A comparison of fuel consumption between hybrid and intelligent vehicles during urban driving

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A comparison of fuel consumption between hybrid and intelligent vehicles during urban driving

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Abstract: Two major emerging automotive technologies are the continued development of hybrid-electric drivetrains and telematics-enabled (or 'intelligent') vehicles capable of garnering and utilizing information about the traffic environment in which the vehicles are operating. The significant costs of each of these technologies are located internal to the vehicle (i.e. the powertrain) in the former case and external to the vehicle (i.e. the road and communication infrastructure) in the latter. In this paper, a simple algorithm is proposed for shaping the velocity profile of an intelligent vehicle subjected to different degrees of traffic information. The fuel consumption of this intelligent vehicle is then compared to a hybrid vehicle with a configuration optimized for an urban drive cycle under the constraint that its performance must match the conventional vehicle it is replacing. This provides some perspective on the extent to which telematics can be used to improve fuel economy relative to the best possible hybrid alternative. Finally, the fuel consumption of an intelligent-hybrid vehicle is investigated; however, the optimal use of information and switching control in the hybrid drivetrain remains an unsolved problem to date.

Keywords: hybrid vehicles, intelligent vehicles, road infrastructure, telematics

1 INTRODUCTION

Presently there are many exciting developments in the automobile industry that will act to improve safety, manufacturing, and economy of production vehicles by a quantum step relative to models currently available. Over the majority of the past century, the automobile drivetrain has been principally based around an internal combustion engine (ICE), and the engine development over this period ensures that the technology is very mature – meaning significant gains in areas such as fuel consumption are no longer readily achievable through further refinement. While fuel cells may one day replace the ICE, current conversion efficiencies and cost mean that this is not going to occur in the short term. However, the advent of hybrid electric drivetrains forms an interim stage in the path towards alternative propulsion sources.

Hybrid vehicles offer the capacity to improve fuel economy by using an electric motor to reduce the energy inefficiencies of the internal combustion engine without unduly sacrificing vehicle performance. The Toyota Prius and Honda Insight are two examples of production vehicles that have demonstrated improvements in fuel consumption relative to a conventional approach, while a hybrid Ford Escape was finally released in 2005. Virtually all other manufacturers have a hybrid model in some stage of development, but the primary disadvantage of the hybrid electric drivetrain is that it can add as much as 70 per cent to the initial cost of the vehicle relative to an equivalent conventional powertrain.

As well as the technology changes internal to the vehicle, the telematics revolution of the past decade has generated the possibility for a vehicle to communicate with the road infrastructure and other vehicles to obtain greater information about the traffic environment in which it is operating. Systems such as the PATH program (see, for example, references [1] and [2]) have demonstrated that platooning of vehicles in an automated highway system can lead...
to increased driver safety, decreased road congestion (increased throughput), and improved fuel consumption (not only through improved traffic flow but also through reduced wind resistance from travelling in a platoon [3]). In these types of systems, the demonstrated performance to date has relied primarily on intervehicle communication and passive road information in the form of magnetic sensors.

With fuel consumption in urban environments up to 50 per cent higher than during highway driving, there is an even greater need to address this area of operation when considering how to improve the fuel economy. While integrating platoons of fully automated vehicles in a highway environment is considered a logistical issue, it is a more difficult problem to do this in an urban environment given the greater abundance of pedestrians and other potential road obstacles. As a result, a first-generation ‘intelligent’ vehicle operating in an urban environment could be envisaged as providing a driver aid through look-up displays of recommended speeds or routes, rather than a complete driver replacement system, a principle that is similar to the concept of adaptive cruise control systems acting as a precursor to automated platooning scenarios. In order to achieve even this simple objective, it is a clear requirement that an intelligent vehicle must obtain information about traffic flow it is likely to encounter in the near future.

If only local traffic information is relevant, this may be provided completely on-board the vehicle itself through the use of radar and laser technologies. Such devices are already used in adaptive cruise control systems, but do not satisfy the string stability requirements necessary to guarantee safe platooning of vehicles [4]. Incorporation of telematics providing the information between vehicles over a dedicated radio bandwidth would not only address this safe platooning issue in the long term but would also provide information to the vehicle about traffic flow over a larger distance than if each vehicle were operating completely autonomously.

