Maximising Coasting to Reduce Fuel Consumption of Heavy Goods Vehicles

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Keywords: eco-driving, driver assistance, look-ahead, coasting, energy savings, heavy goods vehicles

1. Introduction

Transport is the UK's largest contributing sector to CO_2 emissions [1]. In 2017, approximately 9% of the UK's total greenhouse gas (GHG) emissions were due to heavy goods vehicles (HGVs) [2], which are especially difficult to decarbonise. The UK Department for Transport (DfT) aims to reduce the GHG emissions of HGVs by 15%, relative to 2015 levels, by 2025 [3]. The immediacy of this challenge has spurred interest in solutions to reduce HGV fuel consumption that have low barriers to adoption.

Many fleet operators offer eco-driver training to improve the fuel-efficiency of their fleets [4], [5]. These programmes cover numerous areas including gradual acceleration, de-speeding and maximising the use of cruise control. An important aspect of eco-driving is coasting, where the driver disengages the throttle and allows the vehicle to roll under its own momentum. Owing to the high mass of HGVs, they are able to roll for several kilometres without losing significant speed relative to the flow of traffic. When coasting with a gear engaged (as opposed to in neutral, where the engine consumes fuel at the same rate as idling), the fuel flow is cut-off, enabling the vehicle to travel a substantial portion of the journey without burning fuel.

Drivers on standard routes can be taught to identify visual markers from which to begin coasting either in anticipation of applying the brakes (known as event coasting) or to utilise changes in elevation to reduce the tractive effort of the vehicle (gradient coasting). This is a labour-intensive and time-consuming process due to the myriad of potential coasting events that will be encountered across an entire fleet. Event coasting opportunities, for example, arise at every roundabout, speed limit change, slip road or intersection. Furthermore, the optimal coasting points vary with vehicle characteristics such as mass, aerodynamic drag and rolling resistance so they cannot be fixed to static roadside markers.

Research to date has focused on automating gradient coasting and has led to the development of several in-vehicle system. Eco-roll [6] systems detect when the vehicle is on a downhill gradient and begins coasting until a drop in speed occurs. Predictive cruise control (PCC) [7] systems use knowledge of upcoming road topography to begin coasting at the optimal time; often prior to reaching the crest of a hill. The vehicle's tractive effort is reduced by allowing the HGV to coast on a portion of the uphill gradient, then use the subsequent downhill gradient to assist in reaccelerating to the desired speed. These systems have seen limited adoption in the road freight industry, with market penetrations of PCC systems in the EU, USA and China of 20%, 2%, and 0%, respectively as of 2017 [8]. This is due to the relatively recent introduction of this technology in some markets and the low potential savings quoted by manufacturers compared to other features.

This research aims to develop an algorithm for HGVs to first identify potential event and gradient coasting opportunities along a route, and then to calculate the optimal locations to begin coasting taking into account the unique vehicle parameters. This should reduce the workload for eco-driver training programmes, improvs the performance of current look-ahead systems for gradient coasting, and also incorporate event coasting. Moreover, coasting consistency between journeys, divers and vehicle-loads should be improved.

2. Research Approach

An algorithm was developed to identify gradient and event coasting opportunities for a given route and calculate the optimum location to begin coasting such that a vehicle with known parameters would achieve the maximum possible coasting distance for each opportunity without dropping to excessively low speeds. To do this, the speed profile of a given journey was analysed and a driver's acceleration/braking behavior was measured. A mathematical model of a coasting vehicle was then built and used in an optimization procedure to maximise the overall coasting distance for each trip.

Figure 1 shows a 186 km route frequently travelled by HGVs when transporting goods from the headquarters of a third-party logistics provider, Turners (Soham) Ltd, in Newmarket, England to the distribution center of a major supermarket in Didcot. This route was chosen because of the many coasting opportunities arising from roundabouts and long stretches of hilly motorway. The elevation profile of the route was obtained from the UK Environment Agency's LIDAR Composite Digital Surface Model [9] and peak detection algorithm was applied to locate the most prominent hills along the route. These represent gradient coasting opportunities and are illustrated in Figure 1 by yellow markers. The locations of event

