of curves given by:

$$v = \begin{cases} v_h + v_d \cos(st) & for\ t = 0\ to\ \frac{\pi}{2s} \\ v_h + v_d * \frac{s}{a} * \cos a\left(t - \frac{\pi}{2s} + \frac{\pi}{2a}\right) & for\ t = \frac{\pi}{2s}\ to (\frac{\pi}{2a} + \frac{\pi}{2s}) \\ v_h - v_d * \frac{s}{a} & for\ t = (\frac{\pi}{2a} + \frac{\pi}{2s})\ to\ \frac{d}{v_h} \end{cases} \quad (9)$$

where d is the distance to a specific location such as the traffic intersection. v_h is the upper limit of the possible uniform velocity range required to reach the target location at a specific time. v_d is the difference between the current velocity of the vehicle and the upper limit of the possible velocity range ($v_d = v_c - v_h$).

As before, the parameters *s* and *a* define the family of deceleration profiles. Different values of *(s,a)* correspond to different deceleration and jerk profiles. Parameter *s* controls the rate of change of deceleration in region A and parameter *a* controls the rate of change of deceleration in region B in Fig. 7. Given a value of *s*, the choice of *a* will depend on the requirement that the vehicle has to reach the target point at a specific time. For the case of deceleration where a vehicle needs to slow down in order to reach a signalized intersection, then speed up when the signal is green, we can see that the choice of *(s,a)* play an important role, as shown in Fig. 8. A profile with an initial sharper deceleration will have a greater final velocity when it reaches the intersection. This is important, since the energy requirement for the vehicle to accelerate back to the link speed/free flow speed after clearing the intersection will be less than for other profiles. Therefore, the cumulative fuel consumption to decelerate until the intersection and then accelerate back to link speed/free flow speed after clearing the intersection will occur with the largest value of *s*.

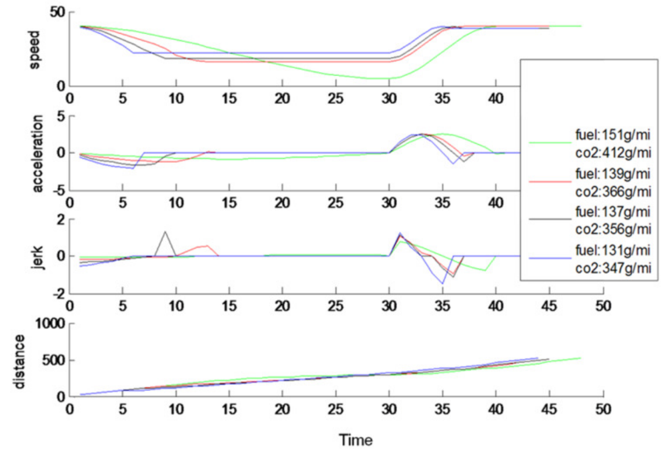

Figure 8. Fuel consumption & emissions for different deceleration profiles parameterized by $s = \frac{\pi}{T}, \frac{1.5\pi}{T}, \frac{2\pi}{T}, \frac{2.5\pi}{T}$.

Similar to the derivations for the acceleration profile, *a* can be determined to minimize cumulative tractive power once *s* has been chosen, given:

$$a = \frac{1}{2}\left(-s\left(\frac{\pi}{2} - Ts\right) + \sqrt{s^2\left(\frac{\pi}{2} - Ts\right)^2 - 4s^2\left(\frac{\pi}{2} - 1\right)}\right) \quad (10)$$

The only limitation on the choice of *s* will be capabilities of the vehicle and riding comfort. Similar to before, we will consider a limit on the riding comfort where:

$$|jerk_{max}| = v_d sa \leq 10 m/s^3\ and\ |a_{max}| \leq 2.5\ m/s^2 \quad (11)$$

IV. SIMULATION RUNS

A. Simulation Setup

Using the dynamic eco-driving velocity planning algorithm for arterial roadways described in the previous section, we have applied this to a hypothetical 10-signalized intersection corridor. We did this in a stochastic fashion in order to capture the variability of infrastructure-related parameters and the randomness of traffic-related parameters. For the corridor, the link lengths between intersections ranged between 500m and 600m (selected from a uniform distribution), the speed limit was set to 70 kph, and advanced information on signal phase and timing was set randomly between 200m and 300m prior to the intersection. For the signal timing, we simply used a two-phase signal at all intersections. We chose an actuated signal strategy with the total green period (i.e. minimum green time + extension green time) to be modeled as a uniform distribution, $t_g \sim U(\alpha, \beta)$, where α is 40 s and β is 50 s. Similarly, we assume the same distribution of the total green time for the cross street traffic. Thus, the total red time on the main arterial corridor is also modeled as $t_r \sim U(\alpha, \beta)$.

The simulation was performed for a typical mid-sized sedan car. As described earlier, the engine power of the vehicle is used to determine the maximum acceleration at different speeds, given that road grade of all the links in the simulated corridor is assumed to be zero. The fuel consumption and emissions were determined for this single vehicle type using the Comprehensive Modal Emissions Model (CMEM, see [20 - 25].

