Towards Egocentric Fuel Efficiency Feedback

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ABSTRACT
Motivated by anecdotal evidence, we hypothesize that an egocentric approach is more appropriate and relevant to providing fuel efficiency feedback than a systemic approach. In this paper we describe a proposed study to test this hypothesis, and present the design of a fuel efficiency feedback system for public transit bus drivers.

Author Keywords
Feedback systems, fuel efficiency, public transit bus drivers

ACM Classification Keywords
H5.m. Information Interfaces and Presentation (e.g., HCI): Miscellaneous

Introduction
Even though we are witnessing a shift from fossil fuel based engines to electric and hydrogen based ones, the energy necessary to make vehicle propulsion possible is still an important aspect to consider. As it stands, electric and hydrogen based engines need to be powered by other means of energy, which usually indicates resorting to fossil based fuels. Independently of the propulsion technology, the premise should remain the same: achieve the proposed objective by consuming as few resources as possible.

Recently, the public transport authority in Madeira, Portugal, installed on-board electronic equipment that gauged driving fuel efficiency by presenting the driver with a simple feedback system: 3 red and 3 green lights suggested that efficiency was increasingly sub-optimal and optimal, respectively. The system purpose was to give drivers feedback on their current driving efficiency in a clear attempt to improve their habits. The result on the other hand was negative: drivers were not happy with the system as it constantly showed red lights only, indicating that the driving was constantly sub-optimal.

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In an attempt to improve feedback, the operations department attempted a "calibration" of the system by tweaking its thresholds. As a result the system became useless and inaccurate, ultimately resulting in its abolishment. In our discussions with the transport authority, it became clear that in addition to the misinterpretation of the feedback by the professional drivers as a rating of their driving, the mountainous terrain of Madeira causes genuinely inefficient driving and in effect skewed the results towards inefficient driving. Furthermore, the attempts at calibrating the system failed because, effectively, the on-board equipment measured pure fuel consumption which in turn is intricately related to the steepness of the terrain.

Our anecdotal experience with the transport authority's feedback system caused us to hypothesize that providing feedback on specific driver behavior may be more appropriate than showing overall efficiency. Adopting a systemic approach, we argue that existing feedback mechanisms relating to efficiency provide a view of the complete system. Since the driver can not be accountable for all factors that influence fuel consumption, we argue that focusing the feedback only on aspects that are controllable by the driver may result in more efficient driving behavior change. We term this approach to feedback egocentric.

In this paper we describe a fuel efficiency reporting and advisory system that takes advantage of the interactive nature of modern smart-phones to present feedback to drivers. Concretely, we propose to deploy a system in public transit buses to measure its effectiveness on positively influencing drivers' behaviors. By continuously capturing real-time data, we calculate the Vehicle Specific Power (VSP), a surrogate variable that strongly correlates with fuel consumption and pollutant emission levels [11]. Crucially, we are able to manipulate the VSP in order to ignore environmental aspects and provide egocentric feedback. As such, we propose a study where we intend to test our hypotheses about the benefits of egocentric over systemic feedback.

Related Work
Research suggests that it is possible to achieve up to 15% of fuel consumption decrease when appropriate driving behavior is used [2,6–8,12]. Independent of contex-

tual settings, appropriate driving behavior is characterized by a combination of two main factors: speed and acceleration. Specifically, it is believed that smoothness of driving (i.e. slow acceleration levels) has a considerable effect on fuel consumption. Therefore, fuel efficiency systems should be dedicated to promoting adequate driver feedback in relation to these two essential factors, i.e., reasonable speeds and low acceleration/deceleration levels. Even though it is a complex exercise to account for all factors that affect fuel consumption, And and Fwa [1] present a possible vehicular fuel consumption explanatory framework: physical characteristics of the vehicle; vehicle usage and route characteristics; road characteristics; and driver's behavior.

Of these factors, engine efficiency (physical characteristics of the vehicle) is considered the most important [4]. Still, the driver's attitude and behavior towards the maneuvering of the vehicle can considerably impact fuel consumption levels. Therefore, it is commonly argued that smoothness of driving leads to higher efficiency of fuel consumption.

Raw fuel consumption levels and pollutant emissions can be calculated through the use of Portable Emissions Measurement Systems (PEMS). These are connected to vehicles through their On-Board Diagnostic (OBD) interface, letting the PEMS system access the vehicle's on-board computer(s) and calculate multiple parameters [13]. Still, PEMS systems work primarily as a diagnostic/analysis tool, not as a feedback support mechanism. Furthermore, PEMS systems fail to reflect contextual characteristics such as road gradient values. It is common to augment PEMS with GPS for analysis purposes [13].

