

AC 2008-2539: CARTOGRAPHY: CREATING A GLOBAL MAP-BASED FUEL USE CALCULATOR

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CARtography: Creating a Global Map-Based Fuel Use Calculator

Abstract

The goal of this work was to create a web tool that offers accurate predictions of fuel consumption based on driving directions. The objective is to promote the adoption of ‘fuel-sipping’ vehicles and car-sharing programs by providing drivers with a more accurate representation of the trade-off between vehicle selection and use and on-road fuel economy. To implement this tool, the MATLAB environment was employed in various capacities. The System Identification Toolbox was used to fit output data generated from the powertrain simulation software CRUISE™ into models that could be compiled in the Simulink Real-Time Workshop and called from the JavaScript web interface. MATLAB was also used to parse and correlate the extremely large data set in the driving cycle generating script. And, last but not least, it provided the consistent working environment between the teams working on opposite sides of the earth but speaking the same (programming) language. The common platform allowed them to learn from each other and build on each other’s strengths while bridging the gap where experience was lacking. The opportunity for education extends beyond the developers and driving public, but into the classroom as well.

Introduction

Poor air quality in urban areas caused by vehicle emissions has a significant negative impact on human health, and the use of fossil fuels in the transportation sector releases vast quantities of greenhouse gasses. To help address these global concerns, we need to adopt smaller, more efficient commuter vehicles, as well as implement changes in driver behavior through the use of car-sharing programs, trip-chaining, and less aggressive driving. Changing these behaviors will require increased public education and awareness about real-world fuel use. Toward this end, graduate students from institutions in the US, Canada, and Switzerland have been collaborating over the last 6 months on a novel method to predict fuel consumption using MATLAB/Simulink and online map directions called CARtography. The CARtography fuel consumption calculator is an online tool that estimates fuel use for a specific vehicle, driver, and route. Instead of relying on EPA or other regulatory fuel economy estimates, CARtography is based simulation results using route- and driver-specific drive cycles. The algorithm is being developed leveraging the strengths of the various groups sharing ideas about vehicle simulation (PSI), driver behaviour (MIT), and web interface (U of W).

CARtography promotes engineering education through international collaboration and knowledge sharing, excellence in automotive energy research, the technological education of consumers and drivers, and real-world engineering lessons for 6-12 students. The university students involved in the process have benefited from their participating in an international collaboration surrounding automotive transportation issues. The communication and sharing of ideas and results across countries helps coordinate global efforts to understand and address our automotive energy use and emissions and share knowledge and skills across continents. In addition, CARtography allows consumers access to a more reliable fuel consumption estimate than is simply available by multiplying EPA fuel economy by distance traveled. This

information is invaluable for consumers making transportation and vehicle choices. In addition, CARtography also provides a valuable resource for 6-12 science and technology education. It can be used in the classroom to demonstrate the complexity of engineering systems and to run thought-provoking experiments comparing travel routes, driver behaviors, and vehicles. This paper describes the need for a web-based fuel use calculator, the factors affecting on-road fuel economy, the technical details of CARtography design and operation, and the educational value of the tool.

Need for CARtography Tool

Reducing our personal transportation energy use and emissions is a global challenge and is made more difficult by the lack of generally available information and public awareness. A recent study at MIT analyzed what it would take to double new vehicle fuel economy in the U.S. by 2035. Cheah et al found that while it is technically feasible, doing so will require significant changes to the automotive market and industry. Estimated production costs are up to 20% higher for vehicles that double fuel economy while maintaining the performance of today's fleet at potentially smaller size^[1]. Without a corresponding consumer demand for more fuel-efficient vehicles, such dramatic cost and investment increases do not seem feasible.

For the last 30 years, overall vehicle efficiency has increased steadily each year. Most of those efficiency increases, however, have been applied toward vehicle performance (more power for acceleration)^[2]. Average U.S. vehicle fuel economy has remained relatively flat. In addition, although individual vehicle fuel economy has increased during that time, most potential fuel savings have been lost because the tendency has been to purchase a bigger, more powerful car, and to drive it further. This is due in large part to a lack of public awareness.

Few drivers are aware of their actual on-road fuel use. And, if they are, fewer still are aware of how their individual driving choices affect that consumption. Turrentine and Kurani interviewed 57 households from nine different lifestyle categories. None of the surveyed households systematically tracked their gasoline use or costs. Their conclusions were that because of this lack of information and awareness, consumers generally do not make economically rational choices about vehicle purchase and use^[3].

Significantly reducing automotive fuel use and emissions will require a dramatic shift in the way the automobile is produced, purchased, and used. It will require new, more efficient vehicle technologies, shifts in vehicle choice and travel demand, and education in efficient driver behaviors^[1]. Coordinated international efforts are needed to research automotive energy use and promote better public understanding of these issues.

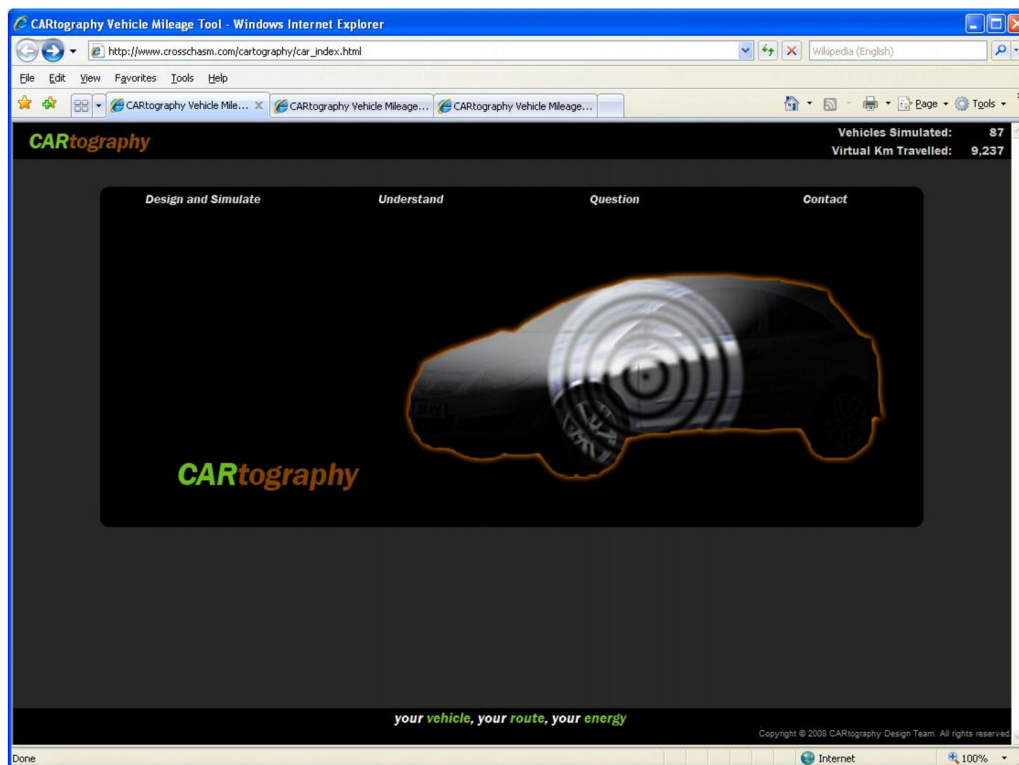
The CARtography Website

There is significant need for a web-based fuel use calculator to encourage excellence in automotive energy research, promote international corroboration, and increase the technical knowledge of society. The best web-tools today are the ones that provide a service that gets better with each use. Wikipedia, Slashdot, Google Maps and YouTube are examples of user communities which encourage members to actively improve their utility. CARtography will

