Development and Field Trial of a Driver Assistance System to Encourage Eco-Driving in Light Commercial Vehicle Fleets

Christopher Vagg, Chris J. Brace, Deepak Hari, Sam Akehurst, John Poxon and Lloyd Ash

***Abstract*—Driver training schemes and eco-driving techniques can reduce fuel consumption by 10% but their effectiveness depends on the willingness of drivers to change their behaviour, and changes may be short lived. On board driver assistance systems have been proposed which encourage driving style improvement. Such systems, when fitted in commercial vehicles, can assume some authority since uneconomical driving styles can be reported to a fleet manager. A driver assistance system has been developed and tried in the field with commercial vehicle drivers. The system aims to reduce fuel consumption by encouraging two behaviours: reduced rates of acceleration, and early upshifting through the gears. Visual feedback is reinforced with audible warnings when the driver makes uneconomical power demands of the engine. Field trials of the system were undertaken in the United Kingdom using 15 light commercial vehicles, driven by their professional drivers from a range of commercial applications. The trials consisted of 2 weeks baseline data collection which drivers were not aware of, followed by 2 weeks of data collection with the system active. During the trials a total of 39 300 km of trip data were collected, which demonstrated fuel savings up to 12% and average fuel savings of 7.6%.**

***Index Terms*—Driver behaviour, Driver information systems, Eco-driving, Fuel economy, Gear Shift Indicator, Vehicle driving.**

I. Introduction

DRIVER behaviour has a significant effect on fuel consumption [1], which is reflected in the growing popularity of "eco-driving" courses as fuel economy has become an increasingly important issue. Studies have shown that suitable driver training can reduce fuel consumption by 10% on average [2-4]. However, it has also been suggested that the long-term effects of such courses are less significant. Beusen et al. [5] followed a set of car drivers for 5 months before and 5 months after such a course and noted that the long-term effects varied between drivers, with around 20% relapsing to old habits. The authors of the study acknowledged that since the drivers volunteered for the course there was also likely to be some bias in the mentality of the drivers (many showed an increase in fuel efficiency in the months leading up to the course, prior to any training). It seems likely that relapse amongst an accurate sample of the population would be higher. Zarkadoula et al. [4] found that real world fuel savings halved in the first two months following training, and a similar study following bus drivers found that 12 months after an eco-driving course fuel consumption was reduced by just 2% [6]. There is an apparent need to give continuous real-time advice to drivers to ensure sustained fuel saving and that they do not forget what they have learnt. A further problem with eco-driving training when applied to drivers of light commercial vehicles is that usually the driver does not pay the fuel bill, and as such may have significantly less motivation to save fuel.

A. Driver Assistance Tools

The idea of using a real-time driver feedback device to try to improve fuel economy is not new. Van der Voort [7] conducted experiments where such a device encouraged drivers to keep the engine near its point of optimal efficiency, and demonstrated fuel savings of 16% in combined cycle driving (urban, rural and highway) using a driving simulator. The same device was then shown to perform well in real world conditions [8, 9], achieving an impressive fuel reduction of 11% during combined cycle driving. These results are based on a prescribed route, but on relatively few hours of driving – around 160 hours in real world conditions. Furthermore the design brief states that using specialised sensors which must be added to the vehicle should be avoided, but the system implemented used inputs such as steering angle and headway (gap to vehicle in front). This information may be accessible to the vehicle manufacturer, but is unlikely to be available to others. As a result the system is most likely viable as original equipment sold with the vehicle, but not as a retrofit product.

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More recently Wu et al. [10] showed that fuel savings during acceleration events (not over a drive cycle) of up to 31% could be achieved by encouraging drivers to follow an optimal acceleration profile. However these are shown using a driving simulator, and once again the system is quite complex, requiring information about headway as well as the state of traffic lights being approached. Also, the human-machine interface consists of a colour bar representing good/bad levels of acceleration overlaid with a black line corresponding to the current acceleration. Drivers are expected to alter their acceleration, moving the black line until it rests in the optimal region. Whilst this is fine in a simulator environment, the safety implications of having a driver concentrate on a moving display during transient events in the real world are questionable. It is likely the algorithms developed here are better suited to autonomous vehicle applications. This tension between safe driving and 'green' driving, and the volume of information made available to a driver is highlighted by Young et al. [3]. Van Driel et al. [11] also set out some guidelines and lessons learnt from the development of such a device, suggesting amongst other things that integrating the system with the vehicle CAN-bus would eliminate the need for dedicated sensors, reducing complexity and cost.

Larsson and Ericsson [12] developed an acceleration advisory tool with a novel implementation, in that it provided feedback to the driver by adding resistance to the throttle pedal. Therefore if the system deemed that the driver was accelerating unnecessarily harshly it would make the throttle pedal more difficult to press. The results showed a significant reduction in throttle depression but no significant reduction in fuel consumption, and it was concluded that rate of acceleration is not the only parameter affecting fuel consumption. Another attempt to move away from visual feedback was made by Riener [13], who showed that subliminal vibrotactile feedback may be a viable means of encouraging eco-driving without affecting cognitive load, though larger scale studies would be required to ascertain the potential fuel savings through this approach.