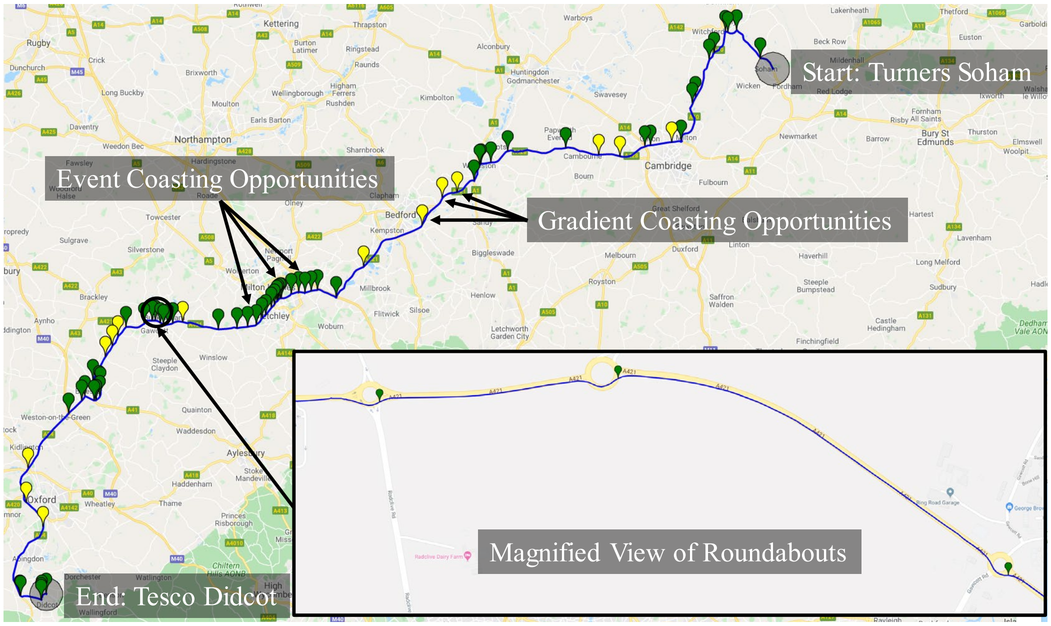

Figure 1: Case-study route with event (green) and gradient (yellow) coasting opportunities.

coasting opportunities were obtained by processing information from an online routing service. These events are shown by the green markers in Figure 1.

Several tests were conducted to parameterize the route's average speed profile and the driver's acceleration, braking and coasting behaviour, using a driver who had been trained to coast on this route and who had demonstrated excellent coasting performance. Telematics data for an HGV travelling on the route was initially collected over 3 journeys. The 3 speed profiles, expressed as vehicle speed versus distance travelled, were averaged to mitigate the effects of traffic. Figure 2 shows the measured average speed profile for a 10 km segment of this trip as a dashed grey line. This speed profile was analysed to estimate the speeds to which the driver normally attempts to accelerate between two events. For two of the test journeys, the driver was instructed to minimise coasting. This test data was used to estimate the rate at which the driver typically accelerates and brakes without changes in speed which arise due to coasting impacting the results. An idealized speed profile (excluding coasting) was then generated using all of this information. This is the upper solid green line in Figure 2. The vehicle was assumed to accelerate at a constant rate to the target speed in each segment which was maintained until the driver brakes at a constant rate when approaching an event coasting opportunity.

Coasting to speeds significantly below the flow of traffic is potentially disruptive and unsafe. For the third test, the driver was instructed to maximise coasting but was otherwise unaided. Generally, the driver would allow reductions between 9% and 19% of the starting speed during event coasting and between 4% and 13% during gradient coasting. Allowing up to 19% and 13% speed reductions during event and gradient coasting respectively is thus acceptable since it is consistent with the behavior of an experienced, professional driver. This data gives empirical 'windows' which the final speed should not exceed for the two types of coasting (shown in Figure 2 by the green and yellow-shaded regions for events and gradients, respectively).

To model a vehicle's speed over a given topography, the vehicles mass, aerodynamic drag and rolling resistance must be known. For each test, the vehicle mass was measured on a weighbridge. Estimates for the drag and rolling resistance parameters were made and the model presented by Hunt et al. [10] used to simulate coasting events which were identified in the third journey. The aerodynamic drag and rolling resistance parameters were then tuned to maximise agreement between the simulated and measured speed profiles.

For each event coasting opportunity, the optimal location to begin coasting was calculated such that coasting distance was maximised without the speed exceeding the event coasting window. Coasting was assumed to end at the point where braking was required in order to provide sufficient deceleration to bring the HGV from the final speed (as defined by the coasting windows) to a stop or other target speed. Gradient coasting opportunities were then optimised: the points at which the vehicle could begin coasting to reach the lower bound of the gradient coasting window at the peaks of the hills was found. If event and gradient coasting overlapped, the gradient coasting opportunity was discarded. Coasting opportunities of less than 100 m were neglected. Figure 2 shows the resulting speed profile, including coasting, as the solid black line.