follow this model, and encourage users to input their trip information and actual fuel consumption with the aim of further improving the tool's functionality. The goals of the CARtography online fuel consumption estimator are to:

- Relate driving and vehicle choices to actual money savings over the long term,
- Provide fleet owners with a valuable method of managing their fleets,
- Provide more accurate fuel economy estimates for environmentally-conscious people who track and report on-road fuel economy values,
- Share engineering knowledge, expertise, and research findings across continents,
- Coordinate international research efforts,
- Generate data for future studies, and
- Provide an educational tool for university and grade 6-12 students around the world.

The web interface was designed with simplicity, clarity, and depth of service in mind. The creative ideas were contributed from the core design group, as well as from collaborators and colleagues from the various schools involved. A sample screenshot of the CARtography front page is shown in Figure 1. The web interface is still under development, and is expected to change significantly before the beta launch.



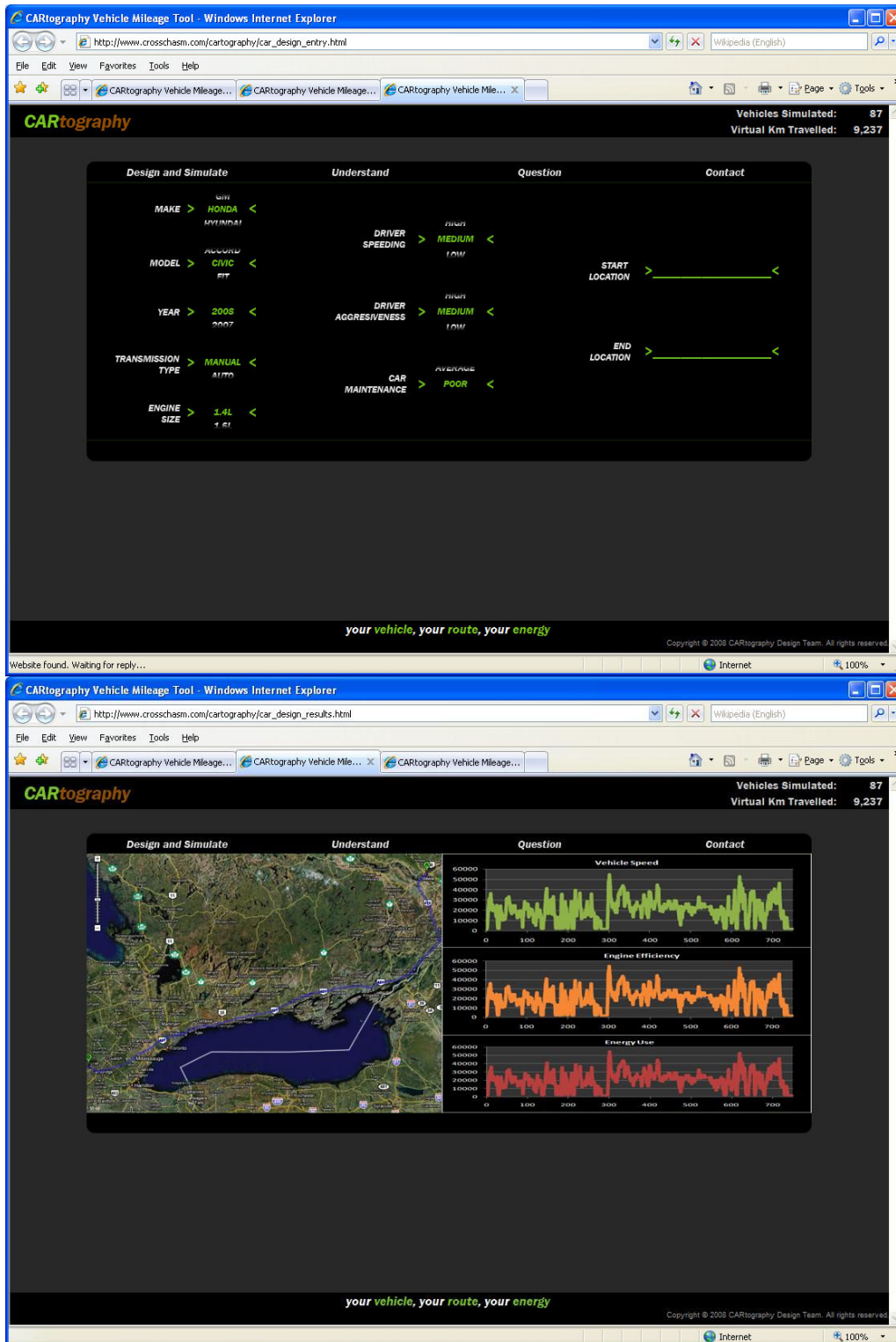


Figure 1: a) conceptual front page of CARTography website; b) inputs; c) simulation results

The following section discusses the factors affecting on-road fuel use, focusing in detail on driving mode and driver aggression.

Factors Affecting On-road Fuel Use

Many factors affect on-road fuel use and cause it to vary from the EPA-rated fuel economy values. While not exclusive, these factors can generally be grouped into three types, all of which can be influenced by the driver:

- **Travel Demand:** Travel demand can be thought of as the travel mission or need, represented by distance, type of travel, and congestion/traffic.
- **Behavior:** Driver behavior includes aggressiveness of acceleration and deceleration, vehicle speed, and amount of idling, as well as, vehicle maintenance and use of accessories. When combined with travel distance and driving mode, driver behavior yields the actual driving cycle of a specific route or travel mission.
- **Vehicle:** Factors affecting the rated fuel economy of the vehicle include payload weight, accessory load, and control.

