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Predictive Intelligent Battery Management System to Enhance the Performance of Electric Vehicle

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1. Introduction

The Electric Vehicle (EV) is emerging as state-of-the-art technology vehicle addressing the continually pressing energy and environment concerns. The benefits of EV emerge from these vehicles' capability of sustaining their energy demands through electric grid rather than fossil fuel consumption. Well- to-Wheel studies have shown that electric drive (E-drive) offers the highest fuel efficiency and consequently the lowest emission of green house gases. Grid electricity in the United States of America has been shown to be four times cheaper than fuel given gasoline prices at \$3/gallon. Consequently, it is crucial to further optimize the electric-drive mode for EV. Battery capacity should be designed to allow EV drivers reach their destination while avoiding unnecessary stops to recharge their vehicles. However, this additional battery capacity would impact the vehicle's space, weight and cost. In view of these limitations, we propose integrating EVs with the vision of Intelligent Transportation Systems (ITS). This chapter starts out by putting the design of EVs into a broader perspective by proposing a Predictive Intelligent Battery Management System (PIBMS), which will enhance the overall performance of EVs including energy consumption and emissions using the ITS infrastructure.

At the end of this chapter, the reader should have an understanding of the capabilities and limitations of the PIBMS. It lays out the design foundation for the future implementation of an interconnected EV equipped with PIBMS, which further contributes to the optimization of energy efficiency and reduced emissions.

2. EV design challenges

Recent advancement in battery and charging technologies has allowed the Electric Vehicle (EV) to be considered as the new generation of automotive transportation. However, the physical dimensions, packaging environment and charging of EV batteries continues to be the main challenge and the focus of attention in the development of EVs. Battery technology selection continues to be the primary challenge in order to achieve the proper balance in the EV design as illustrated in Figure 1 and described below.

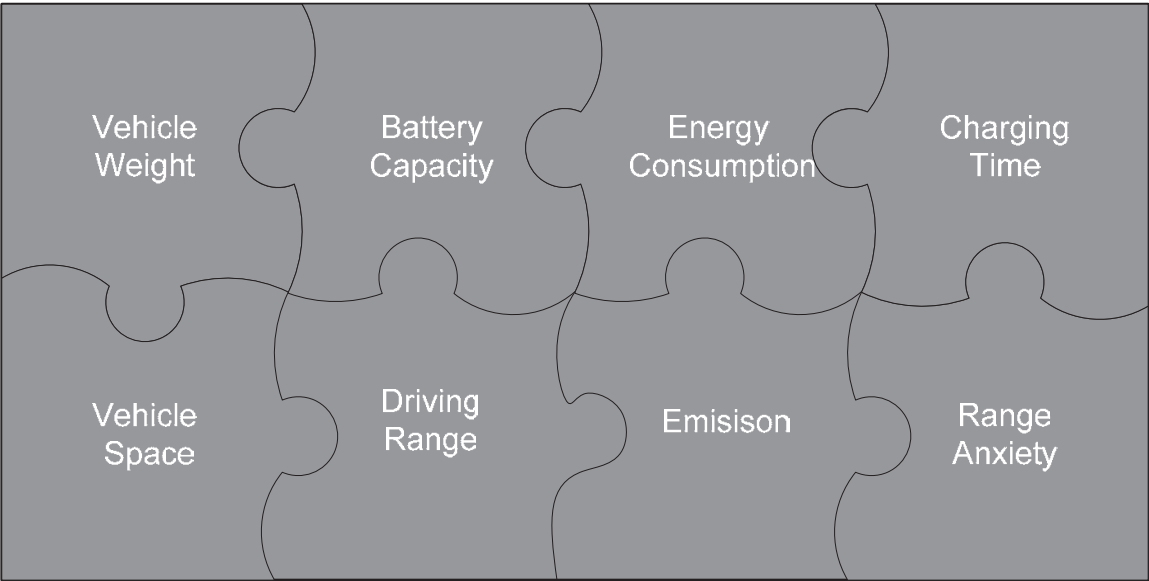


Fig. 1. EV Design Parameters

























- **Battery Capacity:** EV battery capacity is predetermined by the battery design and cell chemistry. Lithium polymer batteries are the target implementation for EV due mainly to their high power-to-weight ratio.
- **Vehicle Weight:** EVs weight increases proportionally to battery capacity increase.
- **Vehicle Space:** Vehicle operators favor personal use of vehicle space. EV requires more packaging space to house the battery in a safe environment. Generally, the battery is packaged in the center of the vehicle where vehicle operators conventionally utilize this space.
- **Driving Range:** EV can only run for 100-200 miles before recharging compared to gasoline vehicle, which can drive more than 300 miles before refueling.
- **Charging time:** EV has no internal source for recharging the battery. EV charging time ranges between 3-8 hours compared to 2-4 minutes of refueling for gasoline vehicle.
- **Range Anxiety:** EV operators are usually concerned with their vehicles’ limited driving range, inadequate charging infrastructure, and long charging time.
- **Energy Consumption:** EV propulsion systems offer around 85% efficiency compared to about 25 % efficiency for Internal Combustion Engines (ICE).
- **Emission:** EV emits no pollutants; however, power plant generating the EV electricity may emit them.

While battery manufacturers are still pursuing further improvement in energy capacity, the navigation technology and rapid advances in wireless communication technology can be used to achieve the vehicle performance balance described as “Target” and presented in Table 1.

Table 1 clearly shows the limitations for utilizing battery capacity as the only design variable for achieving a balanced EV design that is acceptable for EV operators. To realize the success of EVs, achieving the “Target” design option shall be exerted. This call for considering two crucial aspects in addition to battery technology: Traffic information and wireless communication.

The need to identify traffic conditions and the ability to transfer these conditions constitutes the success of optimizing energy consumption and emission reduction in EVs.

Realizing emission reduction in EVs is a crucial step toward emission free vehicles. However, it requires a better understanding of emission free EVs and the ensuing energy sources. These topics are addressed in the following section: EV Emission.