To obtain greater information for the vehicle controller over even longer look-ahead times than provided by intervehicle communication, it is most likely that some form of communication between the infrastructure and the vehicle is required. Presently, systems such as Signal Coordination in Regional Areas of Melbourne (SCRAM) in Australia obtain information about traffic flows in urban environments automatically for use in scheduling traffic signals, so it is conceivable that this information could be made available to a suitably equipped vehicle. The information transfer from the network to the vehicle will also have clear advantages in route selection, as discussed in reference [5]. However, the level of feedforward traffic information, and consequently the level of telematics, required to achieve a certain level of fuel consumption has not yet been addressed.

Consequently, this paper sets out to compare and contrast hybrid and telematic technologies in terms of one metric, fuel consumption, with the intention of providing some basis for devoting expenditure to one technology or the other. To maintain a degree of generality in the results, equivalent (in terms of performance) vehicle platforms utilizing either a conventional drivetrain with telematics or an optimized hybrid drivetrain without telematics are defined in section 2, along with a simple algorithm for utilizing feedforward information. The results from simulations conducted over real-world drive cycles are compared and discussed in section 3. This comparison will demonstrate the differences between adopting the expense of new technology within the vehicle hardware (i.e. a hybrid powertrain) and within the vehicle’s environment (i.e. an intelligent infrastructure). The degree of improvement that can be expected by incorporating different levels of telematics will be quantified by investigations into fuel consumption as a function of levels of traffic information. Also in section 3, the fuel economy improvements obtainable through the incorporation of telematics into a hybrid drivetrain are investigated and discussed.

2 APPROACH AND METHODOLOGY

2.1 Simulation approach and urban drive cycles used

The ADVISOR software package [6] provides a simulation environment in which detailed information over specified drive cycles can be obtained. One shortcoming of using ADVISOR is transient emissions that are not considered to be accurately predicted, but emissions performance was not a focus of this study and thus this inadequacy is not significant to the results of this study. A primary benefit of ADVISOR is that it allows for complete drive cycles to be used in generating estimates of fuel usage, and in this study three major urban drive cycles were considered as these form the basis of either regulatory testing or are considered reflective of real-world driving in urban environments. The US FTP city drive cycle, the European urban cycle (ECE) with extra urban drive cycle (EUDC), and the Australian urban cycle are all
illustrated in Fig. 1. In order to perform accurate simulations, ADVISOR requires detailed information about vehicles to generate accurate estimates of real-world fuel consumption, and the relevant aspects of this information are provided in the following sections for each of the vehicles tested.

2.2 Baseline vehicle

The baseline vehicle chosen for this study was a 4 litre production family sedan, as approximately 30 per cent of the vehicle sales in Australia each year are of a similar size and power to the model used here. The important parameters for this vehicle are provided in the Appendix, and the fuel consumption map for this vehicle (sourced from reference [7]) is also provided in Fig. 2.

In order to validate the simulation environment, the fuel consumption of the baseline vehicle in ADVISOR was compared to both laboratory results and simulation results previously published in reference [7], over each of the three urban drive cycles. The comparisons are displayed in Table 1 and indicate a very close correlation between the known results and the ADVISOR simulations, thereby validating the simulation environment used in this study.

![Fig. 1](image1.png)  (Top left) Australian urban drive cycle. (Top right) ECE-EUDC drive cycle. (Bottom) US FTP drive cycle

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Predicted fuel consumption of the baseline vehicle using simulation and laboratory-based approaches for three urban drive cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel consumption (L/100 km)</td>
</tr>
<tr>
<td></td>
<td>Laboratory tests</td>
</tr>
<tr>
<td>Australian urban cycle</td>
<td>12.3</td>
</tr>
<tr>
<td>ECE-EUDC cycle</td>
<td>(N/A)</td>
</tr>
<tr>
<td>US FTP cycle</td>
<td>11.42</td>
</tr>
</tbody>
</table>
2.3 Use of telematics with a conventional drivetrain to create an intelligent vehicle

One of the most significant contributors to fuel use in an urban environment is consistent vehicle acceleration and deceleration over short distances, culminating in stop–start traffic flow. A suitably equipped vehicle that is capable of obtaining information through a combination of direct sensing technology (e.g. an on-board radar) and communication with other vehicles on the road or the infrastructure through dedicated radio links can develop a model of the traffic flow the vehicle is likely to encounter. Based on this model of future traffic flow, the vehicle may adjust its own speed profile to improve fuel consumption without impacting on destination arrival time.

