

## Digital Maps, Connectivity and Electric Vehicles - Enhancing the EV/PHEV Ownership Experience

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### ABSTRACT

Electrification of the automobile is a growing trend and will create both challenges and opportunities for the vehicle manufacturer, road network infrastructure and driver. In addition to innovative fundamental battery and power transfer technologies, electric vehicles will integrate unique driver interfaces, road intelligence, traffic awareness and wireless data communication to provide a complete support system. This networked vehicle will improve efficiency, increase cruising range and contribute to the overall driving enjoyment of an electric or plug-in hybrid-electric vehicle. Through tailored applications created by content and service providers the driver will identify the most efficient travel routes, learn efficient driving behaviors, avoid energy-wasting situations, locate charging stations and have confidence in reaching a destination and returning home. Using map-based predictive technology, vehicle power controls will become more efficient through knowledge of road terrain, traffic controls and regeneration opportunities. In fact, research demonstrates that connected hybrid electric vehicles using digital map information can demonstrate energy savings on the order of 25%.

### INTRODUCTION

In 1900, battery electric automobiles comprised 28% of the cars produced in the United States (1). Remarkably, during the ensuing 110 years the primary challenges have remained largely the same - developing battery technology that meets mass-market requirements and adapting the support road infrastructure to provide rapid “refueling” service on the road. Conceived as bridging technology, the first mass-produced Hybrid-Electric Vehicles (HEV) were launched in 1997 (2). HEVs combine gasoline and electrical propulsion with integral battery charging capability using a motor/generator and regenerative braking. In late 2009 the first large

scale production Plug-in Hybrid Electric Vehicle (PHEV) reached showrooms in China. The PHEV is functionally similar to the HEV, but allows recharging from the electrical grid. Fully Electric Vehicles (EV) rely entirely on stored electrical energy for propulsion. In this paper, we will consider both EVs and PHEVs as a set, in that they share many traits with respect to battery maintenance.

Electrification of the automobile is subject to massive public and private investment, and while much of the research continues to focus on battery technology and drivetrain systems, there are also important investments being made in a wide range of battery management support schemes, involving new driver interfaces and options for accessing the power grid. For example, in the US alone, it is projected that by 2015 there will be more than 1 million distributed charging stations to augment home charging (3). On the “home front”, smart phone applications are planned to help the driver manage a home charging strategy that takes advantage of off-peak electricity rates and may even permit selling surplus vehicle electricity back to utilities (4).

At any stage of automobile evolution and market development, competition will force manufacturers to make the most of available vehicle technologies to maximize customer satisfaction. For electric vehicles, products and services that directly enhance ease-of-use and maximize value over the vehicle life will be key to mass adoption and long term success. Connected, location-aware applications will play an important role helping the consumer make the most of their EV while enhancing the ownership experience.

### CONNECTIVITY, DIGITAL MAPS AND ELECTRIC VEHICLES

A connected EV/PHEV will operate in an “ecosystem” or framework of intelligent applications that enable evolving EV



**Figure 1. Connected electric vehicle integrates on-board intelligence with dynamic wireless content**

support functions. This connected EV will combine embedded road knowledge used by the driver and vehicle systems with off-board dynamic information regarding the current or anticipated driving environment. Five significant domains: predictive road intelligence from digital maps, awareness of current and future traffic conditions, mobile data communications, Advanced Driver Assistance Systems (ADAS) and Smart Applications will join the driver, vehicle and world together seamlessly.

For background, ADAS is a suite of vehicle features comprised of Active Safety, Driver Assistance and Energy Efficiency. Examples of ADAS applications include Adaptive Cruise Control, Lane Departure Warning, Intelligent Speed Adaptive and Adaptive Frontlight Systems. Increasingly, map-based Fuel Efficiency applications are being linked through new features like Eco-Driving and Eco-Routing, where driver information and fuel efficiency are combined. In vehicles with built-in navigation systems, it is becoming commonplace to integrate map data with any number of ADAS applications where knowledge of the road ahead is relevant. The digital map, when combined with a forward-looking algorithm known as the Electronic Horizon, functions as a powerful “sensor” with a range of 2km or greater, and includes a wealth of road attribution, including three-dimensional road centerline topology (5). In vehicles lacking a built-in navigation system, a special map database for ADAS and fuel efficiency may be integrated in the form of a Map and Positioning Engine (MPE) reference architecture. This reference architecture includes a GPS receiver, yaw-rate gyroscope, map storage, Electronic Horizon algorithm and a Controller Area Network (CAN) interface. The MPE can be integrated in many forms, ranging from a standalone module to a fully distributed solution integrating preexisting resources in the vehicle (6).