Parameter	Design Options		
	A	B	"Target"
Battery Capacity			
Vehicle Weight			
Vehicle Space			
Driving Range			
Charging Time			
Range Anxiety			
Energy Consumption			
Emission			



 Positive Impact
 Negative Impact

Table 1. EV System Design Option Evaluation

2. EV emission

2.1 Electrical energy source

An accurate assessment of EV emission requires the inclusion of the electrical energy source associated emission with the generation and transmission. Electrical energy is generated from two main sources as illustrated in Figure 2:

- Non-renewable source: Coal, natural gas, nuclear, petroleum
- Renewable source: wind, solar and geothermal

Non-renewable energy produces elevated Greenhouse Gas (GHG) emissions. Coal is leading all other energy sources in terms of GHG emissions.

Renewable energy investment has to some extent been very limited due to the associated high development cost. However government subsidiaries continue to make the renewable energy investment more affordable.

The claim of EV proponents is that this type of vehicle is a Zero Emission Vehicle (ZEV). This claim depends on many factors, but a key factor shall be highlighted. The EV operating energy emission is a function of the energy source. The upstream Greenhouse gases (GHG) emission is based on power plant types and efficiency. The claim of EV technology proponents that this type of propulsion technology will offer a potential to reduce a long-

term GHG emission can be verified with the implementation of the Well-To-Wheel (WTW) emission model to analyze the GHG emission of the electrical energy source.

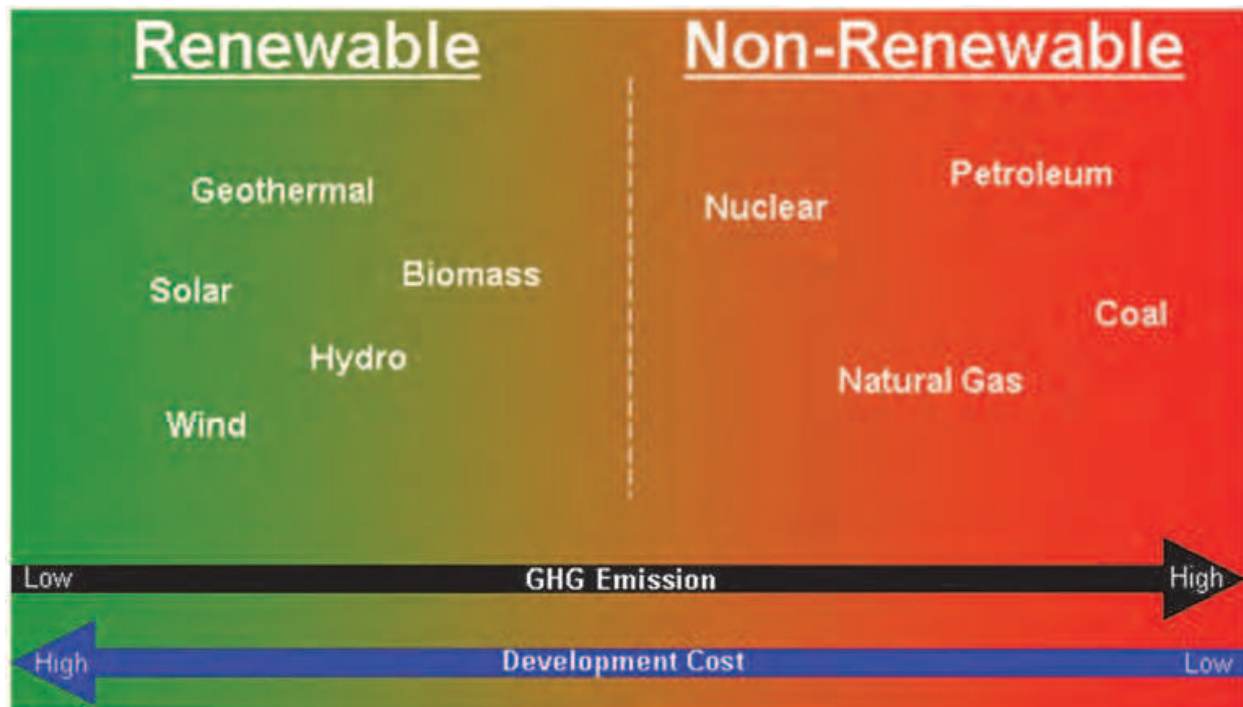


Fig. 2. Electrical Energy Source

2.2 EV configuration

The EV is mainly a conventional vehicle with the following main differences illustrated in Figure 3 and listed below:

1. High voltage electric battery rather than a fuel tank to store and supply the required operational energy
2. Electric motor rather than an internal combustion engine to propel the vehicle
3. Gear box rather than a transmission to couple the power from the electric motor to the drive shaft
4. On Board or Off Board Charger to allow for recharging of the high voltage electric battery
5. Direct current / Alternating current (DC/AC) inverter to convert the DC high voltage battery into AC to drive the E-motor
6. DC/DC converter to convert the DC high voltage battery into DC low voltage battery (Conventionally identified as 12 Volt battery)

2.3 EV efficiency

The EV overall efficiency can be classified in three main categories. The following section describes the categories and their respective components:

2.3.1 Charging efficiency

Automotive charging standards are currently being developed worldwide to allow for DC (Direct Current) charging. In contrast AC/DC (Alternating Current / Direct Current)

charging standards have already been established and are currently being implemented in a number of alternative vehicle technology production models such as the Chevy Volt, EV SMART, Mitsubishi MIEV, Nissan Leaf and Tesla. DC charging enables the vehicle’s high voltage DC battery to be directly charged from the charge station bypassing the vehicles’ on board charger thus further improving charging efficiency and time. DC charging is the target implementation for public charging enabling fast charge. Due to the associated high cost of DC charging infrastructure, AC/DC charging will be the alternative and only solution for residential charging.

The EV charging efficiency is the ratio of energy transferred to the high voltage battery to the energy consumed from the AC source. Charging efficiency is highly dependent on charging power and operating temperature. Figure 4 depicts a typical EV charging efficiency operated at room temperature and utilizing an AC/DC onboard charger with a maximum output power of 3500 W.

