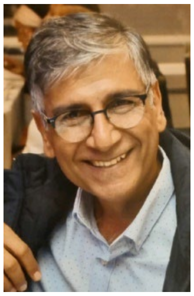
HIGH-FIDELITY IN-SERVICE PERFORMANCE EVALUATION OF HEAVY GOODS VEHICLES IN SOUTH AFRICA





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Abstract

The availability of high-fidelity in-service performance data from road freight vehicles is gaining significance as we transition towards a net-zero future. In this work, the in-service fuel consumption performance of a heavy goods vehicle in South Africa was measured using both a commercial unit from a conventional telematics service provider (TSP) and a novel high-resolution vehicle monitoring system – the "SRF-Logger". The results of this study revealed that the cumulative fuel use and distance data for a given leg of a route reported by the TSP unit are in very close agreement with the SRF-Logger. However, limited insight is possible from the TSP unit given the fewer data channels available and limited data sampling rate. The SRF-Logger is further able to record vehicle combination weight and net elevation change, which was demonstrated to have a significant effect on the fuel economy for specific legs of a journey. In particular, the SRF-Logger data made it clear that net elevation change for a journey leg was a major contributing factor for fuel economy estimation. For level road conditions the TSP could possibly be upgraded to report a modified fuel economy metric (i.e., tonne-km / L) that includes the vehicle combination weight.

Keywords: Heavy goods vehicle, Fuel consumption, Telematics, Sustainable road freight.

1. Introduction

Most freight in South Africa is carried on a Heavy Goods Vehicle (HGV) at some point in the supply chain, thus HGVs are critical in the maintenance of a functional logistics system and healthy economy. Total transportation costs are closely linked to the operational cost of an HGV vehicle fleet, and among the key drivers are diesel fuel costs. Typically, fuel costs contribute roughly 40% to total operational cost of a transportation business in South Africa [1], and thus have incentivised transport fleet operators to find ways to streamline logistics operations and achieve higher operational efficiencies, to offset fuel cost inflation. A mix of fuel-saving technologies and strategies for short term cost savings include (i) low rolling resistance tyres [2, 3], (ii) aerodynamic drag reduction devices [4, 5, 6] (iii) driver training [7, 8, 9], and (iv) telematics data-driven interventions to improve operational efficiencies [8].

Of these fuel saving interventions, telematics data-driven fleet management is receiving increased attention. Typically, a telematics unit is installed on a vehicle and reports certain vehicle performance metrics via the Controller Area Network (CAN) bus. Telematics data available from the vehicle commonly include: distance travelled (mileage), fuel consumption, speed, cruise control activation and utilization, gear selection, and acceleration (harsh corning and braking driving event alerts). A global positioning system (GPS) provides near real-time tracking and visibility of the vehicle. Recent developments in telematics technology has sought to extract greater benefits from the acquired vehicle and position data, to enable more efficient operations, that can further reduce fuel and vehicle maintenance costs [9, 10]. A possible fuel saving intervention is to incorporate telematics data obtained from a vehicle as a *feedback loop*, to encourage positive driver behaviour, where the driver can observe through the telematics data how “good” or “bad” their driving is, against pre-defined fuel use and safe driving targets or a “set point” for a given trip or delivery [10]. Furthermore, the improved telematics offering aims to assist fleet operators’ decision-making concerning the feasibility and transition to battery electric vehicles (BEVs) necessary to decarbonize road freight transportation.