## CONNECTED EV SERVICES AND INTELLIGENT APPLICATIONS

Connected services are a key enabler for enhancement of EV/PHEV efficiency and the ownership experience. Whether incrementally updating an onboard map wirelessly to ensure the latest changes to the road network are represented, or delivering traffic-enabled routes to the nearest available charging station, a variety of innovative services are made possible by the combination of wireless connectivity, map data for ADAS and back-end services and delivery capabilities. As these capabilities converge, and “cloud computing” services mature, the electric vehicle driver interface, mobile handset, and home computer all become relevant to this enhanced ownership experience.

Alternate fuel vehicles are gaining popularity both for economic reasons as fuel prices rise and for ecological reasons, as “green” consciousness reaches the mainstream. On the one hand, industry forecasts predict more EVs and PHEVs sold annually, but in the meantime the current charging infrastructure is limited. This will create challenges for automotive OEMs marketing EVs to a mass audience beyond the most motivated early adopters. Given this paper is about an ownership experience, perhaps it is appropriate to experience connectivity through this “day-in-the-life” vignette illustrating how connectivity can benefit the future EV owner.

Jeff Johnson (not a real name) is a freelance commercial photographer who travels around the west coast to practice his trade. Jeff has recently purchased an EV and uses the rich EV support toolset made available by the manufacturer. On Mondays Jeff travels to a studio in downtown Los Angeles for an ongoing assignment.

**SUNDAY, 8:00 PM**

Jeff has strolled to a restaurant near his home in Malibu to meet friends for dinner. Remembering he has to drive to Long Beach the next day, he accesses his car profile from his smart phone. Noticing the battery is a little low, he initiates a charge remotely so he'll have a full charge to start his day the next morning.



**Figure 2. OnStar Battery Management application**

**MONDAY, 9:00 A.M.**

Using his home computer, Jeff has set up commuter alerts, which notify him if traffic conditions are poor, and on this particular day, he receives an alert on his Smart Phone indicating an accident-related backup on the highway which would delay his commute and consume more energy. To compensate, Jeff jumps into his fully charged electric vehicle a little earlier than usual, and calculates a new dynamic route utilizing ADAS data and current traffic conditions from a server that gets him to the studio on time while also minimizing energy consumed, with road attributes like slope, curvature and stop/starts factored into the route calculation. As he's driving, traffic probe data is being sent back to the server, improving the accuracy of the real-time traffic data for other drivers.

**MONDAY, 11:30 A.M.**

Jeff receives a call from a prospective client asking for a meeting on a new business opportunity that same afternoon in San Bernardino. Jeff uses his in-dash navigation system to plan a route. Realizing the vehicle won't reach the planned destination without re-charging his intelligent onboard system contacts the server for the location of charging stations along his route and prompts Jeff to add a convenient station as a waypoint along his journey. Before arriving at the charging station, Jeff's in-dash system receives an alert from the server that there is a traffic incident 10 miles ahead and recommends an alternate route. As this new route takes him away from the planned charging station, the server has taken into account the current battery level, traffic conditions and ADAS data to confirm he can indeed take this alternate route and reach an

alternate charging station on his current charge, still arriving at his destination on time.

**MONDAY, 6:00 P.M.**

Having successfully closed the business deal, Jeff begins his return home. Halfway home, he pulls over for a quick bite to eat at a favorite restaurant. As he is preparing to get back on the highway, he notices a charging station and decides to pull over and get a fresh charge. While the vehicle is charging, data is being sent back to the server indicating the GPS location of the charging station. Aggregated with probe data from other vehicles, the algorithm determines that this is in fact a public charging station, and it is included on the server for future charging station searches.

**TUESDAY, 9:30 A.M.**

With no assignments this morning, Jeff fires up his laptop and logs onto his account. He sees his current battery level, the amount of energy he used on his last few trips and his overall efficiency rating. Despite a few "roadblocks" the day before, by using dynamic traffic data and ADAS data, along with his excellent driving skills, he gets a 4-Star rating for efficient energy use on his trips!