The velocity planning algorithm was run over 30 times for a vehicle traversing the corridor with various link lengths and random signal phase and timing as dictated by the actuated signal control. For each run, the vehicle velocity profile was extracted across the entire corridor. An example of the velocity profile is shown in Fig. 9. Also shown in Fig. 9 is the distance-time diagram of the vehicle as well as the signal phase and timing at each intersection for that simulation run.

For each simulation run, we also created the vehicle velocity profile for a baseline case (i.e. for vehicles that do not have the eco-driving velocity planning algorithm) for comparison purposes. For this baseline comparison, we assumed that the typical driving behavior along a signalized corridor is where the drivers attempts to cruise at or around the speed limit until they are visually aware of the traffic signal ahead (assumed to be at 75 m before the intersection). If the signal is green, the driver simply maintains the cruise speed while crossing the intersection. If the signal is red, the driver slows down, stops, and then waits until the light turns green. Once the signal turns green, the driver accelerates back to the speed limit on the link. This driving behavior is applied at every intersection in the baseline case.

B. Simulation Results

For comparison purposes, the energy and emissions for the baseline case (i.e. for vehicles that do not have the eco-driving speed planning algorithm) are also calculated for the same vehicle type. Table 1 shows the energy and emissions comparison results between the vehicles without and with velocity planning for the vehicles. The results for both cases are given in terms of the average value and the standard deviation of the sample set of 30 velocity profiles. According to Table 1, the vehicles with velocity planning consume about 12% less fuel and CO_2 emission. Further, the travel time (TT) on an average is approximately 2% shorter for the vehicles with velocity planning as compared to the vehicles without velocity planning.

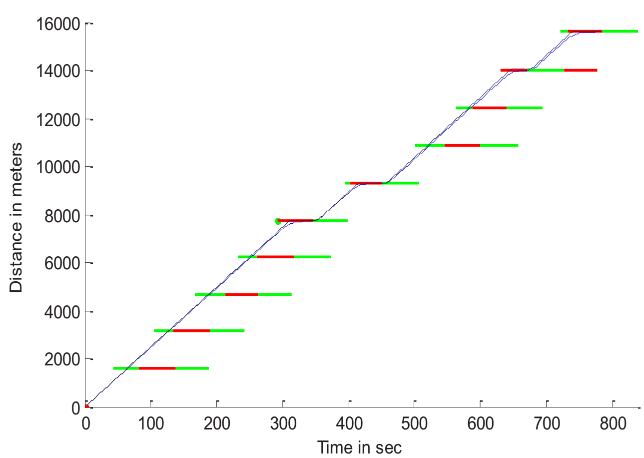

Figure 9. Example velocity profile using the dynamic eco-driving velocity planning algorithm.

TABLE 1. ENERGY AND EMISSIONS COMPARISON

passenger car	**Without**		**With**		**% Diff. in Avg.**	***p*-value of *t*-test**
	Avg.	*S.D.*	*Avg.*	*S.D.*		
Fuel (g/mi)	118.3	13.2	103.8	9.3	-12.3	8.7E-06
CO_2 (g/mi)	371.0	41.2	318.8	25.3	-14.1	3.2E-07
TT (sec)	456.7	60.7	451.9	56.9	-1.06	0.635

V. CONCLUSIONS AND FUTURE WORK

Fuel consumption and emissions are directly related to the acceleration/deceleration patterns of the vehicles traveling on the arterial and the idling at traffic signals. Unlike freeways, traffic on the signalized corridors suffers from inherent acceleration/deceleration maneuvers at the traffic signals and idling when they are waiting for the lights to change. By taking advantage of the recent developments in communication between vehicles and road infrastructure, it should be possible to obtain the signal phase and timing information. Using this real-time signal information, we have developed a dynamic eco-driving velocity planning algorithm that attempts to get through an arterial corridor using a minimum amount of fuel.

Based on this research, there are several key findings that are counter-intuitive when compared to typical eco-driving advice. When traveling on a roadway where there are specific points where traffic is controlled (traffic lights), specific constraints emerge in time and space; as a result, it has been found that hard accelerations that quickly get a vehicle up to a target speed and then have a steady cruise to reach a specific location at a specific time are less fuel consuming compared to a velocity profile that takes a longer period of time of acceleration to reach the same point and time. Similarly, it is beneficial to decelerate quickly, then hold a steady state cruise speed when reaching a traffic signal just as it is turning green. At that point, it takes less energy to accelerate back up to typical speed traversing the corridor, compared to starting from a stop.

Preliminary results of our velocity planning algorithms show approximately a 10% to15% fuel economy improvement over a standard baseline case without the velocity planning. Thus far this has been evaluated under low density traffic conditions. In subsequent work, it is planned to expand this research by evaluating under heavier traffic conditions and also incorporating additional information along the corridor (e.g., traffic speed, density, and flow, as well as other vehicle travel parameters).

REFERENCES

[1] International Energy Agency, "Energy efficiency policy recommendations in support of the G8 plan of action", Paris, 2008.

[2] Onoda, T., "IEA policies – G8 recommendations and an afterwards" *Energy Policy*, 37(10), pp. 3823-3831, 2009.