There is an increasing need to be able to analyse in greater detail all the factors that drive energy consumption of a vehicle, and thereafter to measure the effectiveness of energy saving strategies over time. A focused pilot study of this nature may then be scaled to include more fleet vehicles. To this end, vehicle data should be recorded at an increased frequency or sampling rate to adequately resolve driver-initiated events (e.g., accelerator pedal and braking actions by the driver). However, there are questions related to how well commercially available telematic systems can satisfy the need for the acquisition of high-resolution data, to accurately measure the effectiveness of fuel saving interventions (e.g., positive reinforcement of “good” driver behaviour). For example, commercial telematic systems record data in the range of sampling intervals between 6 to 60 seconds, which are relatively long intervals in comparison to a driver action, and therefore possibly all critical driver related behaviour that occurs between data recordings will be lost or effectively filtered out [2, 11]. In addition, commercial telematic systems are usually conflicted by the need to balance the recording of multiple data channels at high sampling rates (i.e., reduced time intervals) with storing and processing large amounts of data (particularly important for large vehicle fleets) [12]. Thus, as a compromise limited vehicle data channels are accessible to the fleet operation management and the telematics system typically reports *cumulative* fuel use and distance (milage) parameters at the end of a trip or leg. Here, we segment a route or trip of a journey into discrete legs with a start and end point.

Since fuel consumption is dependent on several factors, it is critical for fuel benefit qualification that multiple channels are recorded, which usually exceed what is available via commercial telematics [11, 12]. Here it is necessary to consider vehicle combination mass and road elevation when evaluating fuel savings, and these parameters are not recorded by commercial telematics service providers (TSP). Current telematics systems determine the average economy per leg as the ratio of distance travelled to fuel consumed (i.e., km/L), however, since the combined mass and net elevation change over a trip or leg is not recorded, the fleet operator may not be able to distinguish between the primary factors that underpin the fuel used on a leg-by-leg basis.

For example, a driver may have a designated route, which involves a considerable increase of elevation between the start and end points of a leg, and therefore that driver is likely to record reduced fuel economy compared to a driver that typically drives on level roads with the same vehicle combination mass. The same consideration also extends to drivers that on average travel with more lightly loaded vehicles, and hence will be more likely to record improved fuel economy compared to drivers with higher average vehicle mass. The total combination vehicle mass, and the net change of elevation is not usually recorded by a conventional TSP unit on a per trip or leg basis, which therefore poses a challenge when comparing driver performance across the fleet based on fuel economy (km/L) alone. The fleet operators are likely to gain an improved understanding of fuel or energy use characteristics per leg if more parameters (e.g., elevation and vehicle combination mass) is recorded by the TSP unit and used to calculate a driver's performance metric.

To understand the possible limitations of a commercial telematics system in the assessment of fuel use characteristics, this study aims to compare the recorded data from a commercial telematics system with a custom-built high-resolution vehicle monitoring system: the "SRF-Logger". The SRF-Logger was developed at the Centre for Sustainable Road Freight (SRF) at the University of Cambridge. In this study, we evaluate several trips completed by two trucks and analyse the differences in data quality that result from reduced sampling rate and limited data channels of the TSP unit compared to the SRF-Logger.

2.Methodology

The comparative study was carried out with two HGVs operated by KDG Logistics. Figure 1 shows the two test vehicle combinations used in this study. They comprise identical truck-tractors (i.e., Volvo, model: FM42 T1HA) and identical semi-trailers (i.e., Lohr, model: SHR EVO 2), and are used for the transportation of passenger vehicles (also known as "car-carrier" truck combinations). These vehicles typically transport new vehicles from a port-side hub situated in the city of Durban, South Africa to original equipment manufacturer (OEM) dealerships established in the interior of the country and neighbouring countries such as Namibia (~1890 km trip) and Botswana (~ 960 km trip). On the return trip, new vehicles that are assembled at inland production facilities are transported to the port of Durban for export. The tare weights of the tractor and trailer units are 6 533 kg and 9 820 kg respectively, and the combination has a capacity of up to 8 passenger vehicles. Each HGV has a dedicated driver, both of whom have been with the fleet operator for at least 5 years and completed fuel saving driver training.