**Figure 3. Personal webpage for vehicle management, driving rating and trip planning**

## CONNECTED TRAFFIC SERVICES

Traffic jams can be the bane of any driver, and being stuck in stop-and-go traffic is wasteful of time and energy for any type of vehicle. Certainly this will still be true for EVs and PHEVs. The ability to plan routes and times to avoid peak traffic and bypass incidents is important. Also, "range anxiety" is a unique issue for drivers of EVs. There is a "point of no return" beyond which the driver may not make it to a charge point or back home. Although EV drivers may be tempted to operate close to the battery limits, they will not happily accept being stranded. It can be argued that EVs will





**Figure 4. Arterial road traffic modeling enables efficient route calculation**

be more reliant on traffic information than other vehicles, and unique connected EV applications will support cruising range calculations by integrating traffic information and navigation routing more reliably than ever.

Real-time and predictive traffic services are the two main options available for EV/PHEV route planning and traffic avoidance. To produce high quality real-time and predictive traffic information, reliable traffic data sources with sufficient coverage are required, combined with sophisticated models and algorithms to merge the data. The backbone of traffic data acquisition has traditionally been a stationary network of inductive loop, microwave, acoustical and optical sensors (7). However, this model is migrating to a mobile networked traffic solution, and here wireless connectivity is the real key.

Mobile traffic detection began with classic floating cars that transmit observations to a data center, but this is giving way to a networking approach that uses the installed base of GPS-enabled phones to form an ad-hoc traffic data network. The EV/PHEV owner can be both a probe and beneficiary in this traffic monitoring network. The critical number of sensors is in-place to measure travel times, travel speeds and traffic volume, so as the number of EV/PHEVs take to the road, the network infrastructure is already in-place.

In the early market, EVs will likely be driven mostly for urban commutes rather than long distance drives. Therefore, the particular problem of avoiding arterial traffic congestion must be solved in order to make running out of power a virtual impossibility. Specific risk factors include problems associated with city traffic like traffic signal cycles, random temporary bottlenecks, traffic density fluctuations due to major events, turning ratios, demand in the form of time-dependent origin-destination flow, and more. All of this can be known in principle but is very hard to know in practice, at all places and times. Consequently, city traffic is much more unpredictable than freeway traffic and communicating

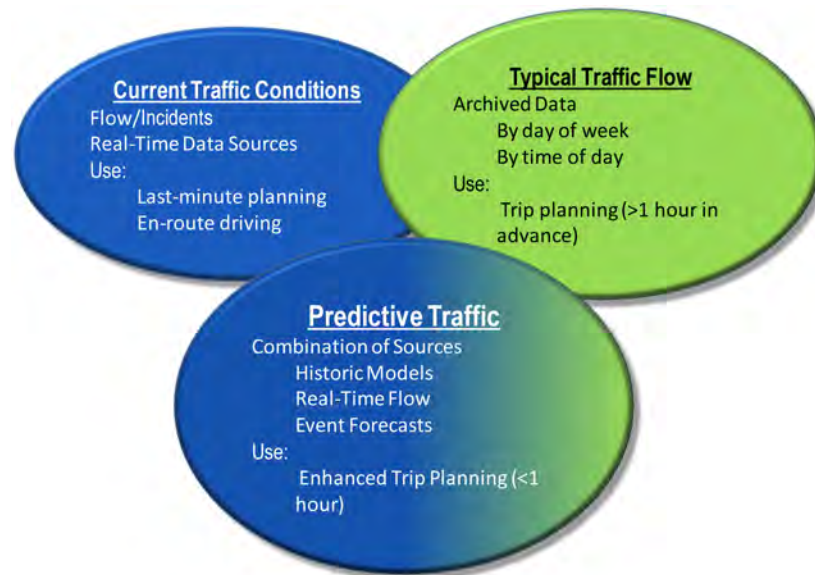
knowledge of current and future traffic dynamics will be very reliant on wireless connectivity.