B. METRICS OF DRIVER BEHAVIOUR

The conclusions of Larsson and Ericsson [12] highlight the fact that in order to reduce fuel consumption by modifying driver behaviour it is important to first understand what behaviours affect fuel consumption and to define quantifiable metrics. This in itself is no simple task, as there are many facets of driver behaviour, some of which will vary depending on driving conditions and drive cycle, and not all of which the driver may be willing to change. Ericsson [14] defines 26 parameters to characterise driving patterns, divided into level measures (for example average speed and average acceleration), oscillation measures (which describe 'jerkiness') and distribution measures (proportions of time spent in various operating windows). Whilst level measures and distribution measures are good for quantifying behaviour over a drive cycle they rely on collecting a sample of data over a period of time and then reviewing it, and for this reason they are difficult to use as instantaneous measures of driver performance. In this study the aim was to give real-time feedback to the driver in order to help them reduce fuel consumption, since real-time feedback is likely to be of more use for three reasons: (1) the driver is immediately aware of actions which negatively impact fuel economy, rather than trying to relate statistics to their driving style; (2) there is no danger of the driver forgetting to adjust their driving style, as they are continually reminded; (3) the driver is not required to set aside time to analyse their feedback.

For these reasons a measure which can be calculated instantaneously is required, restricting the possible metrics identified by Ericsson to the three oscillation measures:

1) Frequency of maximum and minimum values: This is calculated by finding the time between peaks and troughs in the vehicle speed trace, where the minimum speed difference between a peak and a trough is defined (e.g. 10mi/h);
2) Integral of the square of the acceleration: This is defined as

$$(1/t)\int a^2 dt \tag{1}$$

where a is the vehicle acceleration and t is the total duration;
3) Relative Positive Acceleration (RPA): This is defined as

$$(1/x)\int v \cdot a^+ dt \tag{2}$$

where v is the vehicle speed, x is the total distance, and a^+ is positive acceleration only.

Whilst measure #1 may be calculated over a relatively short period of time, measures #2 and #3 (the square of the acceleration and the RPA) allow the best potential for real-time insight as the terms inside the integrals may be calculated instantaneously. RPA was shown to have a strong positive correlation with fuel consumption [15].

Fomunung et al. [16] defined the same quantity ($v \cdot a$) as the Inertial Power Surrogate (IPS), also defining a Drag Power Surrogate ($v^2 \cdot a$). The IPS was shown to have a positive correlation with NO_X emissions.

In an effort to quantify driver aggressiveness Ford Motor Co. later used a similar approach [17] to define a Power Factor (Pf):

$$Pf = 2 \cdot v \cdot a\,. \tag{3}$$

Pf was identified as a loose measure of inertial load, or change in kinetic energy, and the driver's total 'aggressivity' was defined as the root mean square of Pf over a journey.

II. Aims

It was the intent of this study to demonstrate the potential for a retrofit driver advisory tool operating in real time to help encourage eco-driving and reduce fuel consumption in drivers of light commercial vehicles. There are therefore two aims:

1) Design a system which can be integrated into a vehicle to provide real-time feedback on driving style with the aim of reducing fuel consumption;
2) Undertake field trials of the device to demonstrate its effectiveness, and recommend improvements.

Furthermore, in order to be commercially relevant the system must be designed such that it is:

a) Cheap – requiring the minimum of dedicated sensors (preferably none);
b) Simple – such that the principles of its operation are transparent to the driver, and to reduce the need to calibrate it to different vehicle models, where possible;
c) Safe – demanding minimal active concentration from the driver and adding minimal cognitive loading, such that their attention is not diverted from the road conditions.

The focus on commercial drivers in this study opens greater opportunity in some respects, whilst offering additional challenges in others. On the one hand the system effected can assume some authority since a driver's performance can be fed back to their employers. Therefore whereas drivers in their own vehicles may choose to ignore the advice of the system, commercial drivers may be obliged to improve their driving behaviour. On the other hand commercial drivers do not typically pay for the fuel they use and consequently may be less motivated to save fuel. Furthermore, since the installation of the system is probably the decision of the employer and not the driver, there is a risk the driver may resent the advice of the system if it is perceived to be unfair.

It is important to note a subtle but significant difference that arises from this focus on commercial drivers. In much of the existing literature the drivers are aware of the high level objective to save fuel, and are encouraged to 'buy in' to the objective by implementing the advice of a system during trials. In contrast, the device proposed here is does not assume any self-motivation to save fuel on the part of the drivers, and is designed to operate under minimal 'buy in'.

III. Methods

The system developed during this study continually monitors the driver's driving style, providing feedback where necessary to maximise the fuel savings possible by eco-driving. If the system detects unnecessarily aggressive periods of acceleration, which cause uneconomical demands to be made on the vehicle power plant, the driver is informed of this behaviour and encouraged to avoid it in the future. Since the aim of this technology is to modify driver behaviour in the real world, it is essential that it is evaluated through field testing with representative drivers. The design of the system and of the field testing will be described in the following sections.

A. System Design

The logic for the system was developed in the Matlab/Simulink environment, using Real-Time Workshop to build automatically generated C code which runs as embedded code on a target microprocessor. Several approaches were tried during the development of the code; the following describes the approach that was selected.