As shown in Figure 2, the combination and interaction of these various factors determines the amount of fuel actually used by a particular driver, in a particular vehicle, on a particular route. A fourth type of factor could be classified as environmental factors such as temperature, humidity, and precipitation. These have the potential to influence fuel use dramatically; however, they cannot be controlled, by the driver, automaker, or policy measure and are not considered at this time.

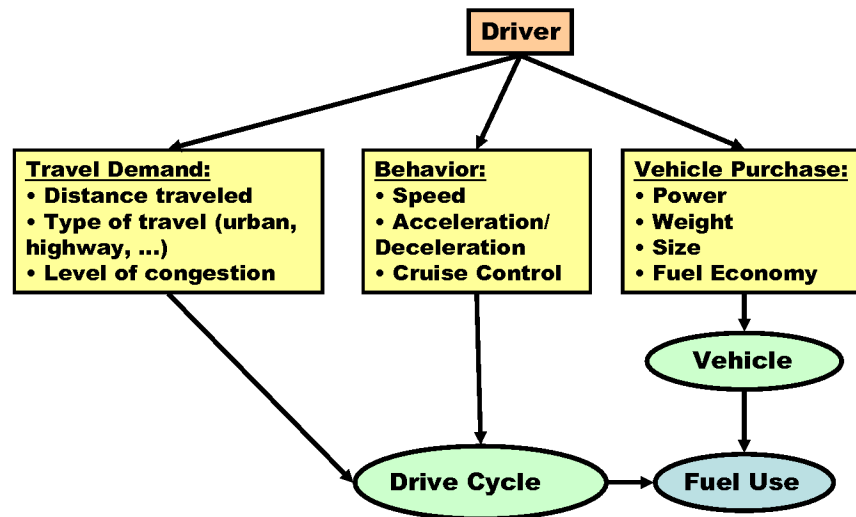


Figure 2: Factors affecting on-road fuel economy and how they related to the driver choice

Travel demand and vehicle specifications clearly impact fuel use. However, while these factors are generally understood, they are not correlated to actual real-world fuel and price impacts by the general public. Even less well understood are the impacts of driving mode (city, hwy, etc) and driver behavior on on-road fuel use. The importance and impact of these factors on trip drive cycle and actual fuel use is usually underestimated. It is not uncommon for real-world driving to result in on-road CO₂ emissions and fuel use 25% greater than estimated sticker or label values^[4]. In one study that considered 18,945 km of driving data from Vasteras, Sweden, it was found

that the individual factors with the greatest increase in fuel use were 1) very high power demand or acceleration and 2) occurrence and duration of stops ^[5].

Driving Mode

The driving mode refers to the type of driving scenario encountered (urban, rural, highway). The driving mode combined with the amount of traffic and congestion has a significant affect on fuel use by changing drive cycle speed and acceleration, consistency of vehicle speed, and frequency idling and stops significantly. These various driving modes can be represented by vastly different driving cycles for the same trip.

As part of the European Assessment and reliability of transport emission models and inventory systems (ARTEMIS) project, driving data from 77 vehicles over 10,300 trips, 88,000 kilometers, and 2200 hours across four European countries (UK, France, Greece, and Germany) was used to identify 12 separate modes of travel including urban, secondary road, main road, and motorway driving at various levels of steady, unsteady, congested, and free flowing traffic ^[6]. As shown in Figure 3, these various driving modes are characterized by different speed and accelerations. For the first CARTography implementation, only 4 driving modes will be considered.

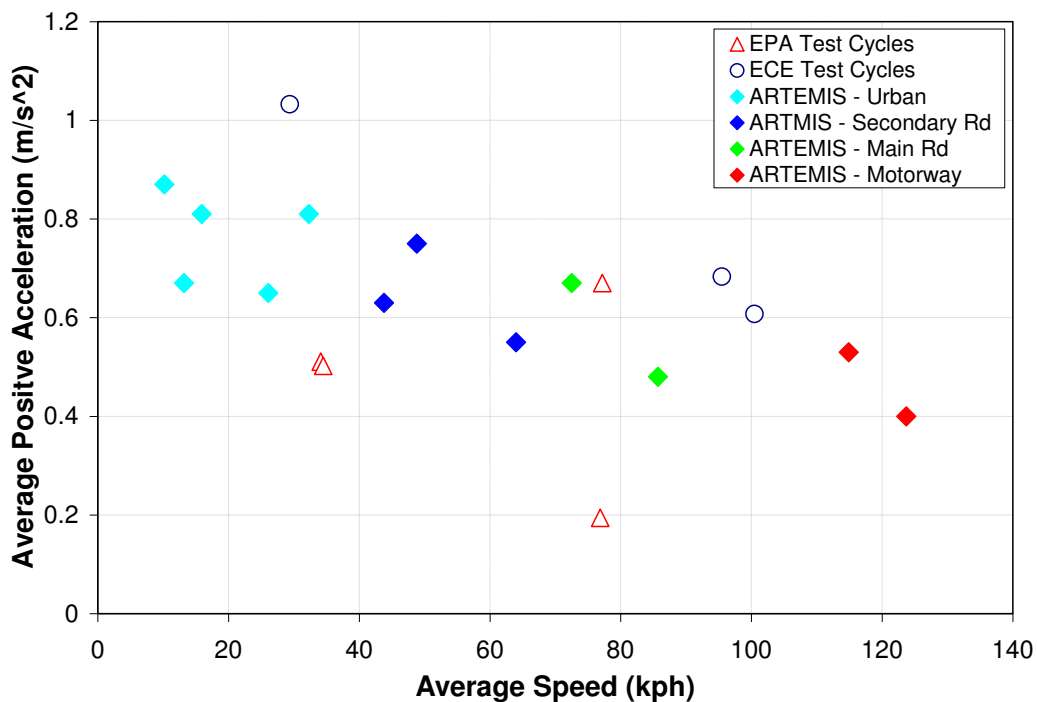


Figure 3: Average speed and positive acceleration of various driving modes determined by ARTEMIS along with the standard EPA and ECE regulatory test cycles.

Driver Aggression

Driver aggression influences both average vehicle speed and acceleration and deceleration levels. It can have a significant impact on on-road fuel use. Even within the same driving mode and under similar traffic and vehicle speeds, aggressive driving has been seen to increase fuel use by as much as 40% in the city ^[7]. Conversely, some drivers have been known to achieve on-road fuel economy values as much as 60% higher than EPA labels by not using brakes, accelerating very gradually, never driving above 88 kph, manually turning the engine on and off at stops, and eliminating accessory and air conditioning use. Known as “hypermilers,” these drivers push gentle driving to the extreme ^[9]. Hypermilers on the CleanMPG.com online community have logged fuel economy values as high as 2.4 L/100km for the Honda Insight hybrid, close to 3.35 L/100km for a 1992 Honda Civic, and 5.3 L/100km for a 2007 Ford Focus ^[10].