The VSP approach is used to approximate and predict actual emissions levels and fuel consumptions [10, 11]. VSP models fuel consumption from a physical perspective; it corresponds to the Power Demand or Vehicle Engine Load values, therefore correlating strongly with fuel consumption and pollutant emission levels [13]. The VSP model is defined as follows [11]:

$$VSP = v * (a + g * sin(\varphi) + rcoef) + acoef * v^3 \quad (1)$$

where v is speed in m/s, a is acceleration in m/s^2, g is 9.807 m/s^2, φ is the road gradient value, $rcoef$ is the rolling resistance term coefficient, and $acoef$ is the air drag term coefficient. Another characteristic of VSP is its ability to support payload modeling, especially important in situations where this value has noticeable impact, such as is the case with public transit buses [11]. Still, VSP does require that we calibrate the model for each type of vehicle, as it is necessary to obtain the ground truth for fuel consumption and pollutant emission levels for the model to be effective.

Devices such as smart-phones possess a wide variety of sensors, like GPS and accelerometers, that enable calculation of vehicle dynamics and consequently VSP values. It is then possible to approximate fuel consumption using solely internal smart-phone sensors. These devices can be easily incorporated into vehicles, and their ability to provide a rich and extensible interaction platform make them a feasible alternative mechanism to provide drivers with fuel efficiency feedback. Furthermore, and comparing with usual commercial systems such as Scania Fuel-Saving Driver Support System[1], smart-phones are not restricted to specific vehicles, and can even be device independent, which is the case when using development platforms such as Google's Android.

Receiving timely feedback is key to motivating behavior change, people need to be aware of their behavior in order to change it. Fischer found the most successful feedback was given frequently, clearly presented, used computerized tools and allowed historic or normative comparisons [9]. Our mobile interface reflects these types of feedback. Utilizing a mobile display allows frequent opportunities for self-reflection and should increase driver awareness of their behavior.

Consolvo, McDonald, and Landay [3] suggest a number of design strategies for persuasive technologies that wish to motivate behavior change. These strategies are based on psychological theories and recent persuasive technology research and we have chosen to follow some of their guidelines. First, we make use of abstractions rather than counting solely on raw data to display to drivers. Secondly, the data shown should be unobtrusive. This is of paramount importance for safety reasons, as we need the mobile display to support ignorability and not distract the driver unnecessarily. Thirdly, since the data is to be presented in public, we need to present it in a way that the driver will not feel uncomfortable if others are aware of it. Fourthly, we decided to ensure that only positive feedback is given, not punishing any "bad" behavior. Concretely, we aim at rewarding possible low consumption levels, but not use punishment for poor performance. This decision is supported by the notion that positive feedback can indeed increase intrinsic motivation by affirming competence [5]. The anecdotal evidence from the use of a commercial system by the public transit company also supports this notion. Finally, we have chosen to provide historical feedback. Doing so allows the driver to reflect on past behaviors in order to make more informed decisions on current behavior.

Research Methodology

We propose an experimental approach to study to what extent we can, through the use of egocentric feedback, influence public transit bus drivers driving behavior. In our study we are interested in the following research questions:

- Can we accurately establish driving behavior profiles for bus drivers through the use of VSP calculations?

[1]http://www.scania.com/media/feature-stories/sustainability/every-drop-of-fuel-counts.aspx

	Real-time	Historical
VSP	Real-time & VSP	Historical & VSP
egoVSP	Real-time & egoVSP	Historical & egoVSP

Table 1. 2x2 design of combination factors

- To which extent can we positively influence driving behavior through the use of egocentric feedback techniques?
- Is the use of real-time more effective than the use of historic feedback, or is a combination of the two approaches most effective?

Consequently, and based on the previous mentioned research questions, we raised the following hypotheses:

- H1. The use of the VSP surrogate variable (and its' derivatives) allows for accurate driving profile characterization
- H2. The use of egocentric driver feedback significantly improves average fuel consumption levels compared to normal feedback
- H3. The use of historical feedback significantly improve average fuel consumption levels compared to real-time feedback

To test these hypotheses we propose to develop an Android based software to continuously collect sensor information so that trip instantaneous parameters, such as speed and acceleration, can be calculated. We will also consider the use of additional variable(s) to model the influence of passenger payload on the overall vehicle weight. Then, we intend to install equipment on-board public transit buses and calibrate the VSP model. The ground truth establishment of instantaneous fuel consumption levels is a necessary condition for the success of the VSP model. This may be achieved through the use of a PEMS system or a similar mechanism. Subsequently, we will develop a derivative of VSP called egoVSP, which ignores road gradient and is defined as follows

$$egoVSP = v * (a + rcoef) + acoef * v^3 \qquad (2)$$

Terms of the equation are defined equally as in eq. 1. These two fuel efficiency models, VSP and egoVSP, are one of the two variables we intend to manipulate in our study. The other variable is the type of feedback to provide: real-time versus historical. Table 1 shows the possible combinations of these two variables.