At the most fundamental level the algorithm used follows the method set out by Fomunung et al. [16] to determine the IPS real-time. As discussed in Section I-B this is one of relatively few metrics which can be calculated instantaneously. Studies have shown this metric to have a clear link to fuel consumption, and so it is regarded as well established and robust.

Instantaneous IPS shall be referred to as the Short-Term IPS (IPS_{ST}), and is fed back to the driver by means of a series of 9 LEDs mounted inside the instrument cluster of the van following the green-amber-red convention. Since IPS_{ST} fluctuates rapidly it is difficult to use as an indicator of driving style, as all drivers sometimes need to accelerate sharply. For this reason a second IPS is derived – the Long-Term IPS (IPS_{LT}) – which is calculated by using the current value of IPS_{ST} as the reference signal input to a P-controller. The current value of IPS_{LT} is therefore dependent on the previous value of IPS_{LT}, and the "error" between the current value of IPS_{ST} and the previous value of IPS_{LT}. Calculation of IPS_{LT} can be seen as similar to passing IPS_{ST} through a low-pass filter, where the P-gain, *Kp*, is analogous to the inverse of the filter time constant (τ^{-1}).

IPS_{LT} is also fed back to the driver via a series of LEDs, and it is this signal which is used to assess the behaviour of the driver. Three thresholds are in place such that when IPS_{LT} crosses the first a Level 1 Warning is issued audibly, when the second is crossed a Level 2 Warning is issued, and if the third is reached a Violation is issued. The value of IPS_{LT} is saturated at the third threshold, so it is not possible to exceed this. The number of Violations received is logged and made available to the Fleet Manager, who is then able to keep track of driver behaviour.

During the trials presented here no formal consequences were put in place relating to the number of Violations that

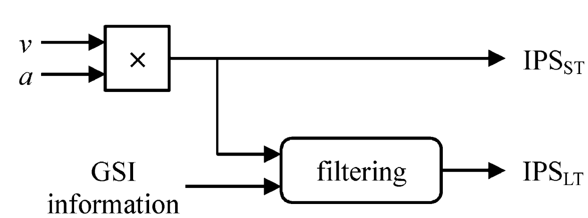

Fig. 1. Schematic showing the calculation of IPS_{ST} and IPS_{LT}.

TABLE I
DETAILS OF COMPANIES INVOLVED IN THE TRIAL

	№ Vehicles	Vehicle Use	Baseline duration days (active days[a])	Live duration days (active days[a])
Company A	3	Technical call-out service	14 (13)	14 (13)
Company B	3	Retail parts delivery	15 (13)	14 (12)
Company C	2	Fresh produce delivery	11 (9)	14 (12)
Company D	2	Technical call-out service	14 (10)	22 (16)
Company E	2	Site visits	16 (10)	22 (13)
Company F	2	Technical call-out service	14 (9)	18 (12)
Company G	1	Support service	14 (12)	16 (14)

[a]Active days are the days during each phase of the trial where the vehicle(s) were in active use.

drivers received, though it is expected that when implemented across an entire company fleet some policy would be adopted. An interesting further question arising from this issue surrounds the effectiveness of positive and negative feedback in the corporate environment, specifically whether it would be better to reward those drivers who receive few Violations, or penalise those who receive more.

Having established this algorithm as a foundation the most significant addition was the use of gear shift advice. Since minimising engine speed is critical to the goal of reducing fuel consumption [18] it was decided to include a gear shift indicator (GSI). Since many modern vehicles are equipped with GSIs as standard the vehicle's own gear shift signal was used where available on the CAN-bus. For vehicles where a gear shift signal was not available a simple GSI was implemented in the code which advised upshifts at 2200r/min, but was suppressed at higher throttle positions where an overtaking manoeuver or a steep gradient was suspected. The advice of either gear shift signal was conveyed by means of a light on the vehicle dashboard as well as a short beep when the light activated, and was enforced by adding an offset to IPS_{ST} which in turn causes IPS_{LT} to climb gradually (Figure 1). The offset applied to IPS_{ST} was high enough such that the maximum value of IPS_{LT} was reached after approximately 25 seconds, causing a Violation to be issued. Further to the rules described above several additional systems were implemented to identify very specific operating conditions, and to modify the response of the core algorithm in order to make sure the advice of the system as a whole felt fair.

The provision of audible warnings is an unusual feature in this application. It is arguable that many drivers would find such a system irritating if installed in their own car, however in a commercial setting the system can afford to exert more authority, as discussed previously. During normal driving it is not reasonable to expect the driver to watch a moving display and therefore this solution is considered safer, requiring minimal attention from the driver.

B. *FIELD TESTING*

In order to determine the effectiveness of the system in helping drivers to save fuel it was fitted to 15 light commercial vehicles belonging to 7 separate companies. In general these companies were operators of large fleets of light commercial vehicles in urban environments, typically to provide delivery services or technical support services. The type of business and number of vehicles tested for each company is shown in Table I, as well as the duration of each phase and how many of these days the vehicles(s) were in active use (these numbers are approximate as they may have differed slightly between vehicles in the same company). In all cases each van is normally paired with only one driver, and so a comparison between two vehicles is also a comparison between two drivers.

Vehicles involved in the trial were all Ford Transit vans of Euro IV emissions stage specification, further details of which can be found in Table II. Devices were installed by a technician inside the instrument cluster of each vehicle, this taking around 20 minutes per installation.