Still, due to the limitations of traffic prediction, drivers will need to adapt to some degree of uncertainty. Stochastic navigation (an approach to navigation which is based not on average traffic quantities but on their statistical distributions) won't provide them with a sharp distinction between those charging stations that are within reach and those that are not. Instead, it will provide a probability with which a charging station or any other type of destination can be reached, and each individual driver will have to define his or her personal threshold value above which he or she will attempt to go there. The challenge of the integration of traffic and navigation connectivity will be to provide "reach-ability probabilities" that adjust smoothly over time to avoid unpleasant surprises. For longer EV/PHEV commutes, predictive traffic information is at least as relevant as real-time information, so suitably prepared historic traffic information should be communicated as additional forecasting context for longer routes.

Another essential ingredient for traffic predictions is weather and road surface conditions. To correctly estimate travel time and to avoid dangerous driving situations due to heavy rain or snowfall, the existence of slippery road surfaces and hydroplaning conditions en-route will be known and broadcast to the vehicle. Available data sources to generate this information include precipitation radar images for entire countries and ground-based weather stations delivering a variety of temperature measurements (road surface, above/below surface, dew point), humidity, type of precipitation, wind strength and direction, and visibility.

## DIGITAL MAP-ENHANCED ENERGY EFFICIENCY

There are five distinct ways digital map data and wireless connectivity enhance EV/PHEV and driver efficiency - Everyday Navigation, Eco-Routing, Eco-Driving, Predictive



**Figure 5. Current and historic traffic combine to create predictive traffic**

Cruise Control and Predictive Powertrain Control. These applications all demonstrate some kind of efficiency gain - in fact, one study of Hybrid vehicles using map-integrated predictive cruise algorithms demonstrated fuel savings ranging from 5% to 24%, in-part by anticipating and mitigating energy waste from traffic jams, aggressive driving behaviors, excessive starting and stopping cycles and demanding road slopes (8). The digital map can also identify EV/PHEV charging station locations and regenerative charging opportunities along a route.

## INTERACTIVE DRIVER-BASED APPLICATIONS

There are three important map-based applications where an EV/PHEV driver's decisions and behavior can directly affect energy efficiency, and these fall into two general categories - everyday use of a navigation system and the use of advanced map-based applications. The advanced driver-based applications include "Eco-Routing" and "Eco-Driving". While it can be stated that these applications provide benefits to drivers of conventional powertrain-based vehicles, the unique characteristics of EV/PHEVs will influence how these advanced applications are implemented, the relative value of various map attributes included, and the potential combined energy savings achieved.

### A. EVERYDAY NAVIGATION

Before delving into the details of the advanced Eco-Routing or Eco-Driving applications let's briefly look at the value of basic route planning. Although everyday driving in familiar surroundings may not dictate a navigation system in a conventional vehicle, routes that incorporate current traffic or traffic patterns can be very beneficial to EV/PHEVs.

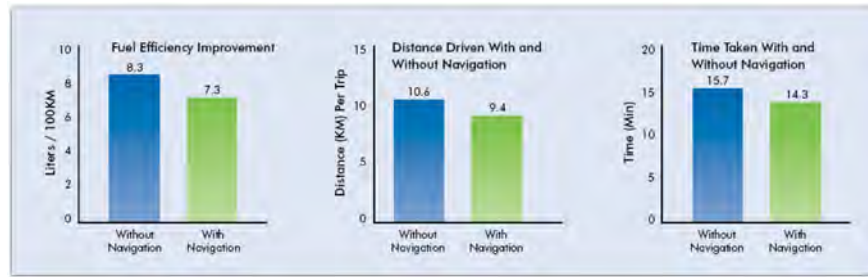
Avoiding a severe delay caused by a traffic incident may be critical to returning home or reaching a charging station.

In 2009 NAVTEQ conducted primary research into the benefits of navigation systems on vehicle energy efficiency. This study was significant in size - involving more than 2,100 individual trips, nearly 12,500 miles of driving, and almost 500 hours of driving time. (9)

While it seems logical that drivers who don't get lost will consume less energy, the trend revealed by the study was far more interesting. There was a clear tendency over time for drivers to organize trips in a way that resulted in fewer miles driven each week and less time spent behind the wheel. One conclusion drawn was that drivers who integrate navigation systems into their routine are more aware of the distances associated with commutes, errands and other trips, and they tend to become naturally more efficient. Additionally, some other unobvious reasons were cited - e.g. knowing in advance where turn maneuvers were located, allowing drivers to coast more and, therefore drive in a more eco-friendly manner. Although this study was conducted on participants driving conventional vehicles it is reasonable to assume that the same phenomenon would occur with drivers of EV/PHEVs, especially given the cruising range challenges of EVs.