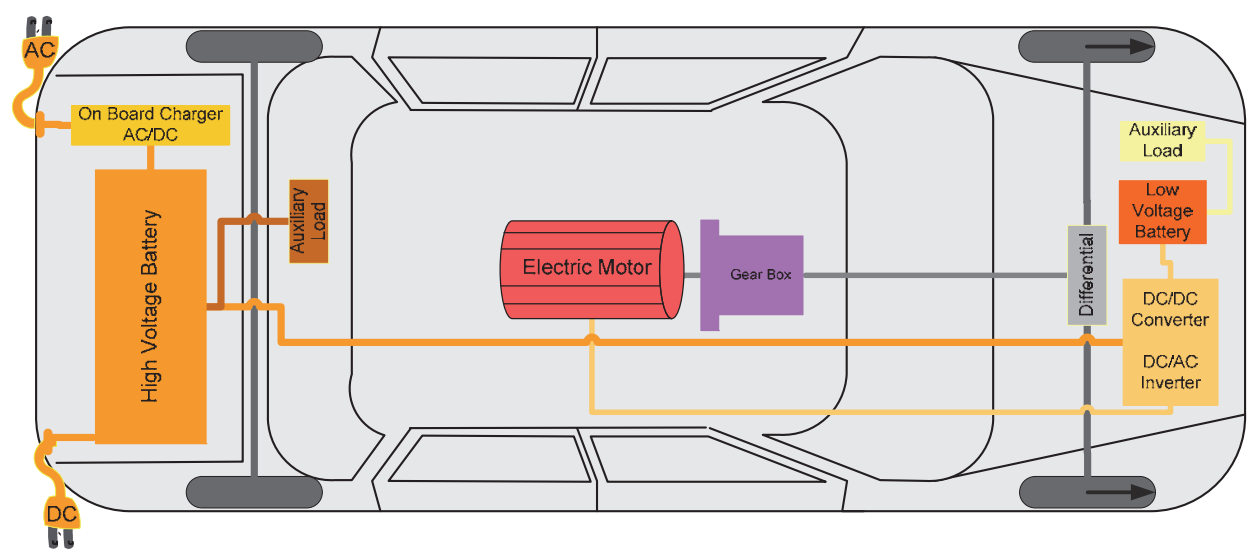


Fig. 3. Electric Vehicle Model

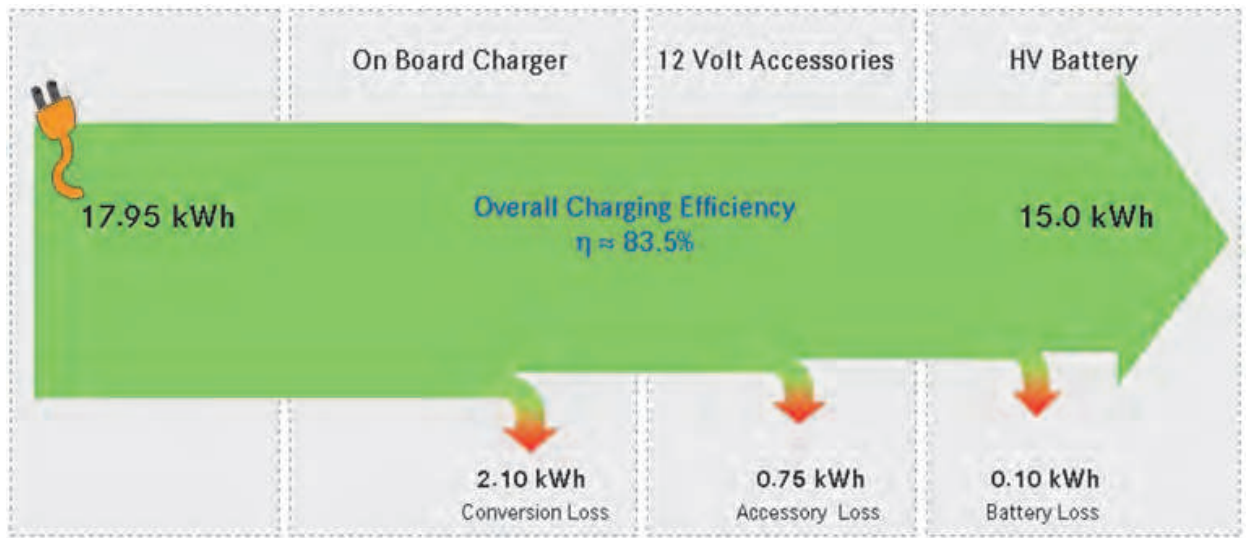


Fig. 4. EV Charging Energy Flow and Efficiency Diagram

2.3.2 Operational efficiency

Generally the efficiency of the EV Electrical Motor (EM) is exceptionally high ~ 85 % compared with an Internal Combustion Engine (ICE) ~ 25 %. Power losses in an EV are negligible, in this section we will focus on power losses from key components occurring in an electrical propulsion system during driving mode due to power conversion, operation and propulsion. As illustrated in Figure 5 approximately 81.3 % of the energy stored in the HV battery is utilized to propel the EV. Combining the EV overall charging efficiency with the EV overall operational efficiency, the EV efficiency becomes ~ 67.9 % around four times more efficient than an ICE propelled vehicle with an overall efficiency of ~ 14 %.