Trials were run for approximately four weeks: two weeks of baseline data collection followed by two weeks of testing with the system enabled. This period of time is considered to be long enough to negate the effects of short term fluctuations in vehicle use such as caused by weather conditions, drive cycle, loading, or traffic, while short enough to avoid issues arising from factors such as seasonal changes in weather conditions (ambient temperature). In this way the impacts of confounding factors are minimised. During the baseline phase the system was installed such that it was logging vehicle data, but the dashboard display was not fitted and audible feedback was disabled; the driver was therefore not aware that the device had been installed and so this phase of the trial was 'blind'. At the start of the second phase ('live' trial) the display was installed and audible feedback was enabled. Each driver was briefly familiarised with the display and the key features of the system, but no eco-driving training was given.

During the trials a total of 39 300 km of real world trip data were collected, representing 1 107 hours of driving and 5 587

TABLE II
SPECIFICATIONS OF VANS INVOLVED IN THE TRIAL

Vehicle models	Ford Transit
Emissions stages	Euro IV
Build years	2008, 2009, 2010, 2011
Van series'	260S, 280S, 300S, 300M, 350M, 350L, 350E
Engines	2.2L Duratorq
	2.4L Duratorq
Transmissions	6 Speed Manual Transmission - MT82
	6-Speed Manual Transaxle - VMT6
	5-Speed Manual Transaxle - VXT75

separate trips. Essential data from the vehicle Engine Control Unit (ECU) were logged via the On-Board Diagnostics (OBD) port at a frequency of 10Hz throughout. This data included vehicle speed, throttle position, engine speed, engine load, engine fuelling demand, and engine coolant temperature. These data cover the most essential inputs and outputs of the ECU, which allows significant insight into the operation and behaviour of both the engine and driver. Information on vehicle cargo load (mass) was not collected, however it is expected that since each vehicle generally has a daily routine, an average over two weeks ought not to fluctuate significantly, and therefore this should not be a confounding factor.

One of the primary aims of this paper is to establish the fuel saving achieved through use of the proposed device, and clearly this requires a reliable measurement of fuel use. The ECU fuelling demand is considered to be inaccurate but precise: it is expected that there may be small calibration errors in the absolute measurement of fuel, though for each vehicle the error should be constant. For this reason it is reasonable to calculate the percentage fuel saving made by each vehicle, to compare these figures between vehicles, and to calculate the average fuel saving of the test fleet. However, caution must be exercised when directly comparing the absolute fuel consumption of different vehicles/drivers.

IV. Results

Examples of the data collected and the operation of the algorithm during the baseline and live phases of the trial can be seen in Figures 2 and 3 respectively. Both of these extracts represent a short period of urban driving with similar average speed. All signals have been normalised for data confidentiality, however each signal has been scaled similarly in the two figures to allow comparison between the cases. In both figures it can be seen that periods of harsh acceleration correspond to peaks in the IPS_{ST} trace, which in turn cause the level of IPS_{LT} to rise. Comparing the figures it can be seen that there is a considerable reduction in IPS_{ST} during the live trial, and that IPS_{LT} has almost halved – this is typical of the change in driving styles observed.

Values for several key parameters with and without the system fitted are shown in Table III. These values are the weighted averages for the 15 vans and so account for the differing levels of use between them; values for throttle, engine speed and load are weighted by total journey time (for the entire trial), whilst fuel use (L/100km) is weighted by total distance covered (during the entire trial). By weighting the averages according to vehicle use the values account for any trends linking the effectiveness of the system to vehicle usage. The values presented therefore represent the overall changes that would be expected in a large population of vehicles, which

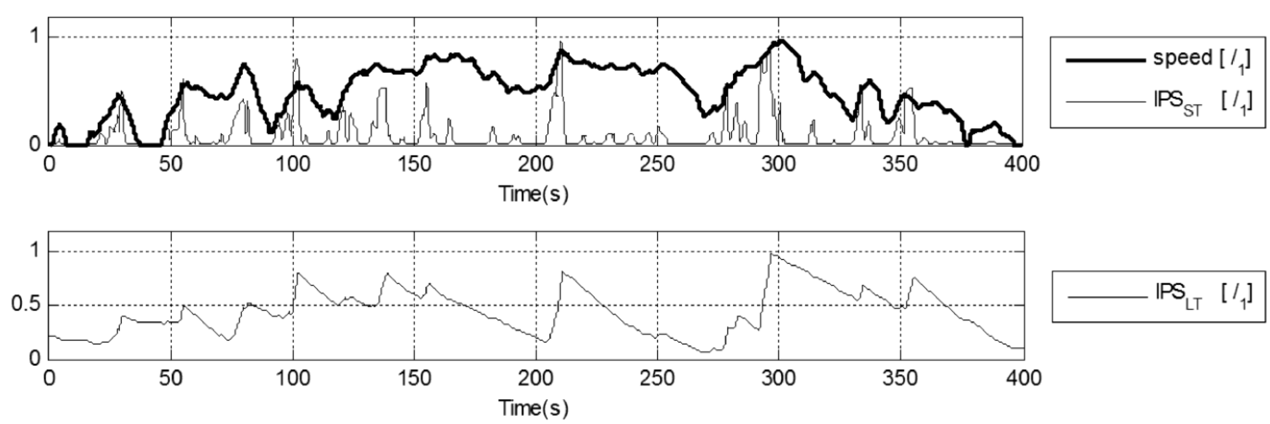

Fig. 2. An example of urban driving and the response of the algorithm during the baseline phase.