Under the assumption of linearity in the fuel use as a function of engine/vehicle speed, decreased fuel consumption in the current vehicle should be obtained through reductions in transient speeds. From Fig. 2, it is apparent that linearity is a reasonable approximation in the fuel consumption maps for non-idle engine speeds at relatively constant
torque requirement. Therefore, given a vector of the future traffic velocity, \( [v_{\text{future}}(k), \ldots, v_{\text{future}}(k+N)] \), parameterized by the time difference from the current time, \( [T(k), \ldots, T(k+N)] \), one approximation to the optimal vehicle velocity at the current time, \( v_{\text{applied}}(k) \), is simply to use the average of the predicted future velocities of the vehicle. [Note that the initial entries in these vectors are assumed to be \( v_{\text{future}}(k) = \text{‘current vehicle velocity’} \) and \( T(k) = 0 \)].

Mathematically, the algorithm used in this paper to shape the velocity profile of the vehicle using the look-ahead information is calculated at each time step according to

\[
v_{\text{applied}}(k) = \frac{\sum_{i=1}^{N} v_{\text{future}}(k+i)[T(k+i) - T(k+i-1)]}{T_{\text{look-ahead}}}
\]

(1)

The look-ahead time, \( T_{\text{look-ahead}} \), is defined as the maximum time ahead of the current vehicle for which the traffic velocity profile is supplied, and for complete generality, it is defined as

\[
T_{\text{look-ahead}} = T(k+N) - T(k)
\]

(2)

As an example of the effect this algorithm has on a vehicle travelling through an otherwise standard urban drive cycle, Fig. 3 shows the US-FTP city drive cycle and the velocity profile resulting from the use of equation (1) with a traffic flow information from the next 40 s. This amount of look-ahead time corresponds to an average 350 m distance over the US drive cycle, and could readily be achieved through on-board sensing and intervehicle communication only.

2.4 The optimized hybrid vehicle

In order to compare the performance of the conventional drivetrain vehicle to a hybrid configuration it is necessary to define a hybrid configuration to be used in place of the 4.0 litre ICE. To obtain best-case performance for the hybrid vehicle, the hybrid configuration should be optimized for fuel economy over urban drive cycles. Thus the first stage in specifying the hybrid powertrain to compare to the intelligent vehicle described previously is to perform this optimization. In order to reflect the existing vehicle accurately, the majority of vehicle dimensions was maintained from those stated for the baseline vehicle in the Appendix (total vehicle weight changes depending on the number of battery modules), thereby allowing for an accurate comparison of hybrid and telematic technologies.

From reference [8] it was decided that a 1.3 litre, 71 kW turbocharged GM Opel engine would be a suitable starting point for the hybrid’s ICE. This choice was based on the result that by turbocharging a small engine the output power is increased by 30–40 per cent relative to a non-turbocharged engine of the same size. This allows a smaller engine to be used, thereby producing lower frictional losses in comparison to a larger engine supplying the same amount of power as the turbocharged one. Furthermore, by using a smaller capacity engine, the weight can be reduced. A fuel consumption map of this engine, prior to scaling as deemed necessary by the optimization, is provided for comparison to the baseline vehicle in Fig. 2. The other half of the hybrid drivetrain is the electric motor, and in this work a 49 kW Honda permanent magnet, brushless d.c.

Fig. 3 US FTP city drive cycle with \( T_{\text{look-ahead}} = 40 \text{ s} \) and without preview information about traffic flow.
motor was chosen as the base motor to be scaled, with electric power provided through NiMH battery modules.

As a result there are three factors that can influence the total performance of the baseline hybrid vehicle: the scaling of the ICE, the scaling of the motor, and the number of battery modules used. Naturally, increasing the power output of the powertrain components and the number of batteries also increases their weight, and hence will impact on fuel economy. In order to get the best performance of the hybrid vehicle, the engine configuration was optimized over a given drive cycle in order to find the best motor size, number of battery modules, and engine size. Constraints on vehicle acceleration, speed, towing capability, and battery state of charge difference between the start and end of the drive cycle were imposed to ensure that the hybrid performance was comparable to that of the baseline vehicle. The optimization process now becomes a constrained multidimensional one that is not easily solved. In reference [9], genetic algorithm and particle swarm optimization approaches were used to optimize the configuration for fuel economy over different Australian driving cycles. The resulting optimized hybrid vehicle configuration is listed in Table 2, and is used to represent an optimal hybrid in this study.

It is worth noting that the result of the optimization presented in Table 2 agrees with conventional wisdom that drive cycles containing a significant degree of stop–start behaviour benefit from an almost 50–50 split of power between the internal combustion engine and the electric motor. If typical highway driving scenarios are considered, the balance would be expected to shift towards larger internal combustion engines, in what is referred to as a mild hybrid configuration.