(a) **(b)**

Figure 1 - Photographs of the two KDG Logistics HGVs, Volvo (model: FM42 T1HA) and semi- trailer (Lohr, model: SHR EVO 2) "car-carrier" truck combinations (a) fleet number 194, and (b) fleet number 195

Both a TSP unit and SRF-Logger was installed in each of the two HGVs. Data from the TSP unit was available to the company's operations department via a web portal user interface. The TSP tracking unit interfaces with the vehicle using the universal Fleet Management System (FMS) gateway and simultaneously records the GPS position for vehicle tracking. The web portal has a dashboard with several customisable displays that best suits the role of the fleet management operator. For example, all the vehicles in the fleet can be tracked based on near real-time data (e.g., position, fuel level, speed, route, heading) that is transmitted to the TSP server, and vehicle's GPS position can be overlayed on a regional map, with an update rate of 60 seconds. The dashboard is configurable to report data on either an individual vehicle, groups, or the entire fleet. Thus, using the dashboard an individual vehicle or driver in the fleet can be compared to the fleet average according to various parameters such as fuel consumption, vehicle speeding, idle time, and driver performance metrics.

Furthermore, reports can be generated that provide averaged fleet-level data (e.g., average fuel consumption) across the fleet over a selected period (e.g., daily, weekly, or monthly period). It should be noted that the TSP software also features an advanced application programming interface (API) that facilitates detailed interrogation of the FMS messages (< 500 messages) transmitted across the CAN bus of a vehicle at a maximum sampling interval of 6 seconds. However, the implementation of the API requires specialized software development skills, which is not likely to be implemented by the fleet management operator using the web portal of the TSP thus, the API functionality of the TSP will not be evaluated in this study. However, the findings for this study can guide future development of the TSP to improve existing capabilities, by the development of tailored functionality updated into the existing platform.

In comparison, the SRF-logger can record multiple data channels from the vehicle's CAN bus via the FMS gateway at a sampling rate of 10 Hz (i.e., 0.1 seconds data sampling interval), which is substantially higher than the 60 seconds data update interval available from the TSP. The logger recorded data from both the vehicle CAN bus (i.e., vehicle speed (km/h), fuel use (litres), cruise control status (on/off), accelerator pedal position (%), engine speed (rpm), engine temperature (°C), and combination vehicle weight (tonne)) and from the smartphone's internal sensors (i.e., GPS, accelerometers etc). Using the GPS data, external factors that affect fuel consumption were collected, including elevation and local wind and weather conditions.

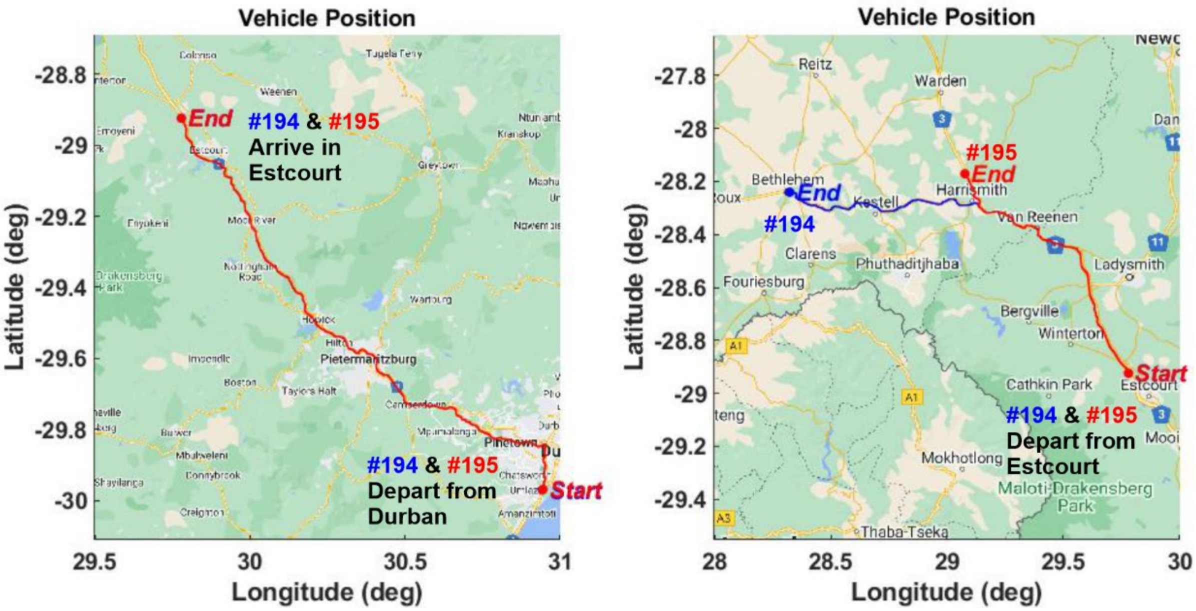
All data recorded via the SRF app was streamed in real-time via a 3G or 4G mobile data connection to a server at Cambridge University Engineering Department (CUED) – the 'CUED server'. The "Combination Vehicle Weight (CVW)" parameter available through the FMS gateway was calibrated against records about the combined mass of the passenger vehicles loaded onto the trailer and the known tare mass of the truck and trailer. Processing of the vehicle data involved segmentation according to vehicle mass (~ 30 tonne) and journey (i.e., highway route and direction) to isolate the *average fuel consumption*. The SRF logger data enabled a complete reconstruction of the time history of the vehicle parameters recorded for specific legs of a delivery route, which will enable comparison of the recorded cumulative data available from the TSP.