[3] Y. Muraki and H. Kanoh, "Wide-area traffic signal control using predicted traffic based on real-time information," Proceedings of the 11th International IEEE Conference on Intelligent Transportation Systems, Beijing, China, October 12-15, 2008.

[4] J., Barbé and G. Boy, "On-board system design to optimize energy management," Proceedings of the European Annual Conference on Human Decision-Making and Manual Control (EAM'06), Valenciennes, France, September 27-29, 2006.

[5] H. Johansson, P. Gustafsson, M. Henke, and M. Rosengren, "Impact of eco-driving on emissions," Proceedings of the 12th Symposium Avignon, June 16-18, 2003.

[6] N. Haworth and M. Symmons, "Driving to reduce fuel consumption and improve safety," Monash University Accident Research Centre, August 20, 2004.

[7] O. H. Koskinen, "Improving vehicle fuel economy and reducing emissions by driving technique," Proceedings of the15th ITS World Congress, New York, Nov 15-20, 2008.

[8] M. Barth and K. Boriboonsomsin, "Energy and emissions impacts of a freeway-based dynamic eco-driving system," *Transportation Research Part D*, 14, 400-410.

[9] G. S. Pierre and J. Ehrlich, "Impact of intelligent speed adaptation systems on fuel consumption and driver behavior," Proceedings of the 15th ITS World Congress, New York, Nov 15-20, 2008.

[10] S. Myhrberg, "Saving fuel and environment with intelligent speed adaptation," Proceedings of the 15th ITS World Congress, New York, Nov 15-20, 2008.

[11] M. Li, K. Boriboonsomsin, G. Wu, W.-B. Zhang, and M. Barth, "Traffic energy and emission reductions at signalized intersections: a study of the benefits of advanced driver information," *International Journal of Intelligent Transportation Systems Research*, vol. 7(1), pp. 49-58, 2009.

[12] A. Stevanovic, J. Stevanovic, K. Zhang, and S. Batterman, "Optimizing traffic control to reduce fuel consumption and vehicular emissions: an integrated approach of VISSIM, CMEM, and VISGAOST," Proceedings of the 88th Annual Meeting of the Transportation Research Board, Washington, DC, 2009.

[13] H. Nishuichi and T. Yoshii, "A study of the signal control for the minimization of CO2 emission", Proceedings of the 12th World Congress on Intelligent Transport Systems, San Francisco, CA, 2005.

[14] X. Li, G. Li, S.-S. Pang, X. Yang, and J. Tian, "Signal timing of intersections using integrated optimization of traffic quality, emissions and fuel consumption: a note," *Transportation Research Part D*, vol. 9, pp. 401-407, 2004.

[15] P. Morsink, N. van Nes, L. Waltaand, and V. Marchau, "In-car speed assistance to improve speed management," Proceedings of the 15th World Congress on ITS, New York, Nov 2008.

[16] F. Jime´nez, F. Aparicio, and J. Pa´ Ez, "Evaluation of in-vehicle dynamic speed assistance in Spain: algorithm and driver behavior," IET Aug,2007.

[17] I. Spyropoulou and M. G. Karlaftis, "Parameters related to modelling intelligent speed adaptation systems with the employment of a microscopic traffic model," European Conference on Human Centered Design for Intelligent Transportation Systems, France, April 3-4, 2008.

[18] M. Barth and K. Boriboonsomsin, "Real-world carbon dioxide impacts of traffic congestion," Transportation Research Record, vol. 2058, pp. 163-171, 2008.

[19] K. S. Yi, and J. T. Chung, "Nonlinear brake control for vehicle CW/CA systems," *Ieee-Asme Transactions on Mechatronics,* vol. 6, no. 1, pp. 17-25, Mar, 2001.

[20] M. Barth, F. An, T. Younglove, G. Scora, C. Levine, M. Ross, and T. Wenzel, "The development of a comprehensive modal emissions model," NCHRP Web-Only Document 122, Contractor's final report for NCHRP Project 25-11, National Cooperative Highway Research Program, 307 p., April 2000.

[21] M. Barth, G. Scora, and T. Younglove, "Modal emissions model for heavy-duty diesel vehicles," Transportation Research Record, vol. 1880, pp. 10-20, 2004.

[22] M. Barth, N. Davis, G. Scora, J. Collins, and J. Norbeck, "Measuring and modeling emissions from extremely low emitting vehicles," Transportation Research Record, vol. 1987, pp. 21-31, 2006.

[23] D. Schulz, T. Younglove, and M. Barth, "Statistical analysis and model validation of automobile emissions," Journal of Transportation and Statistics, vol. 3(2), pp. 29-38, 2000.

[24] M. Barth, C. Malcolm, T. Younglove, and N. Hill, "Recent validation efforts for a comprehensive modal emissions model. Transportation Research Record, vol. 1750, pp. 13-23, 2001.

[25] K. Boriboonsomsin and M. Barth, "Impacts of freeway high-occupancy vehicle lane configuration on vehicle emissions," Transportation Research Part D, vol. 13(2) , pp. 112-125, 2008.