Ongoing Work

As it stands, the system is a working prototype. Targeted mainly at public transit bus drivers, the system is flexible and extensible enough to provide support for any kind of vehicle.

An overview of the system's architecture is seen in Fig. 1, where the logic used to produce the final output to

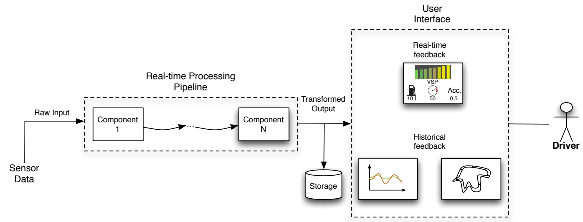

Figure 1. Overall view of system functionality

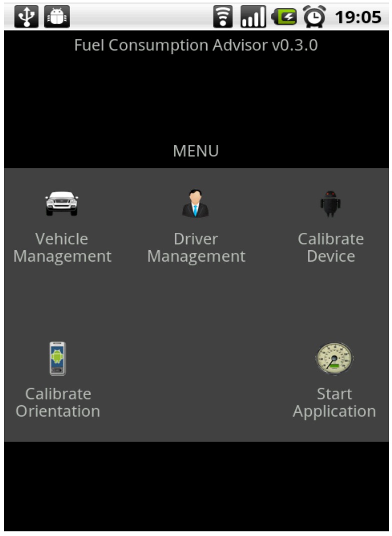

Figure 2. System main menu

the driver is seen. Raw accelerometer sensor data is sampled at several times per second, being fed into a processing pipeline where a Kalman Filter is used to integrate the accelerometer data with the GPS unit. This allows us to provide continuous velocity approximation, correcting these approximations when the GPS sample comes in. This data integration also tries to improve potential road grade calculation errors. Since we need to compute vehicle dynamics and contextual settings, we perform several rather heavy computations at a high frequency. Therefore, the use of the real-time processing pipeline allows us to keep the system responsiveness and interaction capabilities at acceptable levels.

After exiting the pipeline, the transformed output is passed to the feedback mechanism, which in turn, according to the type of feedback, transmits specific information to the driver. All data is continuously stored in a local database, so that further off-line analysis may be performed. Repeated sampling from sensors will undoubtedly drain the battery in its' full in a matter of hours, as will repeated computational effort. As such, there is the need to ensure that the device is fed continuous power by connecting it to the vehicle's internal electric circuit.

Drivers initiate interaction through the system's main menu (see Fig. 2). In order to use the system, drivers must register themselves before receiving a 3 digit PIN code that uniquely identifies them. Vehicles registration and VSP model calibration is also required, but this may be done by the developers before the system is made available to the drivers. This will be the case when doing the experimental study with the public transit bus drivers. Besides the VSP model calibration, it is also possible to calibrate both the device accelerometer, as well set up the desired orientation of the phone inside the vehicle. This last step has some limitations, as currently we are working with a phone with only one accelerometer and no gyroscope, which limits the phone's orientation recognition. Just before starting a trip, the driver introduces his PIN code and indicates the vehicle that he is currently using. After this, the trip is marked as initiated.

In order to test the effectiveness of the feedback system, we propose using two different types of feedback: real-time and historical. In the first, we will show a real-time VSP graph that represents an approximation to the actual VSP value. The graph is an abstract representation, where it goes from green (low VSP values) to red (high values) with an approximate quadratic function increase. Additionally, actual fuel consumption, speed, and acceleration values are to be represented.

In regard to the historical feedback, our system will make available two modes to the driver. The first will show the distribution of time in the pre-defined VSP bins, and the second will show a heat map of the route, indicating VSP "hot zones". The use of historical feedback gives the driver a more broad perspective of his driving behavior, as it recalls and identifies potential patterns that may be improved. Furthermore, historical feedback will only take place when the driver is not actively driving.

Conclusion

In this paper we have argued that egocentric feedback on fuel efficiency can be more effective than systemic feedback on motivating driving behavior change. Motivated by anecdotal evidence, we hypothesize that an egocentric approach is more appropriate and relevant. By re-defining the VSP surrogate metric, we are able to switch between systemic and egocentric feedback while maintaining minimal changes between our experimental conditions. Orthogonal to the manipulation of the efficiency model, we describe our interest in testing the effect of instantaneous versus historic data in the feedback system.

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