3. Results

In-service data was collected for four weeks during April 2023. The test vehicles transported passenger vehicles to both inland and port-side destinations over this period. To make systematic comparisons of the data characteristics of the vehicle monitoring devices, a specific route along a national highway route (i.e., N3) departing from Durban was selected for further investigation. In particular, the route was completed by both test vehicles on the same day and the fuel level at the start of the journey and the combination vehicle weight (CVW) were similar (i.e., approximately 100% and 30 990 kg).

3.1 Route

Figure 2 shows the GPS data recorded by the two SRF-loggers. The analysed route was split into two legs: (i) for the first leg, the vehicles departed from Durban and arrived at Estcourt travelling on the N3 route for most of the journey (Fig.2a), and (ii) where both vehicles travelled on the same route along the N3 until the town of Harrismith before heading in separate directions (Fig. 2b). It is important to note that the journey inland from Durban, involved a significant increase of elevation of approximately 1670 m. The elevation profile of this route will be presented later, based on the GPS location recorded by the SRF logger.



(a) (b)

Figure 2 - SRF logger GPS data showing the route taken by both test vehicles, (a) Leg 1 Durban to Estcourt, (b) Leg 2 Estcourt to Bethlehem #194 (blue), and Estcourt to Eeram #195 (red)

3.2 Comparison of Conventional Data Streams

The TSP data for both legs of the journey are shown in Table 1. For comparison the cumulative distance (km) and fuel used (L) from the SRF-Logger data are also shown. The cumulative data from the TSP and the SRF-Logger are in close agreement, which can be attributed to both devices logging the CAN bus signal via the FMS gateway, and the TSP calculating the total distance and fuel used at the end of each leg. From Table 1, three characteristics can be identified. Firstly, comparing the fuel economy between Leg 1 and Leg 2, Leg 1 appears to have resulted in significantly lower fuel economy than Leg 2. The fuel economies for Leg 1 were 2.0 km/L (#194) and 2.1 km/L (#195) versus 2.4 km/L (#194) and 2.5 km/L (#195) for Leg 2. Thus, Leg 1 demonstrated ~17.4% more fuel per kilometre than Leg 2 despite having a similar distance (~200 km).

Secondly, since the route, combination vehicle weight (CVW) and weather conditions were similar for both vehicles, it is possible to evaluate the potential effects of the driver's behaviour on fuel use for each leg. Again, referring to Table 1, it appears that the driver of vehicle #195 achieved 4-5% greater fuel economy than the driver of vehicle #194 (i.e., vehicle #194: Leg 1 - 2.0 km/L and Leg 2 - 2.4 km/L, and vehicle #195: Leg 1 - 2.1 km/L and Leg 2 - 2.5 km/L). The driver of vehicle #195 is ranked in the top 15 of KDG Logistics' driver performance table. However, it is important to note that the differences of fuel economy on this trip may also be attributed to traffic congestion, aerodynamic drag (different passenger vehicles on each trailer), tyre rolling resistance, and localized wind conditions on the route.