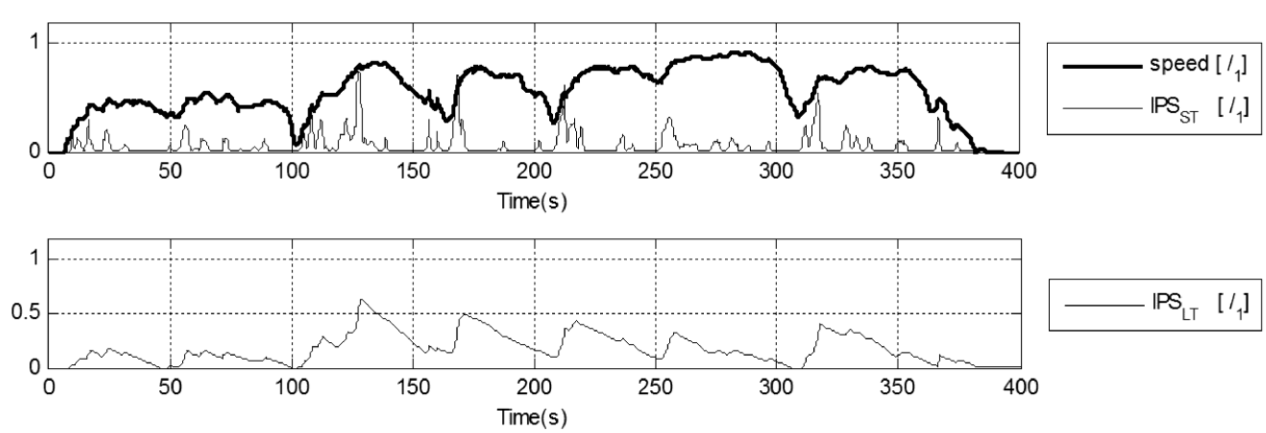

Fig. 3. An example of urban driving after the device was activated. Note that a smoother driving style has yielded considerable reductions in IPS_{ST} and IPS_{LT}.

TABLE III
KEY VEHICLE PARAMETERS CALCULATED FROM THE RAW DATA

	Fuel Consumption (L/100km)	Throttle Position (%)	Engine Speed (r/min)	Engine Load (%)
Baseline	9.83	15.94	1509	34.91
Live	9.12	14.06	1355	37.39
Change (%)	*-7.22*	*-11.75*	*-10.25*	*+7.10*

Average values for several key vehicle parameters during the trial. Values are calculated from the raw data collected and weighted by vehicle usage.

TABLE IV
KEY VEHICLE PARAMETERS CALCULATED USING IDLE-CORRECTED DATA

	Fuel Consumption (L/100km)	Throttle Position (%)	Engine Speed (r/min)	Engine Load (%)
Baseline	9.68	17.45	1575	36.65
Live	8.94	15.54	1412	39.63
Change (%)	*-7.61*	*-10.93*	*-10.36*	*+8.14*

Average values for several key vehicle parameters during the trial. Values are calculated using idle-corrected data and weighted by vehicle usage.

is not the same as the average change that any one driver would expect to see.

From Table III the key finding is that the introduction of the system corresponds to a reduction in fuel use of 7.22%. It is also noteworthy that average throttle position and engine speed have reduced considerably. Interestingly the average engine load (which is a measure of torque) has increased, most probably because the engine needs to generate a similar power output, but at a lower speed.

Clearly the fairness of comparison between the two data sets depends heavily upon the two sets showing similar patterns of vehicle use. Some simple analysis using cumulative probability plots and histograms to examine the vehicle and engine speed distributions suggested that on the whole the vehicle usage patterns are similar. However, this analysis did highlight one important discrepancy: the amount of time spent idling for each vehicle can vary considerably between blind and live trials. This finding is important, since during idling the quantity of fuel injected into the engine is not insignificant (hence the recent introduction of start-stop systems) and no distance is covered, therefore there is potential for a sizable skew to be introduced into the results. The most severe example of this discrepancy in idling time is illustrated in Figure 4(a) for Van 14.

The question of how to overcome this observation raised a dilemma: one solution would have been to completely delete any time spent at idle from the data, therefore ensuring that the comparison is completely fair. However, since time spent at idle represents a genuine and important facet of the drive cycle it seems wrong to delete this; moreover one would then have to ask whether other portions of the data (for example time spent cruising on a motorway) ought to be deleted to ensure parity. Further enquiry into the time spent at idle revealed that whilst the majority of idle instances were short (<60 seconds) there were a small number of instances where vans were left at idle for very long periods (the longest being 2.5 hours). In light of this it was decided that, since it would be very unusual to be absolutely stationary on the road any longer than 90 seconds, any idle instances exceeding this threshold (which corresponds to the 97th percentile) should be deleted. The results of this correction were satisfactory, with data sets showing greater similarity, and all further data processing and analysis were performed with these 'idle-corrected' data sets.