### B. ECO-ROUTING

Eco-Routing is the calculation and following of navigable routes that consume the least amount of energy versus the typical minimum-time or minimum-distance options. Essentially, Eco-Routes are those that minimize vehicle energy consumption due to excessive stop-and-go driving and topographic challenges. Eco-Routing applications are planned



**Figure 6. Research demonstrates use of navigation systems encourages efficiency**



**Figure 7. Example of user interface comparing standard vs. eco-route options**

for current production vehicles with conventional powertrains and Hybrids.

Eco-Routing applications are undergoing an evolution where advanced map content is being identified and integrated into these applications in order to optimize route calculation. The applications will need to go through a similar evolution as they are optimized for EV/PHEVs. For example, physical map attributes (such as ADAS Height and ADAS Curvature), legal attributes (such as Traffic Signals, Stop Signs, and Speed Limits), and real-time traffic information using a connected data support system have been identified to be of value in calculating the most energy-efficient route and are being implemented in conventional vehicles today. These same attributes will also be of value for Eco-Routing applications for EV/PHEVs, but there may be differences in the algorithms that calculate the Eco-Route and the relative weighting of the individual attributes used in these algorithms.

These weightings will need to be tuned to take into account the unique characteristics of EV/PHEVs. For example, both conventional and EV/PHEVs will maximize trip efficiency by taking routes that strike the proper balance between minimizing stops caused by traffic controls and traffic conditions while not significantly extending the total distance travelled as a result. However, EV/PHEVs place a greater importance on smoother braking to maximize regenerative effects, and so routes may be calculated to emphasize avoidance of specific situations that cause frequent quick or

hard braking behavior, for example severe road declines and traffic signals.

Until EV charging stations are as commonplace as conventional gasoline stations, routes for EVs that accommodate the need to recharge and ensure calculated routes that integrate charging station locations will be of immense value. One can imagine the additional peace of mind this information will provide to EV owners when planning long drives. Knowing the planned route is the most energy efficient while also identifying when and where recharging should occur will allow EV vehicle owners to hit the road with much greater confidence in completing trips and returning home. Pertinent information regarding charging stations such as the vehicle connector types supported and electrical ratings, along with dynamic information accessible to a connected EV, including electricity prices and current availability of charging bays will also be valuable. Additional listings of services available while charging such as restaurants, shops, and internet access can make the charging time more productive or entertaining.

### C. ECO-DRIVING

Eco-Driving is a driver-in-the-loop application that provides real-time and diagnostic feedback relative to the smoothness of driving. Studies show that most drivers exhibit aggressive driving behavior some of the time, and that this temporary behavior contributes disproportionately to emissions and energy expenditure. (6) Accelerating smoothly combined with smooth braking and opportunistic coasting are the

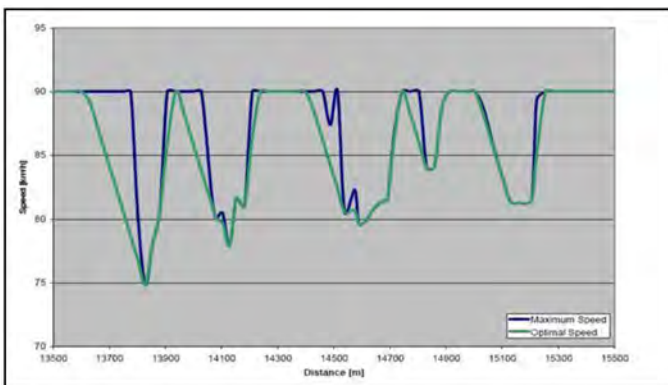


cornerstones of Eco-Driving regardless of the vehicle type. Applications are starting to be offered that provide various cues and feedback to the driver to promote this more fuel efficient driving behavior. However, the unique characteristics of EV/PHEVs will also create subtle differences in the way these applications are implemented when compared with conventional vehicles.

For example, with regenerative braking, smooth braking is even more critical for EV/PHEVs than conventional vehicles in order to maximize the transfer of energy into charging the vehicle's batteries instead of into friction heat. As a result, applications using map data can improve the ability of driver to anticipate upcoming requirements to slow or stop and will encourage smoother braking to maximize the regenerative benefits. Map data such as traffic signals, stop signs, and curve information can be used to cue the driver to come off the accelerator and allow ample stopping distance to brake smoothly.