A similar, yet less extreme form of non-aggressive driving is “EcoDriving.” EcoDriving has been shown to cut fuel use by about 10 to 15% without having to drive more slowly. These techniques include upshifting to avoid engine speeds over 2,500 rpm, maintaining steady vehicle speed, anticipating traffic, accelerating and decelerating smoothly, and avoiding long idles. Many European countries have begun to promote EcoDriving through PR campaigns, driver classes, and workshops. Quality Alliance Eco-Drive, a Swiss EcoDriving Training Company, reports average fuel savings of 11.7% ^[8]. Driving simulators and on line course and training modules are also gaining popularity. Ford recently added an EcoDriving module to its Driving Skills for Life website (www.drivingskillsforlife.com). The following sections present the technical data collection, analysis, and design to create the CARTography web-site and its uses as an educational tool for university students and the public and 6-12 students.

CARTography Creation

Extensive data collection and processing supports the development and validation of the CARTography website algorithms. Specific algorithms build a drive profile and vehicle model before performing a simulation to estimate fuel use. The following sections of this paper focus on each of these steps: data collection and processing, profile generation, and vehicle modeling.

The structure of the website can be seen in the diagram shown in Figure 4. The outputs to the user are still under development, and the driving cycle will likely also be depicted on the website as an output. The front page will request users to find their specific vehicle, which will then be binned into one of roughly 50 models because there are a prohibitive large number of vehicle types that would require simulation for a rigorous approach.

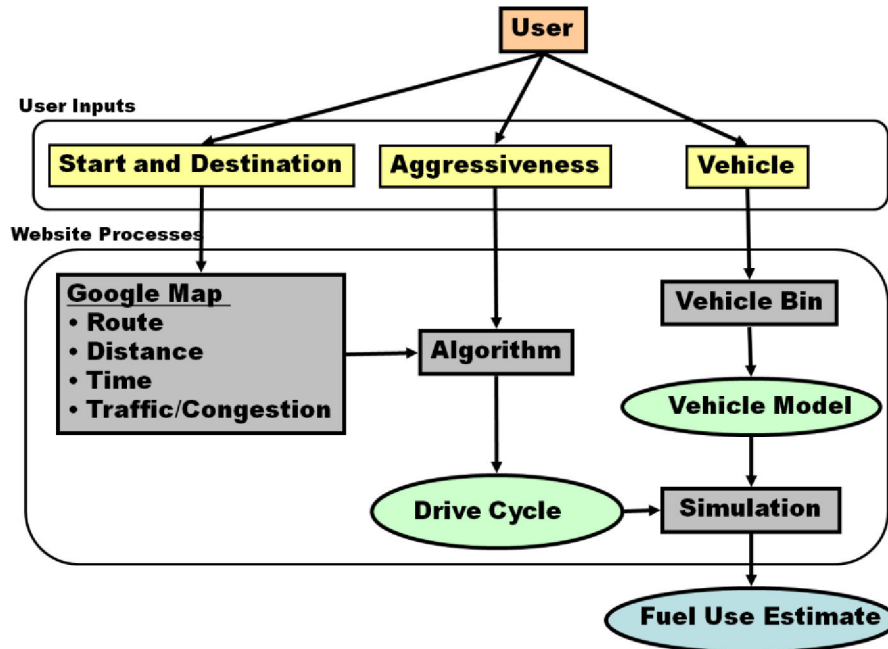


Figure 4: Block diagram of website organization with factors affecting fuel economy

The heart of the fuel consumption calculation relies on the ability to produce an accurate driving cycle to use as a primary input to the vehicle model. The uncertainties that exist make producing an accurate driving cycle for a given route challenging. Variable traffic conditions alone make it extremely difficult to establish a set of rules that govern vehicle speed over a specific road that can accurately reproduce measured values. Adding road features such as traffic signals, pedestrian crossings, roundabouts, school zones, and bridges complicates the algorithm development further. Considering all road features, traffic, weather, and human factors that may contribute to the speed of a vehicle on a mapped driving route would be prohibitively complicated.

Data Collection and Analysis

In order to be able to estimate the speed of a vehicle given directions from a map, a correlation had to be identified between the speed of a vehicle and its defined route. Data was collected from colleagues, co-workers, friends, and family using the CarChip OBDII data logger shown in Figure 5.



Figure 5: CarChip OBD II data recorder with 300 hr recording capability

This data logging device plugs directly into the vehicle’s OBDII port, and logs the parameters listed in Table 1 at 5 second intervals, except for the vehicle speed, which is logged every second. A shortcoming of the logger is that only four parameters may be logged in addition to vehicle speed, which restricts the accuracy of fuel consumption calculation ^[12].

Table 1: Data available to be logged by the CarChip

	Data	
Vehicle Speed	Timing Advance	O2 Sensor Voltage (B1, S1)
Engine Speed	Fuel Pressure	O2 Sensor Voltage (B1, S2)
Throttle Position	Fuel System Status	O2 Sensor Voltage (B1, S3)
Coolant Temperature	Short Term Fuel Trim (B1)	O2 Sensor Voltage (B1, S4)
Engine Load	Short Term Fuel Trim (B2)	O2 Sensor Voltage (B2, S1)
Intake Manifold Pressure	Long Term Fuel Trim (B1)	O2 Sensor Voltage (B2, S2)
Air Flow Rate	Long Term Fuel Trim (B2)	O2 Sensor Voltage (B2, S3)
Intake Air Temperature	Battery Voltage	O2 Sensor Voltage (B2, S4)

A sample of 30 vehicles was chosen from the vehicle pool parked at several lots on the Paul Scherrer Institute campus. The vehicles were selected for their age, status as a commuter vehicle, and to ensure a representative selection of weights, sizes, and classes. Seven colleagues responded to the call for participation resulting in the test fleet shown in Table 2.

Table 2: Paul Scherrer Institute commuter test fleet

ID	Vehicle	Trip
I – 001	2007 Jetta TDi	Baden - PSI
I – 002	2007 VW Lupo	Endingen - PSI
I – 003	2004 Toyota Yaris WT-i	Veltheim - PSI
I – 004	2001 Volvo XC70	Mellingen - PSI
I – 005	2001 Renault Clio	Dogern (DE) -PSI
I – 006	2005 BMW X5	Klingnau-PSI
I – 007	2003 Toyota RAV 4	Zofingen-PSI

A sample route is shown along with Google Map directions in Figure 7. In the figure, the road types and most recent direction followed are identified, as well as the calculated total distance driven. This allows patterns to be identified manually between the map and corresponding velocity events that then lead to rules embedded in the driving cycle generator. Two post-processing methods will be presented that are even more effective for producing rules.