Thirdly, the selected route appears to be severe on fuel economy compared to the fleet averaged fuel economy (i.e., for Leg 1 35.4% (#194) and 32.8% (#195), and Leg 2 22.5% (#194) and 20.0% (#195). Thus, both legs resulted in fuel use that is substantially higher than the fuel economy averaged over the fleet, likely due to the large increases of elevation. The TSP unit does not record the elevation change for a journey leg.

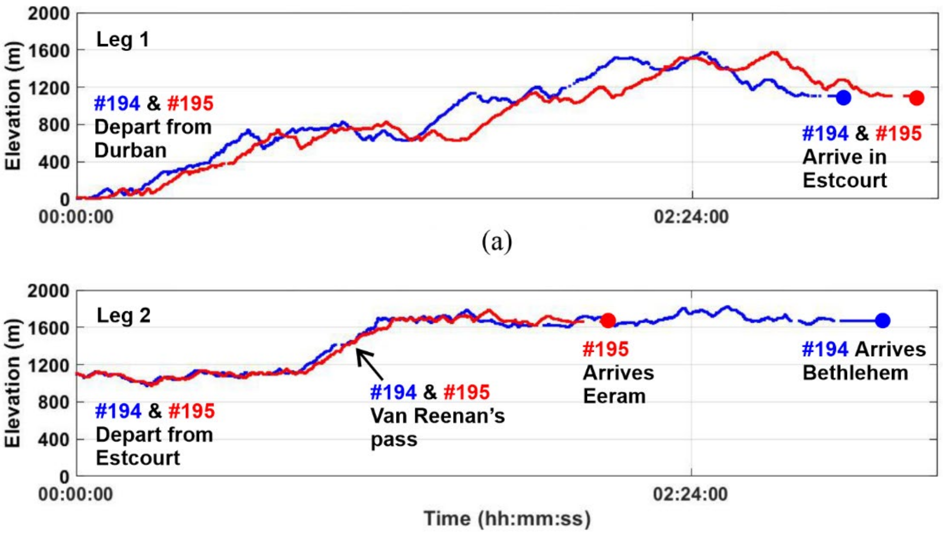
Table 1 - TSP Trip and Fuel Use Data

TSP and SRF logger comparison		**Vehicle: #194**			**Vehicle: #195**		
		TSP	**SRF**	**(%)**	**TSP**	**SRF**	**(%)**
Leg 1:	**Distance (km)**	**199.7**	**199.85**	**-0.1**	**198.8**	**200.9**	**-1.1**
	Fuel Used (L)	**98.5**	**98.5**	**0.0**	**94.5**	**96**	**-1.6**
	Economy (km/L)	**2.0**	**2.0**	**0.0**	**2.1**	**2.1**	**0.0**
	Comparison with Fleet Average (%)	**-35.4**	**(-)**		**-32.8**	**(-)**	
Leg 2:	**Distance (km)**	**205.0**	**204.9**	**0.0**	**131.4**	**131.3**	**0.1**
	Fuel Used (L)	**86.5**	**86.5**	**0.0**	**53**	**53**	**0.0**
	Economy (km/L)	**2.4**	**2.4**	**0.0**	**2.5**	**2.5**	**0.0**
	Comparison with Fleet Average (%)	**-22.5**	**(-)**	**-0.1**	**-20.0**	**(-)**	**-1.1**

Despite being able to make a high-level assessment of the fuel use from the TSP data, it is not possible to obtain a detailed understanding of the factors that contribute to the total fuel consumption. The TSP data was recorded at low sampling rate (0.017 Hz), with limited data channels and only cumulative fuel use data is reported at the end of a journey leg. To investigate the factors that underpin the performance shown in Table 1, the SRF-logger data was analysed in greater detail.