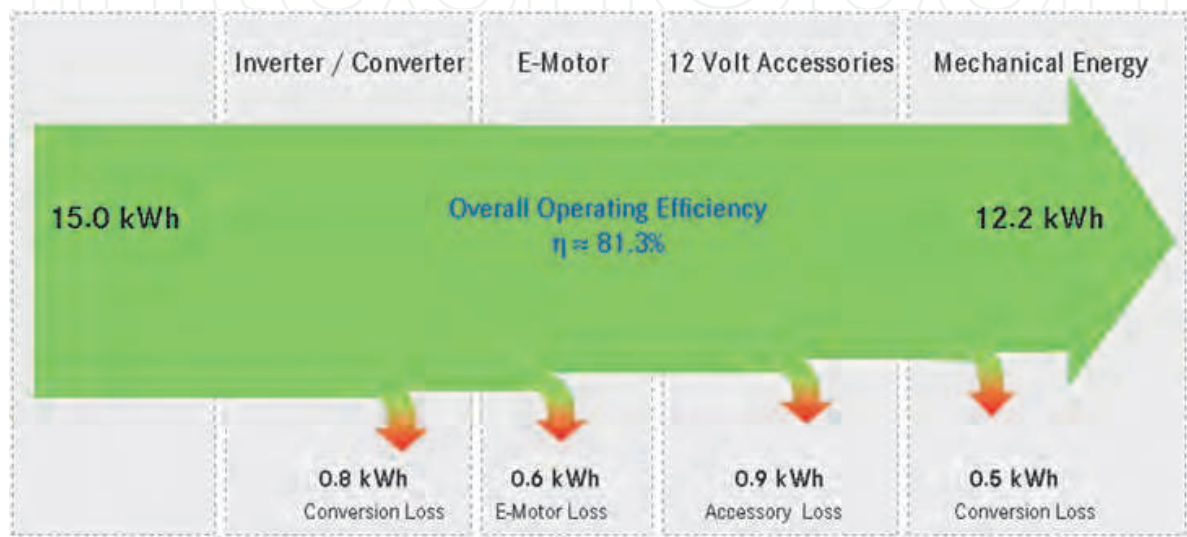


Fig. 5. EV Operating Energy Flow and Efficiency Diagram

2.3.3 Power source generation and transmission efficiency

For a full representation of energy and emission calculation, it is important to consider the efficiency involved in energy recovery, processing and transportation. Complete vehicle energy-cycle analysis tools, commonly known as Well-To-Wheel (WTW) analysis tools are needed to provide an accurate assessment of EV overall efficiency and emission.

The U.S Environmental Protection Agency’s (EPA) offers an emission database “National Emissions Inventory” (NEI); the database includes annual emissions associated with electric energy generation.

To fully evaluate emission impact of EV, a Well-to-Wheel emission model shall be considered such as the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET). GREET was developed by the U.S. Department of Energy (U.S. DOE) to allow researchers to evaluate emissions from a full fuel cycle for EVs and other various propulsion technologies as depicted in Figure 6.

3. PIBMS architecture

Current EV architecture incorporates a Battery Management System (BMS) which is a vehicle integrated electrical module responsible for monitoring State Of Charge (SOC) and maintaining a suitable state of health (SOH) of the EV high voltage battery through controlled charging and discharging processes of the battery cells.



Fig. 6. WTW Emission Modeling

Adding a predictive and an intelligent component to the BMS design can make the architecture of the EV more energy and emission efficient, as it would facilitate acquiring traffic condition; offer a dynamic response to all future stochastic traffic flow situations through travel route and drive profile advisement. The integration of the predictive and intelligent components with the BMS led to the concept of the Predictive Intelligent Battery Management System (PIBMS).

With the rapid advances in wireless communication, global positioning system and the introduction of smartphones, the world is transitioning from being an online connected world to become a mobile connected world. The PIBMS concept will be based on further developing and integrating the existing technologies of the Global Positioning System (GPS), the wireless communication technology “Dedicated Short Range communication” (DSRC), and the advanced computing mobile phones identified as smartphone. The PIBMS receives traffic information from traffic light controllers and roadside units, location data from GPS and charge point data in the vicinity as depicted in Figure 7.

3.1 Intelligent Transportation System (ITS)

The technological progress in wireless communication, Global Positioning System (GPS) and vehicle electronics is enabling the introduction of advanced technologies into the transportation system commonly referred to as the Intelligent Transportation system (ITS).

3.1.1 Dedicated Short Range Communication (DSRC)

Dedicated Short Range Communication (DSRC) defined by the framework of the international standards organization ASTM and standardized by the IEEE 802.11, IEEE P1609.x and SAE J2735 standards, is a two-way short- to medium range (~1000 meters) wireless communication designed for automotive application and currently being systematically deployed throughout the U.S transportation system across the nation and sponsored by the U.S Department of Transportation Research and Innovative Technology Administration (RITA). DSRC enables the attainment of the following vehicle safety critical components for vehicle communication:

- **Fast Network Acquisition:** To allow immediate establishment of communication between vehicles and road side units
- **Low Latency:** To allow least execution time
- **High Reliability:** To allow high level of user reliability

DSRC offers the base and single wireless communication technology for future vehicular safety communications; furthermore DSRC is gaining momentum among researchers for future vehicular applications focused on energy optimization and emission reductions.