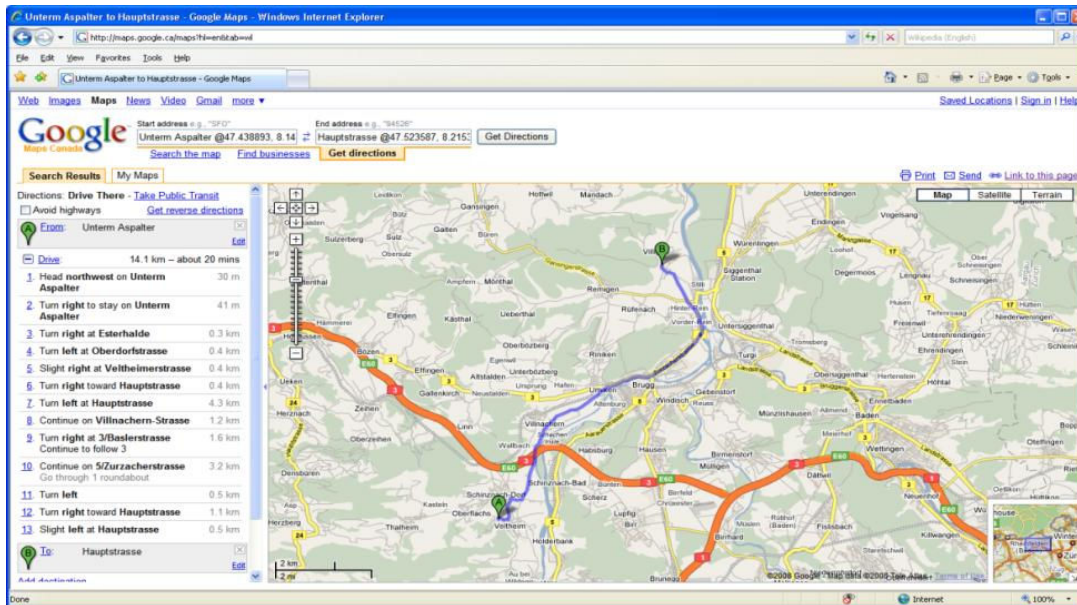


Figure 7: Sample trip: Veltheim to PSI

In order to rapidly and effectively analyze the driving velocity data collected from the data collected, pre- and post-processing algorithms were written in MATLAB. All available information about road features and types identified by Google Maps shown in Table 3 is used to create a ‘base profile’ for each driving route recorded.

Table 3: Deterministic and random inputs to the driving cycle generator

Google Maps Information		Road Features Considered	
turn right	keep right	Normal	Hill
turn left	keep left	Speed limit increase	Toll
continue	at take	Speed limit decrease	Curve
take the ramp	at stay	Stop sign	Yield
take the exit	go through	Stop light (red)	perturbation
merge	slight right	Heavy traffic a (stop)	
head	slight left	Heavy traffic b (go)	

The pre-processor accepts an intuitive encoding of the driving directions and distances between waypoints as well as the known vehicle velocity. The algorithm parses the directions, distances, and road types, and distributes them graphically with calculated distance traveled (for comparison) on a single axis. An example of a parsed trip is shown in Figure 8. Road features which are not explicit from the driving directions are approximated probabilistically according to several studies^[13]. These probabilistic velocity perturbations include features such as traffic, traffic signals, yield and stop signs, etc.

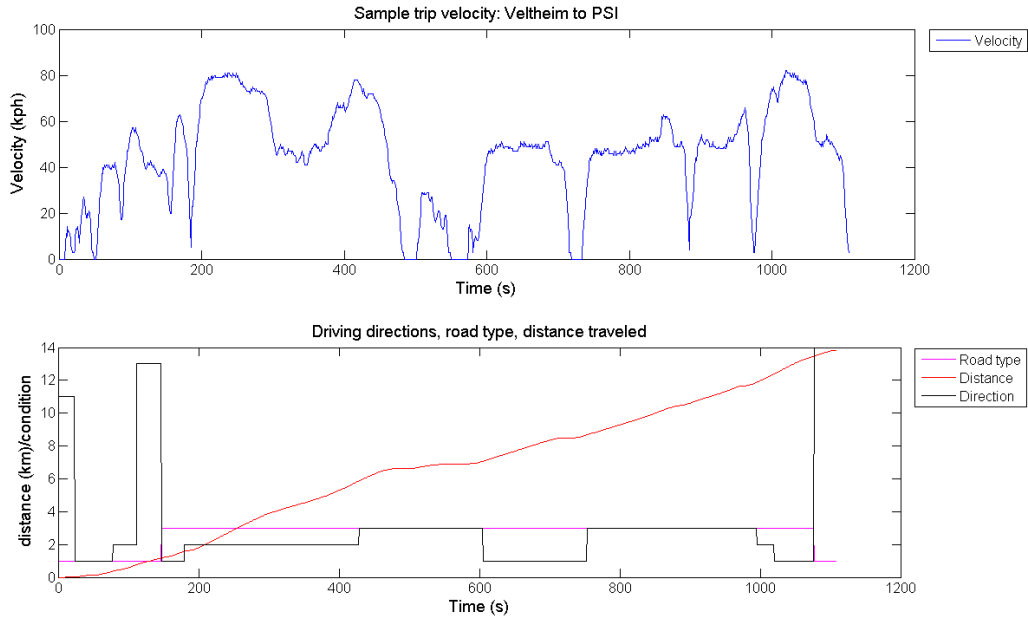


Figure 8: MATLAB CARTography pre-processing algorithm. Top: velocity profile. Bottom: distance traveled, road type, directions

To simplify the task of creating velocity rules according to driving directions from the collected data, the MATLAB post-processor plots both the original and algorithm-generated driving cycles on the same axis, and performs two types of signal processing on them. The first type of post-processing is shown in Figure 9. Trip velocity is plotted, and a different color is used at a road event such as a turn, or road type change which makes it easy to compare with expected behavior. The change points for the trip can be seen in the lower pane of Figure 8.