3.3 High Resolution SRF-Logger Data

As discussed above, Legs 1 & 2 demonstrated greater fuel use per kilometre than the fleet average, and Leg 1 consumed approximately 17% more fuel than Leg 2. To provide further insight into these findings the elevation profile for Legs 1 & 2 were investigated and are shown in Fig. 3. Leg 1 has a net increase of elevation between Durban (roughly at sea level) and Estcourt to be approximately 1106 m (Fig. 3a). For Leg 2 the net increase of elevation is approximately 569 m (Fig. 3b), which is mostly due to the van Reenan's mountain pass. The elevation profile was reconstructed from the recorded GPS latitude and longitudinal coordinates using the MATLAB elevation() function, which estimates the elevation relative to mean sea level using the earth gravitational model, EGM-96.



(a)

(b)

Figure 3 - Elevation profiles extracted from the GPS locations recorded by the SRF logger. (a) Leg 1 Durban to Estcourt, (b) Leg 2 Estcourt to Bethlehem #194 (blue), and Estcourt to Eeram #195 (red)

The significant elevation change provides a clear demonstration of the less-than-average fuel economies that were observed. Further, the differences between Leg 1 and 2 are likely to be related to the latter (Leg 1) having elevation change that is roughly twice that of the former (Leg 2), thus incurring lower fuel economy.

The SRF-Loggers also measured the combination vehicle weight (tonne) as shown in Fig. 4. This weight data is reported by the CAN bus that was estimated by onboard vehicle sensors and was accessible to the FMS gateway. Figure 4 confirms that the vehicle mass is comparable for vehicles #194 & #195, which enabled the combined vehicle mass to be removed as a factor that contributes to the difference of fuel economy between the test vehicles. Accurate measurement of the vehicle mass is critical to carry out fuel benefit quantification of fuel saving technologies and strategies, as demonstrated by Na and Cebon and Madhusudhanan et al. [2, 13]. In this study, the FMS Combination Vehicle Weight (CVW) parameter was calibrated based on load reports provided by the fleet operator for this trip, and measurement certainty was estimated to be within 2%. Therefore. the fleet operators are likely to gain an improved understanding of fuel and energy used per trip if more parameters (e.g., elevation and combination vehicle weight) are recorded by the TSP unit and used to calculate fuel economy. For example, a modified level road fuel economy could be defined based on the vehicle mass that is logged via the CAN-bus and FMS gateway as tonne-km/ L.

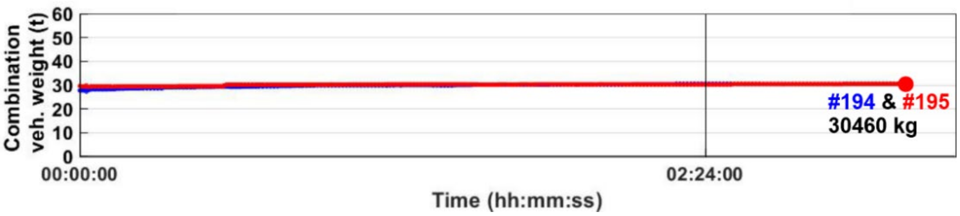


Figure 4 - Combination Vehicle Weight for vehicle #194 and #195

The TSP data provided in Table 1 indicates that the driver of vehicle #195 achieved a fuel economy that is approximately 4 – 5 % greater than the driver of vehicle #194. The possible reasons for this are investigated further based on the SRF-Logger data of vehicle speed (km/hr), cruise control activation (ON/OFF) and distance (km) as shown in Fig. 5. Comparing the speed data shown in Fig. 5a for Leg 1, it appears that vehicle #195 took longer to reach the destination (Estcourt), given that both vehicles cover the same distance (Fig. 5b), thus the average speed for #194 is 67.8 km/hr and #195 is 63.2 km/hr. However, referring to Fig. 5c, #194 activated cruise control for a greater proportion of Leg 1 compared to #195. A reason for this difference is that #195 possibly encountered congestion on the national highway N3 route, which meant that it may not have been safe to activate the cruise control. In addition, higher traffic would have reduced the average speed. This comparison highlights that reducing speed by 6.7% reduced the fuel consumption by approximately 5% for this specific scenario according to Table 1.