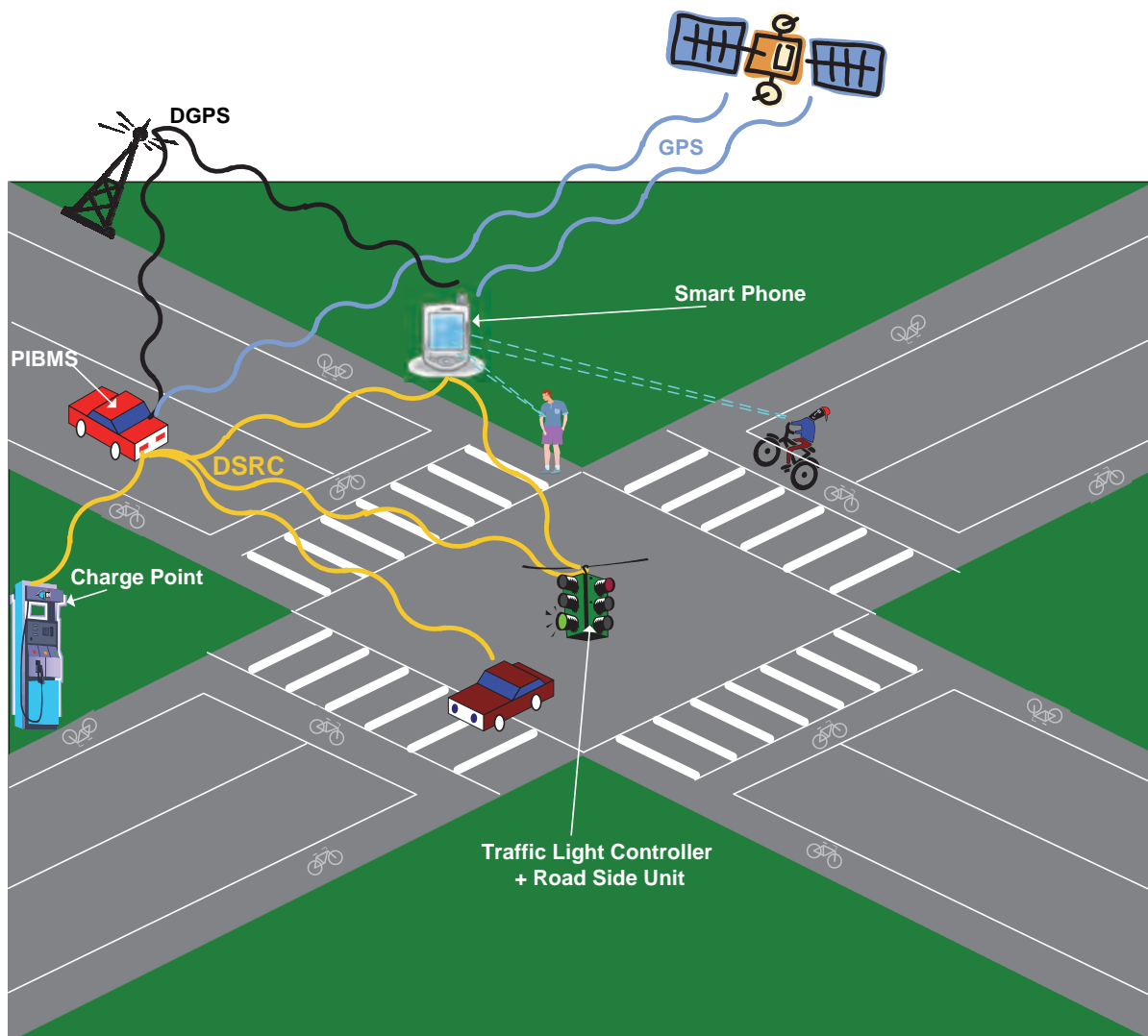


Fig. 7. PIBMS Communication Block Diagram

3.1.2 Positioning system

Real time vehicle position is required with a very high level of accuracy; this would allow the system to optimize the output with both high confidence and reliability.

Several satellite receivers' manufacturers offer systems with an extremely superior accuracy such as the Topcon GR-3 receiver. The Topcon GR-3 is compatible with the US satellite system GPS, the Russian satellite system GLONASS and the European satellite system GALILEO. This receiver system claims a static accuracy of 3mm, a Real-Time Kinetic (RTK) accuracy of 10 mm.

It is important to note than in cases where satellite navigation coverage is not available due to for example driving through tunnels, Differential GPS data shall be used which would offer in this case a slightly reduced accuracy.

3.2 PIBMS design

The PIBMS distinctive features are the predictive and the intelligent:

- The predictive feature of the PIBMS is viable through the capability of the EV to integrate the capability of vehicular wireless communication technology (DSRC) to communicate traffic, charging infrastructure and vehicle data.
 - The intelligent feature is offered through the application of a 2-scale dynamic programming optimization approach onboard the PIBMS operated EV. The proposed PIBMS architecture consists of six modules illustrated in Figure 8 and described below:
1. Traffic Data Extractor (TDE): To extract the future traffic data from the ITS network including traffic flow, intersection light status. This data is consequently used to determine if alternative routes should be considered.
 2. Vehicle Operation Mode (VOM): To provide the vehicle's current operation modes including vehicle speed, gear and SOC.
 3. Trip Model Identifier (TMI): To learn the route road condition including slope and distance, this is accomplished through the use of GPS data.
 4. Trip Model Deflector (TMD): To re-route trip as found necessary following the processing of future traffic data.
 5. State Of Charge Optimizer (SOCO): To optimize battery energy the intelligent algorithm found in this module is expected to have two key criteria: agile and dynamic.
 6. Driver Feedback Control (DFC): To provide the driver feedback relative to drive style including speed, acceleration, and deceleration.

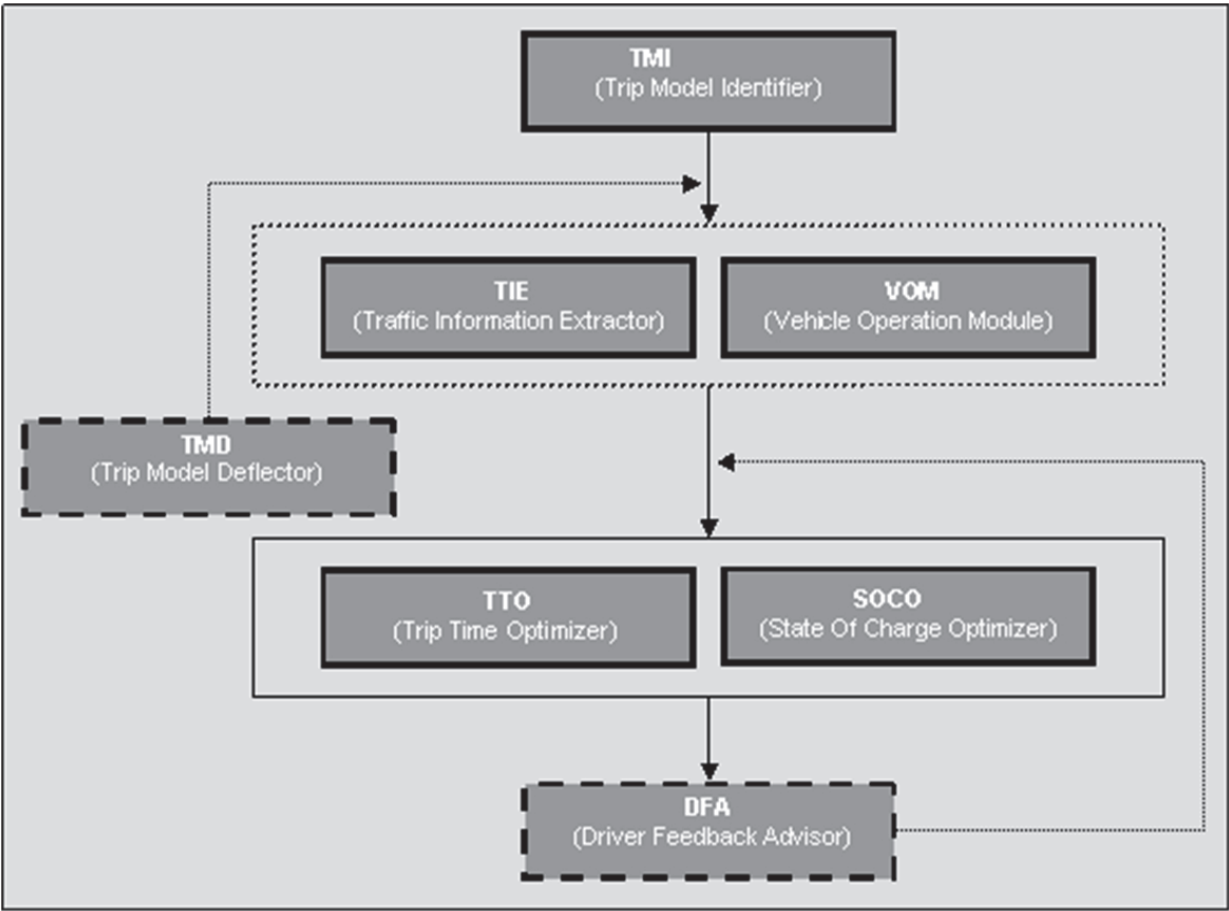


Fig. 8. PIBMS Architecture

3.2.1 Design realization

The system design is to offer the user the ability to follow advised upon route model, trip model and electrical accessory model to optimize the following queries:

- 1. Energy consumption
- 2. Emission
- 3. Travel Time

The system design consists of three phases:

- Phase I uses initial vehicle and route parameters at origin to advise the driver for an initial drive and route profiles based on the historical traffic data.
- Phase II uses the driver input to arrange the cost function to be optimized based on driver selective or combined selection of optimization criteria: energy consumption, vehicle emission and travel time.
- Phase III uses energy, emission and travel time cost function to plan optimized route, drive and accessories profiles.

The PIBMS in combination with the Intelligent Transportation Systems (ITS) data offers the capability of operating the EV amid additional energy optimization and emission reduction. Figure 9 illustrates a block diagram of the Predictive Intelligent Battery Management Sub-Systems and the interfaces to vehicle sub-systems and road infrastructure.

The historical traffic data is utilized for initialization of the system, where vehicle has not yet established a real-time connection with the infrastructure and other vehicle’s communication system.

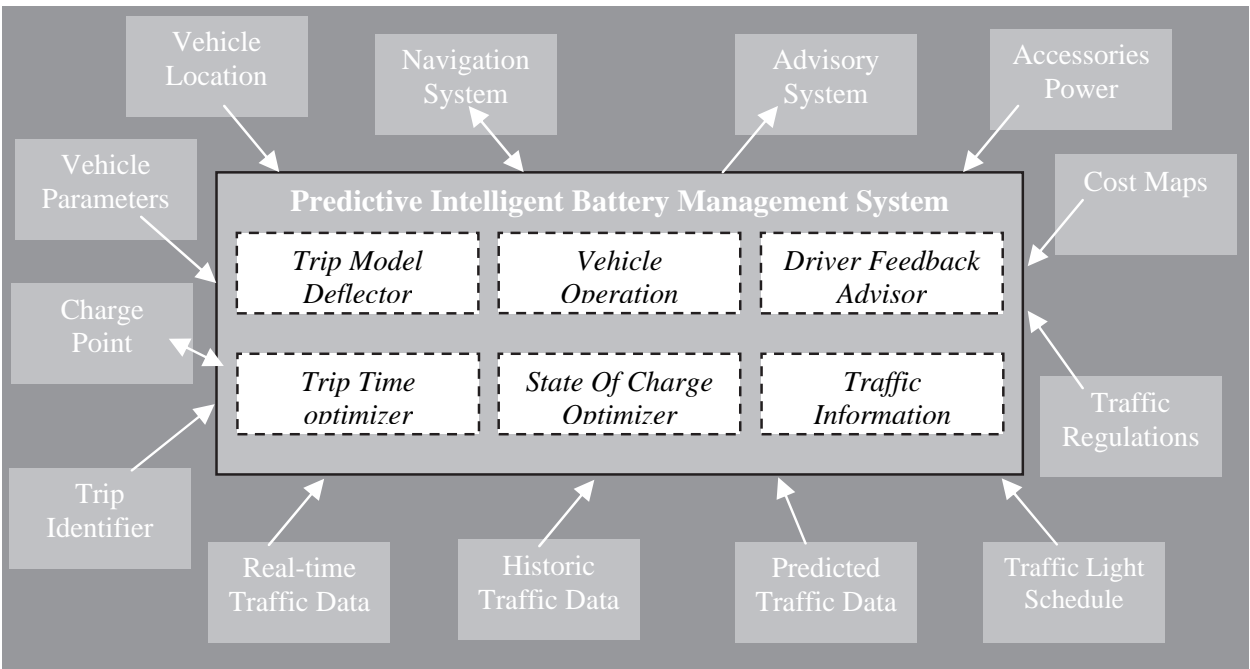


Fig. 9. PIBMS Interface Block Diagram

Referring now to Figure 10, the PIBMS is first initialized with an array of input data including: vehicle position, destination, and the maximum allowed arrival time as set by the driver. The PIBMS in coordination with the navigation system will generate an energy and emission efficient route and drive profile based on historical traffic data. The route will be established in multiple segments. The PIBMS will determine the number of route segments

and assign a maximum constraint in terms of consumed time, energy, and emission to travel those N segments. The PIBMS selects the Kth sequence associated with the expected segment to be traveled next. Through current and predicted traffic data, the PIBMS again in coordination with the navigation system will iteratively seek, compute and compare energy, emission and travel time of the selected segment. If the segment meets or is inferior to original estimated time, emission and energy consumption target costs, driver is advised to maintain driving through the formerly selected segment with its associated driving profile. Lest the originally selected segment does not meet the energy, emission and time constraints, an alternative segment is inquired and projected by the navigation system as an advisory path and drive profile. The navigation system will continuously seek alternative segments; if none are obtained the PIBMS will select the segment with the least calculated cost function. The driver is then advised to follow the recommended segment and driving profile to reduce energy consumption and emissions. In all cases, when driving and route profiles are established, they will be communicated to the Road Side Unit (RSU) to be then utilized as predictive traffic data for other PIBMS equipped vehicles seeking their respective optimized drive and route profiles, in addition to pre-scheduling arrival time to charge point as necessary. It is very critical for EV operators not to be abandoned mid-route where vehicle have no other self propelling means, an alternative route offering re-charge station is recommended to the driver. Provided that final segment has been computed and selected, thus indicating that driver is to commence driving the last segment of the route thus arriving to destination.

3.2.1.1 Phase I: Initialization

At initialization the system calculates a drive and route profiles based on historical traffic data provided by the roadside unit server. The historical traffic data includes current traffic flow conditions for the route profile from origin to destination in addition to charge point locations and energy source emission.

3.2.1.2 Phase II: Optimization

In this phase the route is divided into segments, for each possible path in the segment the travel time, energy consumption and emission are calculated in advance.