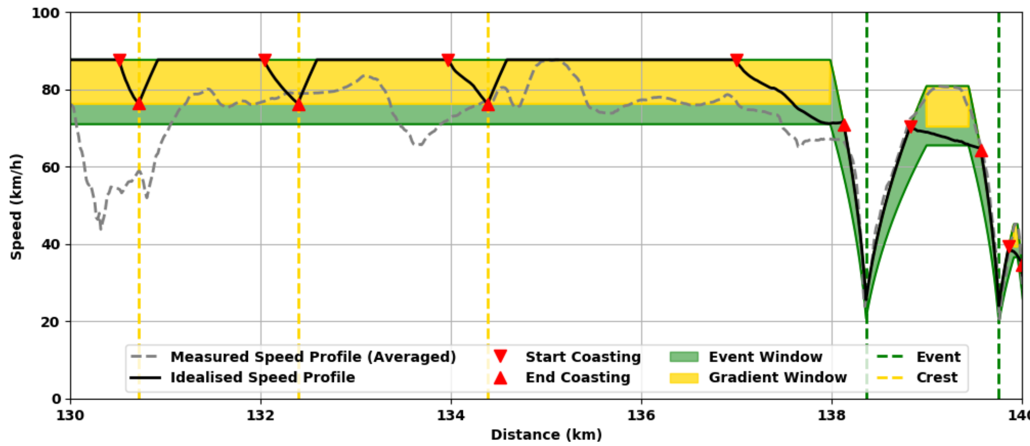

Figure 2: Idealised speed profile illustrating optimized gradient and event coasting.

The optimal coasting points for a range of vehicle masses were calculated and stored in static maps. These maps were imported into a navigation application which displays the current vehicle speed and position as well as the locations of the coasting points. The performance of the above optimization strategy was then assessed in six tests which were conducted to compare the impact of three different coasting strategies on coasting distance, journey time and fuel consumption. For the first two tests, the driver was instructed to maximise coasting but given no further assistance. Two tests were then conducted where the driver was accompanied on the trip and advised on the optimal locations for event coasting opportunities only. On the remaining two tests, the driver was accompanied and advised on both event and gradient coasting.

3. Results and Discussion

The results of the six tests are summarised in Table 1. For the Newmarket to Didcot route, the algorithm identified 51 event coasting opportunities and 14 gradient coasting opportunities. Theoretically, coasting distances between 37 km and 39 km could be achieved on the 186 km journey. (This excluded brief coasting which regularly arises under normal driving conditions, such as slowing down due to traffic or when changing gears). The optimization algorithm also assumed that coasting ends at the peak of the hill since coasting on the downhill gradient is already common practice for experienced drivers. This coasting was thus excluded from the predicted total. Greater coasting distances than the theoretical maximum can therefore be achieved in practice, particularly if the driver executes gradient coasting on hills which were not prominent enough to be identified by the peak detection algorithm.

Table 1: Coasting distance, journey time and fuel consumption for different coasting strategies.

Coasting Advice to Driver	Coasting Distance [km]	Journey Time [hh:mm:ss]	Normalised Fuel Consumption [ml/tonne-km]
None	35.5	2:51:42	9.19
None	34.3	3:11:13	10.0
Events Only	44.2	2:59:50	9.95
Events Only	44.7	3:02:19	9.27
Events and Gradients	59.1	2:55:57	9.46
Events and Gradients	59.8	2:55:34	9.42

On average, the driver was able to coast for 35 km (19% of the total driving distance) when asked to maximise the coasting distance without assistance. When advised on event coasting points only, coasting distance increased by 9 km (5%). Relative to an unaided driver, guidance on optimal event and gradient coasting increased coasting distance by 24 km (13%). The optimization algorithm was thus successful in increasing coasting distance for a driver who had previously demonstrated excellent coasting performance. Greater improvements than shown above are expected for an average driver. It follows that the programmatic identification of coasting opportunities was effective.

The fuel consumption for each test was normalized to account for varying payload and slight differences in journey distance. Taking averages for each of the coasting strategies reveals no significant impact of coasting distance on fuel consumption or journey time. In general, however, longer journeys corresponded to higher fuel consumption. This suggests that traffic conditions dominated fuel consumption, with greater congestion increasing journey time and resulting in poorer fuel economy. The relationship between coasting distance and fuel consumption is therefore unclear with a larger sample size being required to account for traffic.

Traffic conditions also prevented the vehicle reaching the target speeds when approaching some coasting opportunities. This could negatively impact fuel economy, as the driver would potentially need to accelerate at the end of the coasting event because of an excessively low final speed. A real-time implementation of the optimization, which accounts for the instantaneous vehicle speed, would thus improve the performance of this algorithm.

4. Conclusions and Future Work

A programmatic tool for identifying event and gradient coasting opportunities and calculating the optimal locations to begin coasting was developed and experimentally validated for an HGV travelling on a 186 km route. When using offline calculations to advise a driver on optimal event coasting locations, the total coasting distance was increased by 5% compared to an unaided driver's best performance. Advising on both optimal event and gradient coasting locations increased the coasting distance by 13%. Despite these improvements, no strong correlation between increased coasting distance and journey time or fuel consumption was observed. Traffic conditions were found to have a far greater influence on both of these parameters.

Nevertheless, maximizing coasting is a promising strategy for eco-driving, because increasing the distance travelled using no fuel will lower fuel consumption, despite traffic conditions obscuring the results in this study.

Future work will develop real-time coasting algorithms and will examine the relationship between coasting distance and fuel consumption, through further testing and analysis of high-resolution telematics data collected for multiple vehicles over various routes. The influence of individual coasting events on fuel consumption will also be examined in greater detail.

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