3 RESULTS AND DISCUSSION

3.1 Fuel consumption for the intelligent vehicle

The fuel consumption of the conventional vehicle equipped with telematics was obtained from ADVISOR using look-ahead times of up to three minutes (corresponding to information about traffic flow up to approximately 1500 m in front of the vehicle). The results are illustrated in Fig. 4 and quantitatively summarized in Table 3. It is important

<table>
<thead>
<tr>
<th>Table 2 Results of hybrid optimization for vehicle configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal combustion engine power (scaled from turbocharged 1.3 litre, 71 kW engine)</td>
</tr>
<tr>
<td>Electric motor power (scaled from 49 kW Honda permanent magnet brushless motor)</td>
</tr>
<tr>
<td>Number of battery modules (D size 1.2 V NiMH, 6 cells per module)</td>
</tr>
</tbody>
</table>

Fig. 4 Fuel consumption as a function of look-ahead time for different urban drive cycles
Table 3  Quantitative comparison of fuel consumption for varying degrees of feedforward traffic information

<table>
<thead>
<tr>
<th>Drive cycle</th>
<th>$T_{\text{look-ahead}} = 0$</th>
<th>$T_{\text{look-ahead}} = 50$ s</th>
<th>Per cent change*</th>
<th>$T_{\text{look-ahead}} = 180$ s</th>
<th>Per cent change*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian urban</td>
<td>12.5</td>
<td>8.8</td>
<td>30</td>
<td>7.7</td>
<td>38</td>
</tr>
<tr>
<td>ECE/EUDC</td>
<td>11.2</td>
<td>10.4</td>
<td>7</td>
<td>9.2</td>
<td>18</td>
</tr>
<tr>
<td>US-FTP</td>
<td>11.4</td>
<td>9.1</td>
<td>20</td>
<td>8.3</td>
<td>27</td>
</tr>
</tbody>
</table>

*Percentage change measured relative to a conventional drivetrain without telematics.

to note that they demonstrate that a significant improvement in fuel consumption can be obtained through the use of traffic flow information, although the degree of improvement clearly varies between the different the drive cycles.

In assessing the impact of these results, it should be noted that implementation of the algorithm proposed in section 2.3 automatically adjusts the vehicle speed subject to the traffic velocity profile it will encounter over the next $T_{\text{look-ahead}}$ seconds. In principle, this is only possible within a fully automated driving scenario. Initial implementations of the telematics will focus on driver aid, rather than driver replacement, technology. Hence the gains in fuel economy demonstrated in Table 3 would be indicative of the 'best case' fuel economy improvements for a driver aid scenario (i.e. if the human driver does exactly what is suggested by the controller). The willingness of a driver to follow the suggested speed trajectory falls under a human factor experiment and will be highly dependent on the interface chosen, so is considered to be outside the scope of this study. However, earlier research conducted using advisory speeds based on solely SCRAM data have previously demonstrated that fuel economy improvements of 10 per cent are achievable [10].

Also, in a focused inspection of Fig. 4, it is clear that in the case of the European drive cycle the fuel consumption using telematics actually degrades relative to the baseline vehicle for short look-ahead times. Examination of the original drive cycle (Fig. 1) reveals that the idle, constant velocity, and acceleration segments are all approximately 20 seconds in duration, and hence a look-ahead time of around 20 second look-ahead results in a velocity profile being set up that contains more transient behaviour than the original cycle. In fact, there is a peak in the fuel consumption for 20 second look-ahead, seen in Fig. 4, showing this to be the worst-case scenario. The proposed algorithm was set up on the premise of reducing transient velocity regions, and so using this type of drive cycle with a series of steady state driving periods, all of equal duration, actually results in greater periods of transient vehicle operation. While this highlights a potential limitation of the proposed use of the feedforward information, it is worth noting that cyclical driving patterns are not considered to be representative of real-world driving scenarios [11].

Further discussion of these results should begin with the trade-offs in obtaining the different degrees of information. Short traffic flow previews, up to approximately 20 seconds, may be obtained through solely on-board sensing by the vehicle using radar and/or laser-based systems. For medium ranges of feedforward information, including information not in-line-of-sight, the system will require communication between vehicles. This may be provided to the current vehicle through two methods:

(a) backwards propagation of traffic flow profiles, whereby each vehicle tells the car behind it the velocity it has been travelling at, as well as an estimate of the traffic in front based on a fusion of information from its own sensing and other vehicles;

(b) forwards propagation, whereby each vehicle can interrogate other vehicles travelling towards it about up-coming traffic conditions.