As an aside, it is interesting to note from Figure 4 that for a light commercial vehicle such a considerable proportion of operational time can be spent at idle: almost 50% for Van 14. This result may surprise some readers, and certainly highlights an opportunity to save fuel.

Average values for fuel use, throttle, engine speed and load for this idle-corrected data set are presented in Table IV, employing the same weighting approach as before. Idle-corrected fuel consumption figures are given for each of the vans in Table V, which also shows that the average fuel saving across the test fleet (weighted according to vehicle mileage) was 7.61%.

Figure 5 is a histogram comparing the engine speed

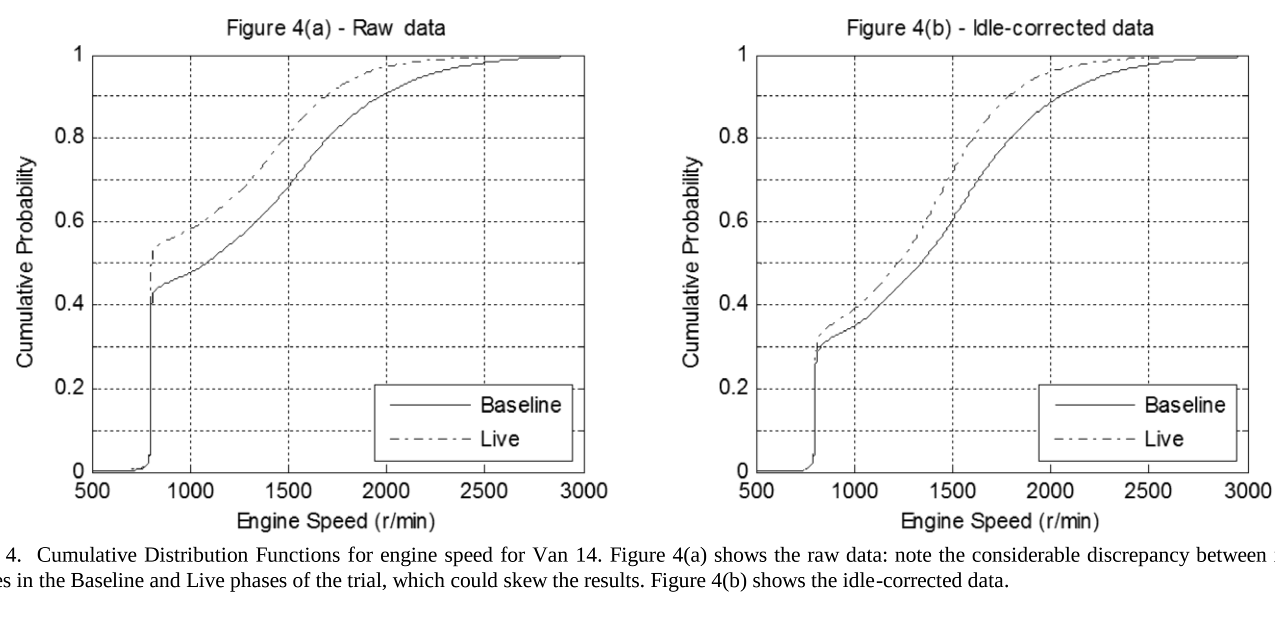

Fig. 4. Cumulative Distribution Functions for engine speed for Van 14. Figure 4(a) shows the raw data: note the considerable discrepancy between idling times in the Baseline and Live phases of the trial, which could skew the results. Figure 4(b) shows the idle-corrected data.

TABLE V
AVERAGE FUEL CONSUMPTION BEFORE AND AFTER THE DEVICE WAS ACTIVATED FOR EACH OF THE VANS INVOLVED IN THE TRIAL

Company	Van	Total Distance Covered (km)	Baseline Fuel Consumption (L/100km)	Live Fuel Consumption (L/100km)	Fuel Saving (%)
A	1	2375.2	8.20	7.44	9.16
	2	1635.0	9.12	9.09	0.43
	3	1402.7	9.08	7.99	12.03
B	4	7666.1	10.12	9.00	11.08
	5	6604.2	7.99	7.20	9.89
	6	2613.4	9.74	9.57	1.75
C	7	3727.9	11.00	10.01	8.97
	8	2918.3	10.43	9.20	11.82
D	9	1740.7	9.92	9.08	8.48
	10	1737.5	9.18	8.86	3.44
E	11	2065.3	11.04	10.98	0.49
	12	2355.3	11.14	10.83	2.77
F	13	917.1	9.05	8.86	2.08
	14	507.3	10.77	10.31	4.29
G	15	1036.0	9.74	8.97	7.91
			Average fuel saving (weighted by distance travelled per vehicle)		*7.61*

probability density for all of the vans with and without the device fitted; the data used in this plot is the idle-corrected data, but the idle condition (<850 r/min) has been omitted from the plot for clarity as it would otherwise dominate. The change in driver behaviour is quite striking – with the system fitted the driver spends significantly more time at lower engine speeds, upshifting earlier. In both cases the data could be described well with a normal distribution with the exception of a large spike in the region 2100-2200 r/min. This engine speed typically corresponds to 96-98 km/h (60-61 mi/h) in top (6th) gear, and so it is likely this results from motorway cruising. It should be noted that many of these vans are limited to 100 km/h).