**Figure 8. Eco Drive Level indicates cumulative smooth driving performance during trip.**



**Figure 9. Smooth acceleration and deceleration leads to energy efficient driving**

## AUTONOMOUS MAP-ENHANCED EFFICIENCY

There are two key applications of digital map data used in autonomous energy efficiency applications - Predictive Cruise Control and Predictive Powertrain Control.

### D. PREDICTIVE CRUISE CONTROL

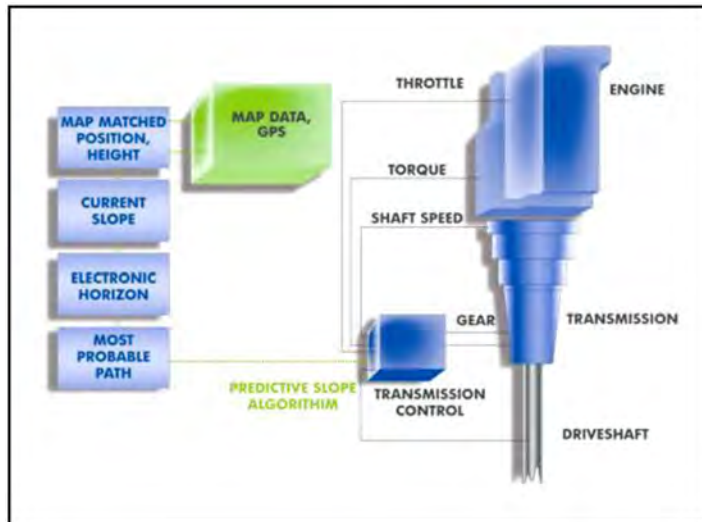
Predictive Cruise Control (PCC) is a speed-based application that will benefit all vehicles including EVs and PHEVs. Standard cruise control maintains the vehicle set speed within a tight tolerance under all terrain conditions (10). PCC however combines expanded upper and lower speed control points with an intelligent speed profile based on assessment of the upcoming road slope. Essentially the vehicle is being used as a “battery” to store kinetic energy gained during downhill sections for use during uphill climbs. Research and trials indicate that PCC can produce a 3-5% improvement in energy efficiency in rolling terrain.



**Figure 10. Road slope data is a key component of Predictive Cruise Control**

### E. PREDICTIVE POWERTRAIN CONTROL

Predictive Powertrain Control involves the use of digital map data, especially height, slope and curvature to add predictive intelligence to automatic transmission shift timing and predictive power mode apportionment for hybrid-electric vehicles. For transmissions, knowledge of road slope and curvature can help engineers optimize gear selection algorithms and avoid poorly timed gear shifts due to terrain-induced torque demands. For hybrid-electric vehicles, anticipation of impending road slope changes will allow more sophisticated gasoline/electric mode control algorithms. Slope data can also be used to identify future regeneration opportunities and safely allow extended depletion of the battery, thereby extending cruising range.



**Figure 11. Intelligent transmission integrates predictive slope information**



**Figure 12. Road slope allows electric and hybrid electric vehicles to anticipate regeneration zones**

## SUMMARY/CONCLUSIONS

It is becoming very apparent that electric and plug-in hybrid electric vehicles will occupy a growing segment of the automobile market as consumers become more eco-aware and these electrified vehicles become more commonplace. Key success factors for this migration will be consumer acceptance of and even excitement over these new propulsion technologies, an overall experience that meets drivers' needs and expectations, and the sense that they are part of a supportive and vibrant driver community. Connectivity in many forms, including home internet, vehicle-to-vehicle, and vehicle-to-infrastructure will enable this community and foster an ecosystem where these unique vehicles will be supported by equally compelling suite of services that enhance the ownership experience.

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## DEFINITIONS/ABBREVIATIONS

### ADAS

Advanced Driver Assistance Systems

### CAN

Controller Area Network

### DSRC

Dedicated Short Range Communications

### EV

Electric Vehicle

### GPS

Global Positioning System

### HEV

Hybrid Electric Vehicle

### MPE

Map and Positioning Engine

### OEM

Original Equipment Manufacturer

### PHEV

Plug-In Hybrid Electric Vehicle