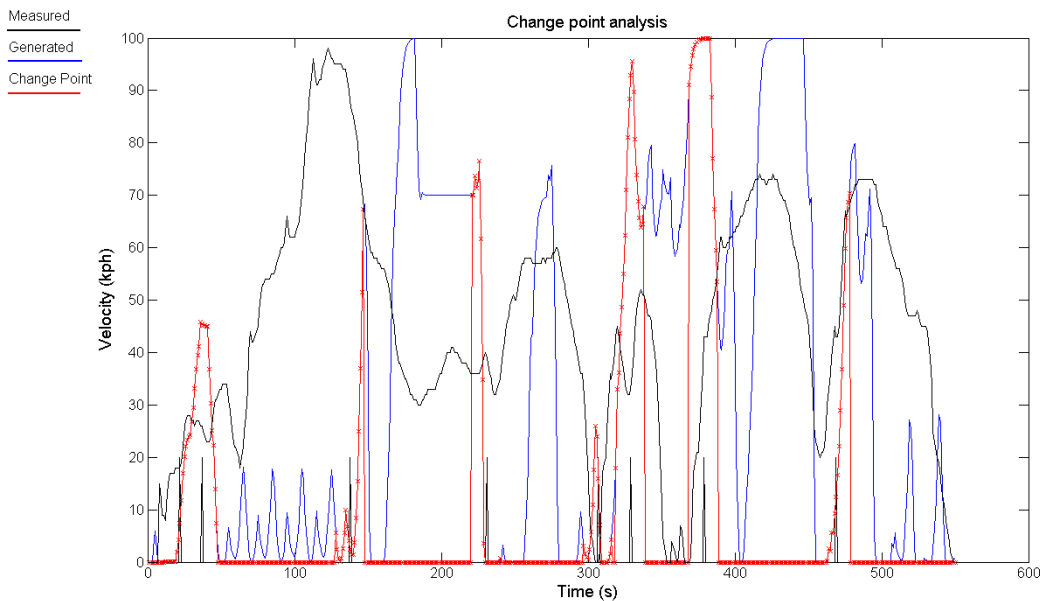


Figure 9: MATLAB post processor plots velocity colored differently at road events

The second post-processor uses the tubular-difference method to identify sections where the profile generator has correctly (or incorrectly) matched velocity to a given map event ^[14]. A representative example of this post-processor output can be seen in Figures 10 and 11. The post-processor removes all generated velocities that do not fall within the ‘tube’ with a pre-defined width. This allows sections where the profile generator properly handles a road event to be clearly identified, and provides an effective way to quickly evaluate the quality of a generated profile. Velocity deviations are flagged not only for deviating in magnitude, but also for occurring too early or too late, which will be discussed in detail in the following sections.

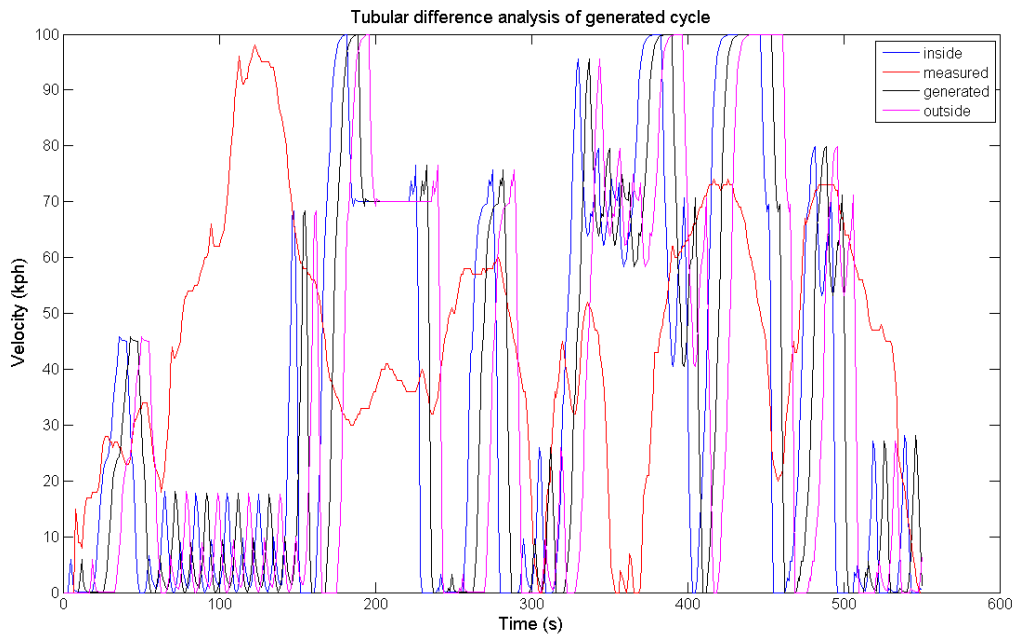


Figure 10: ‘Tube’ of acceptable deviation between measured and generated profiles

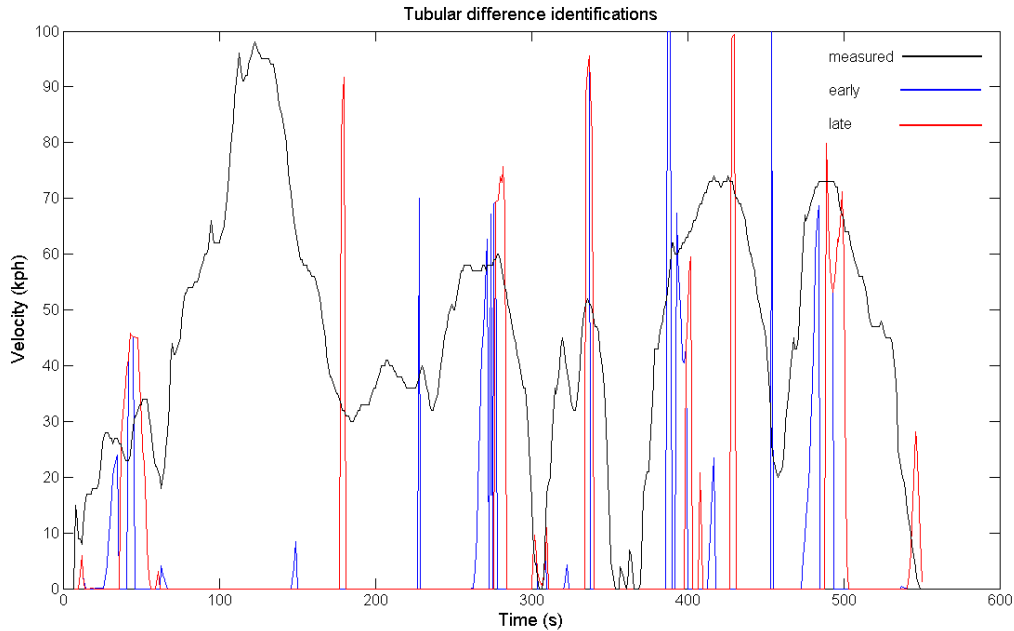


Figure 11: Results from tubular difference analysis velocity points inside tube remain

Profile Generation

Based on the results of data processing, the algorithm generates a number of profiles with different random number seeds, and then analyzes and ranks the set according to the ‘goodness’ features outlined in Table 4. This is a modified Monte-Carlo method, which is a way of handling the fact that meeting a stop sign on a trip can’t simply be simulated by driving at ½ of the speed through the intersection. With this method, the greater the number of profiles, the better the fit to the ‘goodness’ features. This number must also be reconciled with the computation time that is tolerated by the average user of a web tool (often very small!).