In either case there would be only small additional vehicle costs to handle the communication, and the only infrastructure requirements would be allocation of bandwidth. However, it is clear from Fig. 4 that the fuel economy improvements are very significant for this range of feedforward information.

The largest amount of feedforward information would also require communication from the infrastructure in the information fusion algorithms, and naturally this would require the greatest capital investment in terms of communication from the road network to vehicles, as well as the installation and/or maintenance of sensing technology. It would appear that the capital expenditure associated with this information is not justified, given the changes in fuel consumption stated in Table 3 for a 180 second look-ahead compared to a 50 second look-ahead.
3.2 Fuel consumption for the optimal hybrid vehicle

The optimal hybrid configuration described in section 2.4 was tested on the same three urban drive cycles and the fuel consumption recorded. Unconstrained use of the electric motor would obviously result in very low fuel use, but this charge must be replaced during the next drive. Thus, in order to maintain a degree of equality between the simulated vehicles, the difference in state of charge of the vehicle’s battery pack at the beginning and end of the drive cycle was constrained to be less than 0.5 per cent.

Unsurprisingly, the hybrid vehicle’s fuel economy is superior to the conventional vehicle without telematics (see Table 4). However, when the hybrid results are compared to the intelligent vehicle using the proposed algorithm the advantage of the hybrid drivetrain is not so clear. Although the feedforward time needed for the intelligent vehicle to equal the fuel economy of the hybrid is well over two minutes in the cases of the EUDC and US drive cycles, re-examining Fig. 4 it can be seen that the intelligent vehicle has its fuel consumption within 10 per cent of the optimized hybrid after 55 and 80 seconds for the US and EUDC cycles respectively. It should be restated again that the intelligent vehicle is using a simple look-ahead strategy to alter the drive cycle, and optimum use of the traffic information in terms of fuel economy could result in even lower requirements of look-ahead time. While the driving behaviour of the intelligent vehicle has been directly adjusted based on the telematics information (and the level of achievability of this has not been addressed), it is also worth noting that the hybrid vehicle has been optimized for the urban cycles it is being tested on, and therefore represents the best-case performance obtainable, as a production incarnation would be more likely to have mild levels of hybridization.

This result indicates that through relatively low cost (when compared to the cost of including a secondary propulsion source in the vehicle) measures involving telematics, similar magnitude fuel savings to those promised by hybrid drivetrains can be achieved. Furthermore, the incorporation of telematics in the vehicle has further benefits beyond simply fuel economy, including enhanced safety features such as crash avoidance or protection, and improved safety at blind crossings [12], while there are no further advantages over a conventional vehicle by including a hybrid drivetrain other than lower fuel consumption.

3.3 Hybrid vehicle equipped with telematics

As a final point of interest, rather than contrasting the performance that can be achieved through the two different technologies, this section deals with the achievable fuel economies if the technologies are combined to produce an ‘intelligent hybrid’, i.e. a vehicle with a hybrid drivetrain that is equipped with telematics enabling some feedforward information about speed trajectories to be obtained. Again it should be reiterated that the other parameters of the vehicle that affect fuel consumption (coefficient of drag, frontal area, etc.) are maintained from earlier simulation results, in order to isolate the impact of telematics capability on the hybrid vehicle’s fuel economy. The resulting fuel consumption for the intelligent hybrid as a function of look-ahead time provided by the sensors (subject to the condition of approximately zero change in the battery state of charge) is illustrated in Fig. 5, with some of the important levels quantified in Table 5.

As can be seen from Fig. 5, with large amounts of preview there are significant improvements achievable by the incorporation of intelligent technology with the hybrid drivetrain on the US and Australian urban cycles. As in the case of the conventional vehicle with telematics, however, the

Table 4 Fuel consumption for optimized hybrid vehicle over urban drive cycles

<table>
<thead>
<tr>
<th>Drive cycle</th>
<th>Fuel consumption (L/100 km)</th>
<th>Per cent change</th>
<th>Equivalent look-ahead time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional drivetrain</td>
<td>Hybrid drivetrain*</td>
<td></td>
</tr>
<tr>
<td>Australian urban</td>
<td>12.5</td>
<td>10.4</td>
<td>16.3</td>
</tr>
<tr>
<td>ECE-EUDC</td>
<td>11.2</td>
<td>9.2</td>
<td>21.7</td>
</tr>
<tr>
<td>US FTP</td>
<td>11.4</td>
<td>8.3</td>
<td>27.2</td>
</tr>
</tbody>
</table>