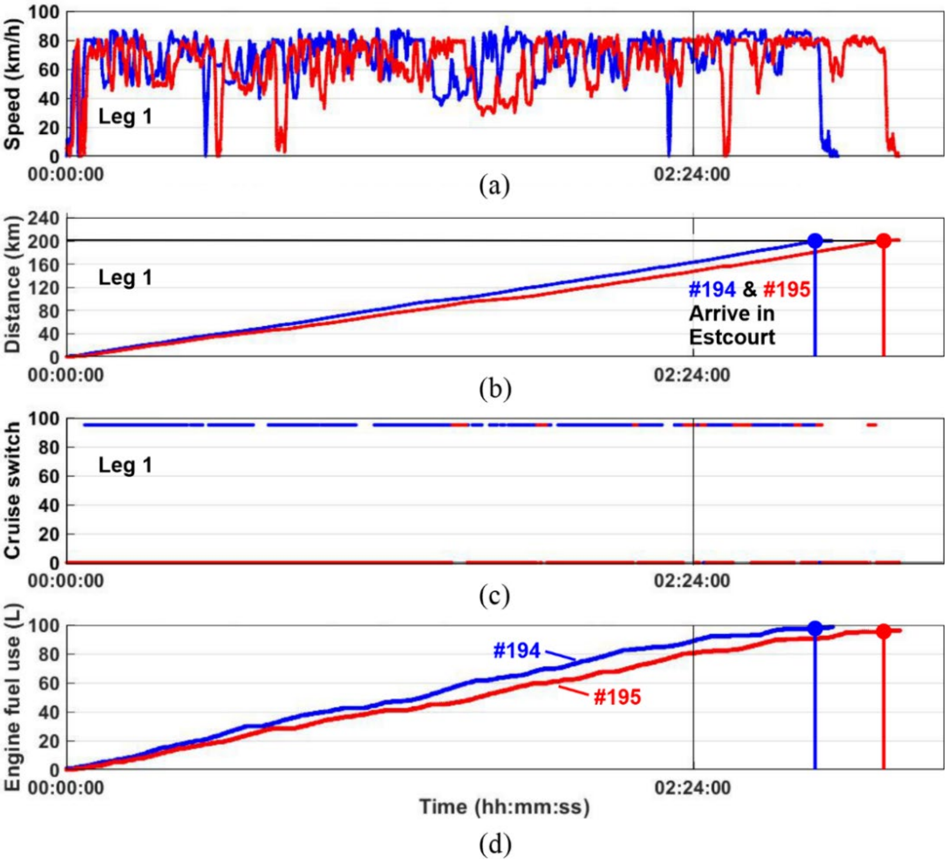


Figure 5 - High sampling rate SRF logger data for vehicle #194 and #195 on Leg 1. (a) Vehicle Speed (km/h), average speed for #194 is 67.8 km/hr and #195 is 63.2 km/hr (b) Distance (c) Cruise control switch (ON/OFF), (d) Engine fuel use (L)

Referring to Fig. 6, some of the effects of elevation on the performance of the vehicle can also be investigated. As was shown in Fig. 3b, the vehicles traversed Van Reenan's pass where the net change of elevation is approximately 569 m; the speed profile for vehicles #194 and #195 during this section are provided in Fig. 6a and are closely matched. Since the vehicles follow the same route leading to the mountain pass (see Fig. 2b) and the speed profiles are closely correlated, any significant reduction of speed is therefore likely to be associated with a localized road climb. Referring to Fig. 6b, the effect of the vehicle speed reductions is then to cause increased engine coolant temperature. Here the engines, are providing the driving torque to the vehicle to go uphill, yet cooling airflow passing through the radiators decreases with vehicle speed, thereby reducing convective cooling of the engine. This effect is most clearly revealed when both vehicles are on the mountain pass and the forward speed is low at around 40 km/h, the engine coolant temperature undergoes a thermal excursion, seen by the rapid increase to a maximum of 100°C at the maximum road gradient.