Table 4: ‘Goodness’ of profile measures

'Goodness' criteria		
Measure	Compare with	Pass criteria
Distance travelled	Google Maps distance	<0.2 km difference
Acceleration/deceleration	Average recorded values	Acc/dec < ave. data
'flat' velocity	Maximum recorded values	Flat time < max. data
Repetition	Recorded values	< max data similar
Idle time	Study values	< max literature value

In order to accurately calculate fuel consumption over a route, it is important that the driving cycle simulate vehicle acceleration and reach top speed in a realistic way. The timing of these events, however, does not make a large difference in vehicle fuel consumption, except for directly after cold-start, during the warm up period. To address the cold-start and warm-up deviation between simulated and actual fuel consumption, user feedback will be drawn upon to generate scaling factors similar to those used by the EPA in their standard dynamometer test

procedures^[15]. The assumption that the timing of driving events has a minimal impact on overall fuel consumption simplifies the algorithm and reduces computation time. The next section describes the vehicle modeling system used and a justification for making this assumption.

Vehicle models

In the first implementation of CARTography the powertrain simulation software CRUISE™ is used to ‘drive’ a particular vehicle along the route specified and to calculate the fuel consumption. The CRUISE™ software was developed by AVL, and had been extensively used and refined by global OEM’s in their vehicle design and control development. Extensive validation has been performed by various research groups and agreement between simulation and measurement within 5% has been reported^[16].

To ensure that the timing of velocity changes and top speeds in a profile does not significantly impact overall fuel consumption of the vehicle models (except when the events occur during engine warm-up), a vehicle driving several permutations of a driving cycle was simulated in CRUISE™. The test vehicle used was a front wheel drive 2.5 L gasoline sedan with an automatic transmission. The offset velocity profiles are shown in the panes of Figure 12, and the corresponding fuel consumption is superimposed on each cycle for both a hot and cold start scenario.

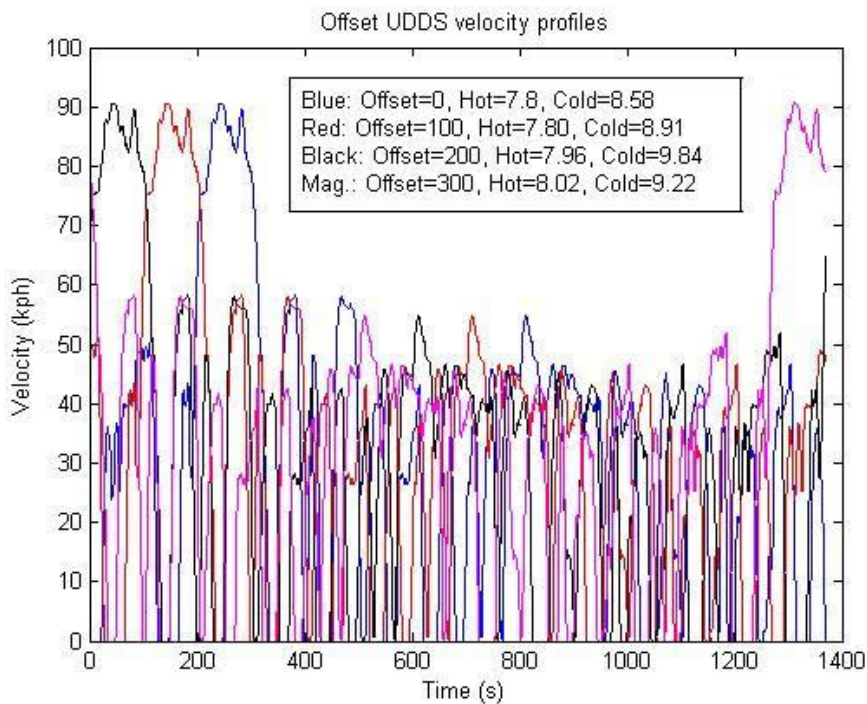


Figure 12: Identical driving cycle offset by a specific number of seconds

The fuel consumption varies by less than 0.001 L/100 km for the hot-start transient case, and by less than 0.3 L/100 km for the cold-start case. This result instills confidence that shifting

velocity traces temporally (especially if they don't fall in the engine warm-up period) will have little effect on the overall fuel consumption estimation. Put differently, if you have a route with 12 lights, and stop at 6 of them, it doesn't make a significant difference in the overall fuel consumption calculated which of the six are red.

Next Steps

There are several areas of work remaining before the beta launch which is scheduled for late-April 2008.

Profile Generation Improvements – The algorithm must be expanded in order to reduce the required computation time through the parameterization of vehicle models and the streamlining of driving cycle generation. Statistical binning methods which are often employed for dynamometer cycle development are being considered to generate the map-based driving cycle^[18]. The existing dataset need to be analyzed more thoroughly to ensure that all useful information about the relationship between map direction and vehicle velocity has been extracted. Concurrently, ongoing data collection with the CarChip data recorder in Italy, Germany, France, and North America is scheduled in order to screen for potential geographic driving effects. The effects of elevation change, weather, and traffic on fuel consumption need to be considered in the algorithm. The treatment of elevation change, in particular, should improve the accuracy of the consumption prediction significantly over standard driving cycle calculation. Appropriate ranges of driver acceleration, deceleration, and speed must be determined for a range of driving styles (aggressive, gentle, average, etc). Once these values are determined, information about the driver's specific aggression level will be included in the profile generation algorithm to give even more accurate results.

Vehicle Model Improvements – In order to reduce computing time (for the impatient web user), CARTography will eventually use a parameterization of full vehicle models for fuel economy and performance prediction using MATLAB's System Identification Toolbox (SIT). This requires analyzing a series of vehicle models for each class (compact, sedan, luxury, etc) of vehicle and creating lumped-parameter models which can be executed more rapidly. Figure 13 shows the performance of a non-linear ARX model and its ability to simulate instantaneous fuel consumption at different velocity points appropriately. The model deviates in several places, and will therefore require refinement.