*Change in the battery state of charge constrained to < 0.5 per cent.
†Percentage improvement in fuel consumption using a hybrid drivetrain relative to a conventional drivetrain without telematics.
‡Look-ahead time required by an intelligent vehicle for fuel economy to hybrid with a constrained state of charge difference.
Fig. 5 Fuel consumption of intelligent hybrid vehicle as a function of look-ahead time

Table 5 Quantitative comparison of fuel consumption for varying degrees of feedforward traffic information for the intelligent hybrid

<table>
<thead>
<tr>
<th>Drive cycle</th>
<th>$T_{\text{look-ahead}} = 0$</th>
<th>$T_{\text{look-ahead}} = 50$ s</th>
<th>Per cent change*</th>
<th>$T_{\text{look-ahead}} = 180$ s</th>
<th>Per cent change*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian urban</td>
<td>10.4</td>
<td>8.1</td>
<td>22</td>
<td>6.2</td>
<td>40</td>
</tr>
<tr>
<td>ECE/EUDC</td>
<td>9.2</td>
<td>9.4</td>
<td>−2</td>
<td>8.7</td>
<td>5</td>
</tr>
<tr>
<td>US-FTP</td>
<td>8.3</td>
<td>8.3</td>
<td>0</td>
<td>6.2</td>
<td>25</td>
</tr>
</tbody>
</table>

*Percentage change measured relative to the hybrid drivetrain with no look-ahead information.

improvement is not as significant for large look-ahead times and the fuel consumption actually degrades significantly for shorter look-ahead times. While the unrealistic drive cycle noted in section 3.1 is a factor, the primary reason for this result is the assumption of linearity in the fuel consumption maps, and highlights the limitation of the velocity-shaping algorithm presented in section 2.3. The fuel consumption in a hybrid drivetrain has previously been optimized offline using full knowledge of the complete drive cycle [13], but a suitable approach for online computation of the optimal (given less than full knowledge of the drive cycle) remains an open, complex non-linear optimization problem. Nevertheless, the degree of improvement that has been demonstrated through the large reductions in fuel consumption for the US-FTP and Australian urban cycles with 180 seconds look-ahead (25 and 40 per cent improvements over standard hybrid powertrains respectively), using even the proposed suboptimal approach, indicates that there are huge benefits to be made by the inclusion of both technologies in a single vehicle.

4 CONCLUSIONS

This paper presents a comparison between two of the emerging technologies in automotive systems: telematics and hybrid drivetrains. Using a best-case approach for each technology (i.e. the hybrid drivetrain was optimized for an urban cycle, while the intelligent vehicle was allowed to adjust its present velocity profile based on some limited information about the traffic in front of it), it was shown that similar fuel consumptions can be achieved either by incorporating the cost of the new technology internal to the vehicle, i.e. a hybrid drivetrain, or external to the drivetrain through the use of improved telematic capability, provided that greater than 40 seconds look-ahead information was obtained. It is anticipated that this look-ahead could be achieved through sharing information between individual vehicles and also between vehicles and the network infrastructure.

It was found that on drive cycles that closely mimicked real-world driving scenarios even sub-optimal (i.e. using linear-based assumptions) use of
feedforward traffic velocities by as little as 50 seconds can result in fuel economies of an ‘intelligent’ conventional drivetrain vehicle being within 10 per cent of the fuel economy of a hybrid vehicle with a configuration optimized for an urban drive cycle. Furthermore, the inclusion of telematics capability can provide additional features such as adaptive cruise control and crash avoidance, which improve safety for the passengers, diversifying the benefits applied through the adoption of this technology relative to hybrid drivetrains.

It was also demonstrated that including both telematics capability and a hybrid drivetrain in the one vehicle provides the potential for the least fuel consumption. However, the optimal use of the feedforward information is not easily determined, as the number of variables in the problem affecting the outcome includes distribution of desired torque between the internal combustion engine and the electric motor, as well as the engine operating point. The linearity assumptions about fuel consumption dependence on the engine operating point made in the intelligent vehicle velocity profile are therefore no longer valid, and so the switching controller design must include scope for recharging the battery powering the electric motor, possibly through a battery state dependent equivalent fuel consumption term. The design of an optimal controller for a hybrid drivetrain with some preview information about traffic flow is a subject that is still under investigation.

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