Similarly, Figure 6 shows a histogram comparing the throttle pedal activation for the two series; again the idle condition is included in the calculation but is omitted from the plot for clarity. It can be seen that with the system active there is a decrease in the proportion of heavy throttle activation (>30%) and a corresponding increase in light throttle activation. This shift towards light activation of the throttle suggests a move towards a smoother and gentler driving style.

When assessing the success of the device it is important to consider any impact on journey time, since there is a risk that driving more conservatively and reducing rates of acceleration may also result in reduced speeds. This is particularly important in the application to the commercial vehicle market where increased journey times would probably mean reduced productivity, and therefore reduce the financial benefit. During this trial the average speed of all vehicles was 38.59 km/h during the baseline phase, which rose slightly to 38.75 km/h during the live phase. It may therefore be concluded that the device did not have any negative impact on average vehicle speed, and therefore journey times.

V. DISCUSSION

As previously described the device tested here encourages mild accelerations and early upshifts. Figure 7 shows the cumulative distribution functions for the IPS during the baseline phase and with the device activated. It should be noted that the IPS is equally well defined in the negative

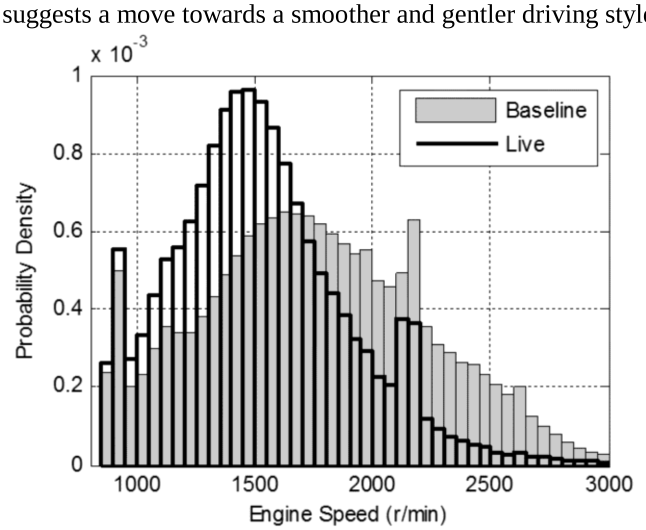

Fig. 5. Engine speed probability density before and after the device was activated. Note the considerable shift towards lower engine speeds when the device is active.

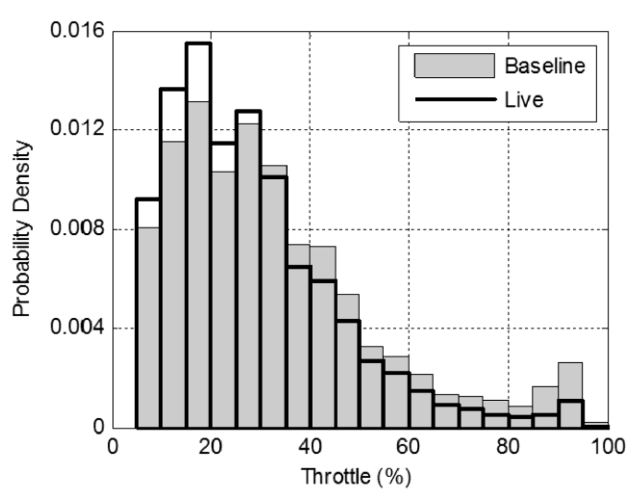

Fig. 6. Throttle activation probability density before and after the device was activated. Note the shift towards lighter throttle activation when the device is active.

domain (i.e. in braking) as it is in the positive, but since the device only considers positive acceleration Figure 7 only includes instances of IPS>0. The results show that the device has no effect at low values of IPS (below 50 km^2/h^2s) but that at higher values the IPS has been reduced considerably.

It is believed that the observed reduction in fuel consumption is the direct result of both reduced engine speed and reduced IPS. Lowering the average IPS results in a reduction in the average tractive work required per kilometre. Equally a reduction in engine speed at a similar tractive force causes a shift in the operating point of the engine in the speed-torque plane, which would typically increase the efficiency of an automotive diesel engine. There are therefore at least two mechanisms by which fuel could be saved, and it is difficult to ascertain precisely how much of the savings may be attributed to each mechanism.

Although the majority of the development time for this device was spent designing the IPS-driven logic, it is interesting to note that subjectively it is often the GSI-driven logic that forces a change in driver behaviour. Indeed if the advice of the GSI is strictly observed then it becomes difficult to generate warnings though the IPS-driven logic, because the available engine power is severely limited and therefore the achievable acceleration is reduced. Since there are currently questions being raised about the ability of GSIs to facilitate fuel saving in the real world [19], it is interesting to regard the findings of this research as the effects of enforcing the advice of a GSI, though this is not strictly the case. Clearly in the usual situation the driver is free to ignore the advice of a GSI, and so the fuel savings achieved here may represent the best case savings if a driver were to consistently follow this advice.