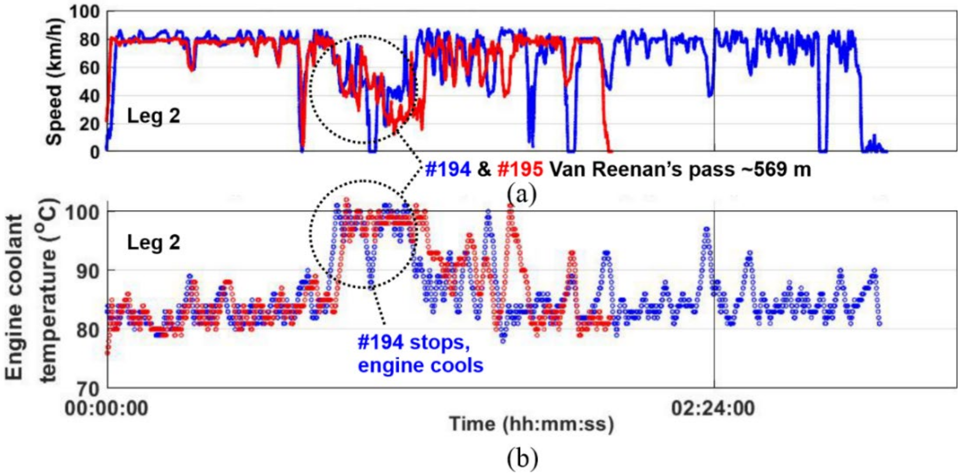


Figure 6 - High sampling rate SRF logger data for vehicle #194 and #195 on Leg 2. (a) Vehicle Speed (km/h), (b) Engine coolant temperature.

Based on Fig. 6 it is also informative to consider the effect of the driver behaviour in the management of the engine coolant temperature. For example, the driver of vehicle #194 made a stop on the mountain climb, which was perhaps to let the engine cool-down from a high 100°C, and thus during the brief stop the coolant temperature decreases by around 13°C. This action of the driver demonstrates awareness of the mechanical limitations of the vehicle when under high loading and low engine cooling, and the effects of proactive steps to ensure that the vehicle does not overheat and suffer engine or transmission damage. Maintenance and breakdown of the vehicle can be mitigated by the drivers' adopting cool-down stops.

4.Conclusions and Recommendations

In this study we have outlined the benefits and insights which can be gained through the use of high-resolution vehicle data logging equipment compared to conventional telematics units, especially as these relate to energy consumption. In this case, the custom SRF-Logger was shown to provide fleet operators with valuable insights into the local factors that underpin fuel economy, reliability and maintenance of fleet vehicles.

The following conclusions were determined:

(a) The commercial TSP unit provided cumulative fuel-use and distance data at the end of each leg of a route, which is in close agreement with the SRF Logger data.
(b) The TSP data did not provide estimates on the combination vehicle mass and the net elevation change for a leg or route.
(c) The net elevation change on a leg appears to be a major contributing factor to deviations of fuel economy for the test vehicles compared to the fleet average for this case study.
(d) TSPs should consider including the cumulative Vehicle Combination Weight (CVW) available from the CAN bus via the FMS gateway and integrating net elevation change data with the recorded GPS data on a leg-by-leg basis. However, this would require calibration using weighbridge data or loading reports.
(e) Additional data streams and higher resolution data streams have been demonstrated to have significant value in R&D applications around fleet decarbonisation and transitioning to electric vehicles.
(f) The introduction of battery electric vehicles (BEVs) with more limited range and challenging charging requirements means that fleet owners will need detailed and accurate knowledge of their current fleet performance than what is possible with existing TSP data to understand how best BEVs will integrate into their fleets in future.

The present logistics partner (KDG Logistics) has recently acquired a BEV and the SRF-Loggers will be used to monitor both the internal combustion engine (ICE) and BEV vehicles to compare them in future work.

5. Acknowledgement

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