3.2.1.2.1 Cost Function

The parameters to be selectively or in combination optimized are travel time $T(i)$ energy $\delta(i)$, and emission $E(i)$, thus the cost function to be minimized can be stated as follow:

$$C = \sum_{i=0}^{j-1} [\alpha.t(i) + \beta.\delta(i) + \omega.E(i)] = \sum_{i=0}^{j-1} TC[x(i), u(i)] \quad (1)$$

where j is the period of the route, α , β and ω are the respective weights for travel time, energy consumption and energy source emission. The PIBMS is to allow the driver to select at initialization the priority of travel time, energy consumption and energy source emission through associating the weights α ; β ; ω , TC is total cost of route as well as energy, emission and time, $x(i)$ is the dynamic state vector of the vehicle such as vehicle speed, energy capacity, motor torque, vehicle route and $u(i)$ is the control vector of the vehicle such as the recommended vehicle speed, the recommended acceleration, the recommended deceleration, the recommended route and the recommended charge point. The optimization problem becomes the search for the control vector $u(i)$.

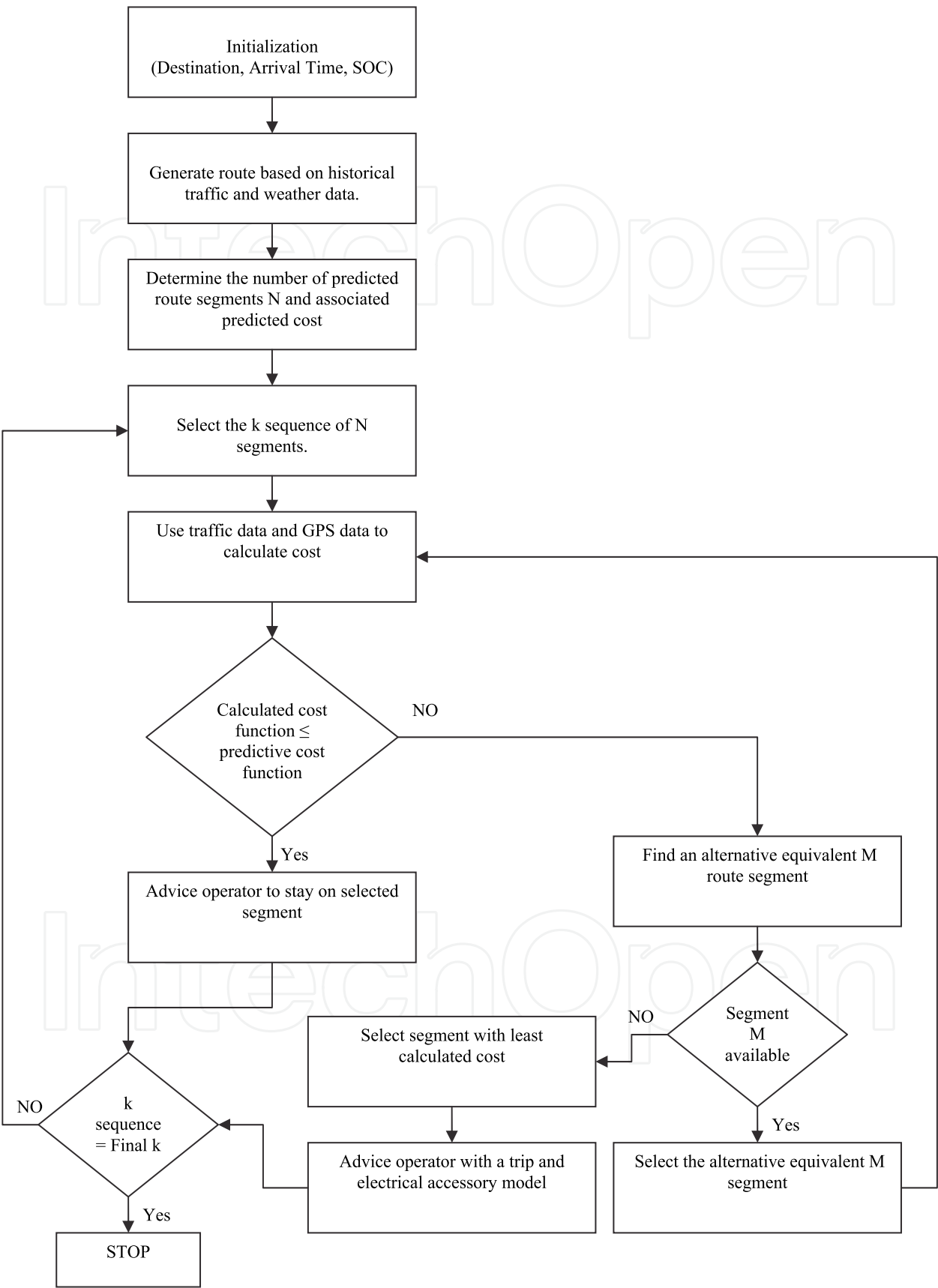


Fig. 10. PIBMS Operational Flow chart Diagram

The cost function will be subject to the targeted EV model thus resulting in the following constraints:

$$\delta_{\min} \leq \delta(i) \leq \delta_{\max} \quad (2a)$$

$$E_{\min} \leq E(i) \leq E_{\max} \quad (2b)$$

$$T_{\min} \leq T(i) \leq T_{\max} \quad (2c)$$

$$V_v(i) = V_{v\text{-req}} \quad (2d)$$

$$\tau_{em}(i) = \tau_{em\text{-req}}(i) \quad (2e)$$

$$V_v(i) \leq V_{v\text{-max}} \quad (2f)$$

$$V_{\min\text{limit}} \leq V(i) \leq V_{\max\text{limit}} \quad (2g)$$

$$\text{Acc}_{v\text{-min}} \leq \text{Acc}_v(i) \leq \text{Acc}_{v\text{-max}} \quad (2h)$$

$$\tau_{em}(i) \leq \tau_{em\text{-max}}(i) \quad (2i)$$

where V_v is vehicle velocity, $V_{v\text{-req}}$ is requested vehicle velocity, $V_{v\text{-max}}$ is vehicle maximum velocity, $V_{\min\text{limit}}$ is minimum speed limit, $V_{\max\text{limit}}$ is maximum speed limit, $\text{Acc}_{v\text{-min}}$ is vehicle minimum acceleration, $\text{Acc}_{v\text{-max}}$ is vehicle maximum acceleration, τ_{em} is electric motor torque and $\tau_{em\text{-req}}$ is electric motor torque requested, $\tau_{em\text{-max}}$ is electric motor torque maximum.