A further question arising from the extension of this work to larger/smaller vehicles is whether the acceptable IPS ought to be dependent on the mass of the vehicle. In this study no adjustments were made to the code to account for the variations in mass between vehicles, and as such the IPS thresholds may be regarded as ‘absolute’. Since we are used to seeing heavy haulage vehicles accelerate much more slowly than smaller vehicles, the argument could be made that heavier vehicles should have more stringent acceleration limits. This argument could be further supported by the rationale that heavier vehicles require more power to accelerate, and therefore the potential savings from limiting this acceleration are greater. Nevertheless in this case the authors felt that it was fair that all vehicles should be allowed to accelerate equally, and therefore the logic essentially defines an “acceptable limit of necessary acceleration”.

Regarding driver acceptance, no formal information was collected following the trials through surveys or interviews for example. However, informal feedback obtained from speaking to drivers during data retrieval, and from conversations with company management after the trails, was extremely encouraging. Drivers generally regarded the system as fair and helpful, and no problems with acceptance were reported by company managements.

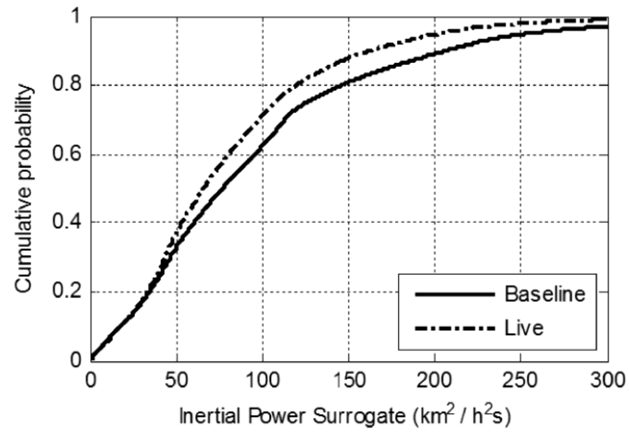

Fig. 7. Cumulative Distribution Functions for positive IPS before and after the device was activated. In the region where IPS>50 km^2/h^2s there is a shift towards lower IPS when the device is active.

VI. Further Work

Examination of Table V highlights the considerable range of fuel savings that were recorded, from a minimum of 0.43% to a maximum of 12.03%. There are several plausible reasons as to why some drivers were able to achieve substantial savings whilst others were not: it could be that some drivers were very conservative to start with and therefore there was little room for change, or it may be that the drive cycles of some vehicles allowed greater savings than others. Further analysis is required to establish the mechanisms of fuel saving, as well as the reasons for the large range of observed savings. Some initial results of analysis on the range of savings are presented elsewhere, including a statistical model to predict the savings that might be expected for any vehicle [20].

It is well known that the potential benefits of hybrid electric vehicles can be limited by the way in which they are driven [21]: for example sudden braking may dramatically reduce the amount of energy that a regenerative braking system can capture. It is therefore possible that the change in driver behaviour resulting from this system would facilitate additional fuel savings when combined with a hybrid vehicle such that the total savings are more than those delivered by the sum of the two systems.

Finally, a logical development of this system would be to introduce a degree of adaptive behaviour such as that proposed by Wada et al. [22]. This would allow the system to continually encourage drivers at an appropriate level, without becoming irritating. All of these further works are being actively pursued by the authors.

VII. Conclusion

This study has presented the development and evaluation of a driver assistance system to facilitate a reduction in fuel consumption. When applied to a test fleet of 15 light commercial vehicles the fuel consumption of the fleet (weighted by the distance travelled by each vehicle) was reduced by 7.61%. It was noted that the savings of individual vehicles/drivers varied considerably, with the maximum saving being 12.03%. These savings were achieved by encouraging drivers to accelerate more gently, and by enforcing the advice of a GSI, thereby reducing the average engine speed. Changes in driver behaviour and fuel consumption were achieved without any impact on average vehicle speeds.

The device presented here represents an improvement on those developed by other researchers because its relative simplicity allows easy integration into vehicles (through the CAN-bus) without the need for dedicated sensors. Furthermore the device is safe for real-time use as it does not require the active attention of the driver. It is likely that because of this minimal additional cognitive loading is introduced, and it is hoped this will be demonstrated in future trials.

If the device developed here were fitted only to commercially owned light vans in Great Britain approximately 482 kt CO_2 emissions could be avoided each year (see Appendix for details of this estimate). The savings delivered by the device could also be loosely regarded as the effect of following the advice of a GSI in the real world, and therefore represent the maximum savings deliverable through GSIs.

Appendix

In Great Britain around 41 billion vehicle miles (66 billion km) are covered each year by light vans (not exceeding 3 500 kg gross vehicle weight) [23]. Approximately 46% of light commercial vehicles are registered to companies [24] therefore, assuming there is no skew in vehicle mileage between private-company registered vehicles, the distance travelled by light commercial vehicles may be estimated at 30.5 billion km each year. Data on average fuel consumption or CO_2 emissions of registered vans is not available in the UK, but for new vans average emissions are estimated at 207.6 g CO_2/km [25]. Since 90% of new vans are sold into business use [26] and CO_2 emissions of new vehicles are continually falling, it is reasonable to use this figure as the minimum emissions level for company registered light commercial vehicles. If all of these were fitted with the driver assistance system developed here, saving 7.61% CO_2 across the fleet (CO_2 savings are usually coterminous with fuel savings), 482 kt CO_2 would be avoided each year.

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