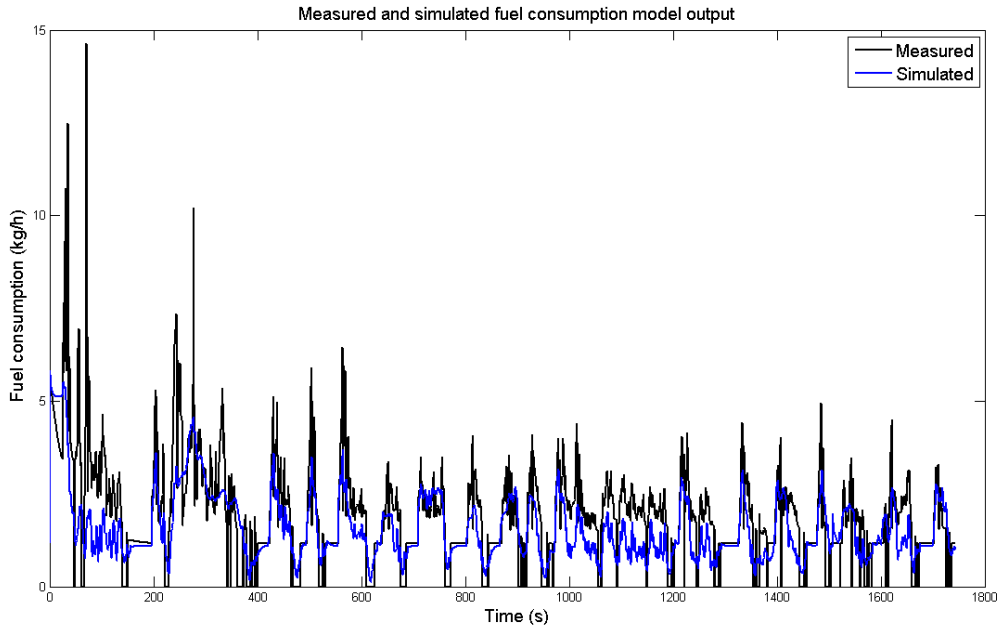


Figure 13: Sample parameterized model of fuel consumption according to vehicle velocity

User Interface Improvements – Before the beta launch, it is important that a system of log-in and contribution be in place so that data can be collected from the beginning of the service availability. The present focus is on creating a method by which a user may enter trips, as well as arbitrary driving cycles (useful in the physics classroom setting). After the user has entered a trip, the actual fuel use can be entered at a later date for on or a series of trips with the hope that every time a user fills their tank, the volume information is added to the website. Before the beta launch, the exact feedback methodology must also be determined to ensure that entered data is used effectively to improve service.

Educational Value of CARTography

The CARTography website has many uses as an educational tool, for both the university students involved in creating the site and its many potential users among both the general public and 6-12 students.

CARTography Creators Experience

The efforts to create the CARTography website have and will continue to promote professional interaction, communication, and collaboration between university students in Switzerland, the U.S., and Canada. Although techniques, research methods, and areas of expertise vary; through regular discussion and sharing of ideas and findings, the members of the CARTography team have and will continue to learn from each other. This level of community and international corroboration supports all three research projects:

- Development of a drive cycle algorithm and vehicle models at PSI,
- Research on driver behavior and driving style at MIT, and
- Website and algorithm development expertise at the University of Waterloo.

Algorithm and website development is accelerated and supported through the use of a common programming language spoken: MATLAB and Simulink.

Once finished, CARtography will provide the creators with valuable data for validation and testing of models and algorithms and to support additional automotive energy research. Although the site will rely on input from site users, there is a growing community of online users. There are many examples of such sites. In the area of automotive fuel economy, two examples include the EPA's "Your MPG" site (<https://www.fueleconomy.gov/mpg>) where people identify vehicle model and year, driving style, percent city and highway driving, and report actual fuel economy for others to see. CleanMPG.com maintains a similar community, with the focus on efficient driving and seeing how high fuel economy drivers can achieve.

Additionally, the site will provide the students with insight into the way online tools are developed and used and will serve to highlight areas where further research should be directed.

CARtography Users Experience

As an online tool, the finished CARtography website will promote the technological education of society and provide a valuable tool for 6-12 science and technology education.

General Public – As shown above, consumer behavior in vehicle purchase and use is the one of the largest determiners of our automotive energy consumption and emissions. The CARtography site will encourage public awareness of actual vehicle fuel use and provide feedback on how transportation choices affect energy utilization, including

- Travel Demand: Compare different travel routes; see the impact of trip-chaining, avoiding traffic, and driving less.
- Behavior: Compare and observe differences due to driver acceleration and speed levels
- Vehicle: Compare real-world fuel use of specific vehicles over a common route prior to purchasing a new vehicle.

Information and awareness has been shown to drive consumer behavior, and CARtography could be expected to generate observable fuel savings. In a study by the Pacific Northwest National Laboratory, homeowners were asked to decide and set the trade-off they wanted to make between cost and comfort. Through automatic control of their home heating and cooling that used electricity pricing, the average homeowner used 10% less electricity every month^[17].

6-12 Education – The finished CARtography site will be a valuable tool for innovative 6-12 education. It will provide teachers and students with a tool to analyze and test the impacts of changing driver, vehicle, and route selection. For example, one potential lesson plan could ask students to find the most efficient way to transport 10 people from the school to a local park. Students could specify vehicle model, route, and driver aggression. This activity would ask

students to compare not only on-road fuel use and rated fuel economy, but the appropriateness of vehicle size to meet specific personal travel demands. Science fair projects that involve the addition to the models capabilities will be facilitated (and encouraged!). The low cost of the CarChip (~150 USD) makes ‘take home’ experiments possible, which would also add to the breadth of the database and increase the utility of the tool.

Conclusions and Future Work

The development of the CARTography proof-of-concept web-tool has been completed. The algorithm effectively (if not quickly) generates a driving cycle from driving directions. This profile is used by a CRUISE™ vehicle model to estimate the fuel consumption for a trip. A method of quickly and effectively analyzing driving data has been presented, and a Monte Carlo-style decision making mechanism has been employed to select the most representative driving cycle. The educational benefits of the system have also been discussed. This tool can be seen as an effective way to collect research data, disseminate accurate fuel use information to drivers worldwide, and educate on driving habits. This is a global collaboration tackling a global problem, and a flavor of the interaction between the students working in different parts of the world was presented in this work.

A beta launch is planned for late-April 2008 after additional improvements in the profile generation, vehicle models, and user interfaces are made in the months to come. Future improvements will be directed at increasing the information and utility of the tool for online users, making it a more effective educational tool, and increasing its potential to change consumer behavior. Potential improvements to the CARTography website could include:

- Data upload – Giving users the ability to upload their own data, recorded using a CarChip or similar device, would provide benefits for both the user and CARTography creators. This ability could be used to improve the profile generation algorithm, provide more accurate fuel use estimates, and collect data for analysis by the site creators.
- Quantization of drive pattern – Quantizing the acceleration of a trip will allow users to compare available and used vehicle performance for a specific vehicle and driving cycle.
- Estimate of fuel cost – Referencing average fuel prices for the region surrounding the specified route to estimate trip cost will make the tool even more valuable for increasing public awareness of tradeoffs.

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