3.2.1.3 Phase III: 2-Scale Predictive Dynamic programming

In this phase a modified 2-scale predictive dynamic programming approach is implemented for obtaining the optimal drive and route solutions. Route is divided into segments, for each possible path in the segment the energy consumption and emission are calculated. The 2-scale predictive dynamic programming approach is implemented based on Bellman's Principle of Optimality; the optimal solution is obtained by identifying the initial and terminal conditions of the state. The optimized solution is then for segment k ($0 < k < i-1$) realized by minimizing the cost function defined as:

$$C_i^*[x(i)] = \min_{u(i)} \{ TC[x(i), u(i)] + [C_{x+1}^*[x(i+1)]] \} \quad (3)$$

The algorithm shows how to plan optimized drive and route profile based on energy, emission and travel time. The PIBMS will generate advisory audible/visual recommendations to the driver, including optimized routes, optimized drive profiles, and optimized electrical load profiles. The optimization algorithms will take into consideration improving traffic safety, congestion, energy consumption, emission and travel time.

The current and predicted traffic conditions are maintained by the RSU. In order to reduce bandwidth utilization for communication between RSU and PIBMS, repeating traffic data will be communicated to PIBMS only in case of traffic condition change thus eliminating message overhead.

4. Simulation environment

To evaluate the performance of the PIBMS a simulation tool integrating traffic, vehicle and network models shall be employed. The simulation platform PIBMST (Predictive Intelligent Battery Management Simulation Tool) consists of three main building blocks described below and illustrated in Figure 11. The traffic, vehicle and network models are to allow for bidirectional coupling among each other, thus resulting in enhanced simulation accuracy however at the cost of increased computation time.

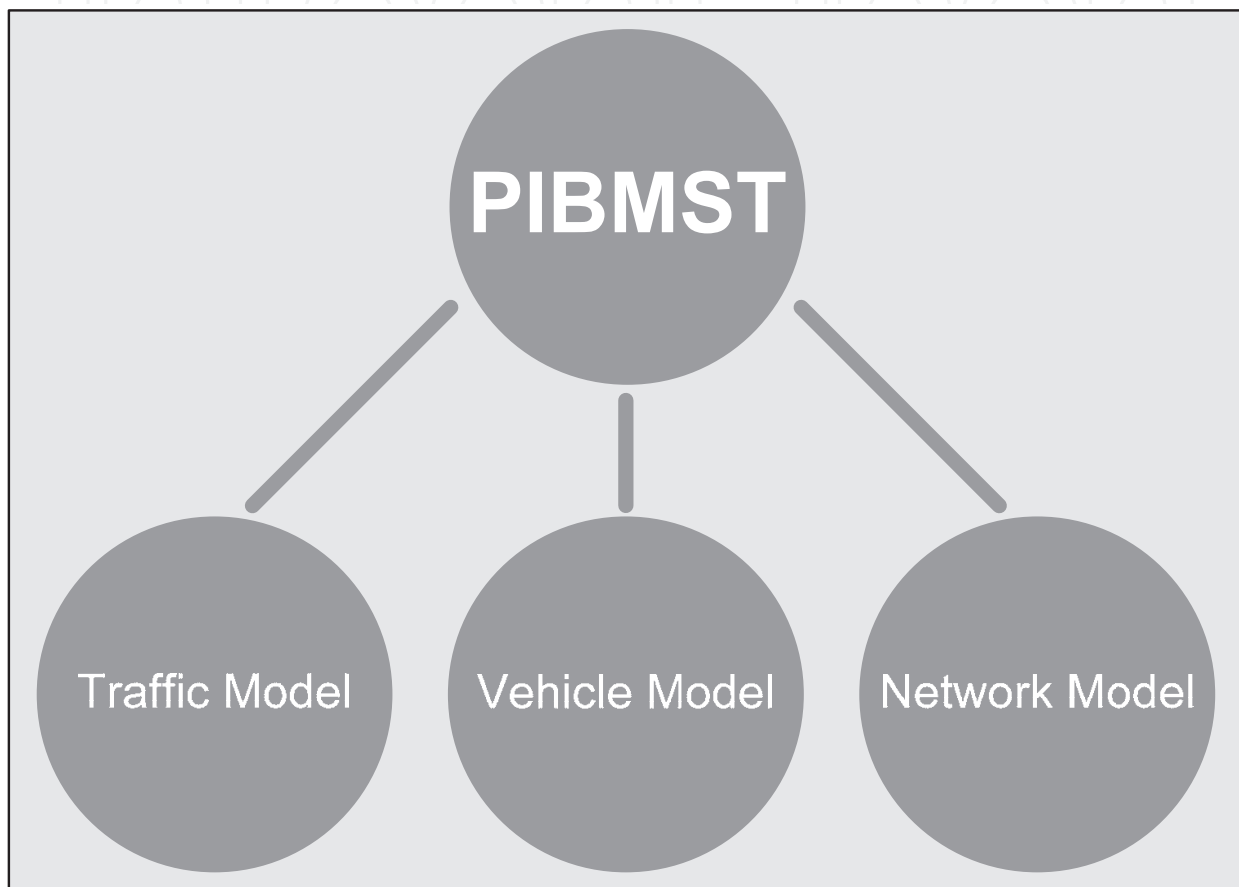


Fig. 11. PIBMST Platform

4.1 Traffic model

A recent study has proven that the traffic mobility model can be represented by trace-based models based on generated vehicular traces. The traces are real world based on mapping the positions of the vehicles. The traffic models are in general classified in two categories:

- Macroscopic: Mathematical model to simulate major traffic characteristics such as average speed, density, and flow.
- Microscopic: In contrast to the macroscopic mathematical model, the microscopic model is to simulate single vehicle traffic characteristics.

Traffic flow is a dynamic problem, influenced by several variables thus for any beneficial performance of the trip model the microscopic traffic model is implemented in PIBMST.

4.2 Vehicle model

The EV model represents a series of mathematical equations representing the characteristics of the identified EV components in Figure 3 and the forces applied to the vehicle as depicted in Figure 12

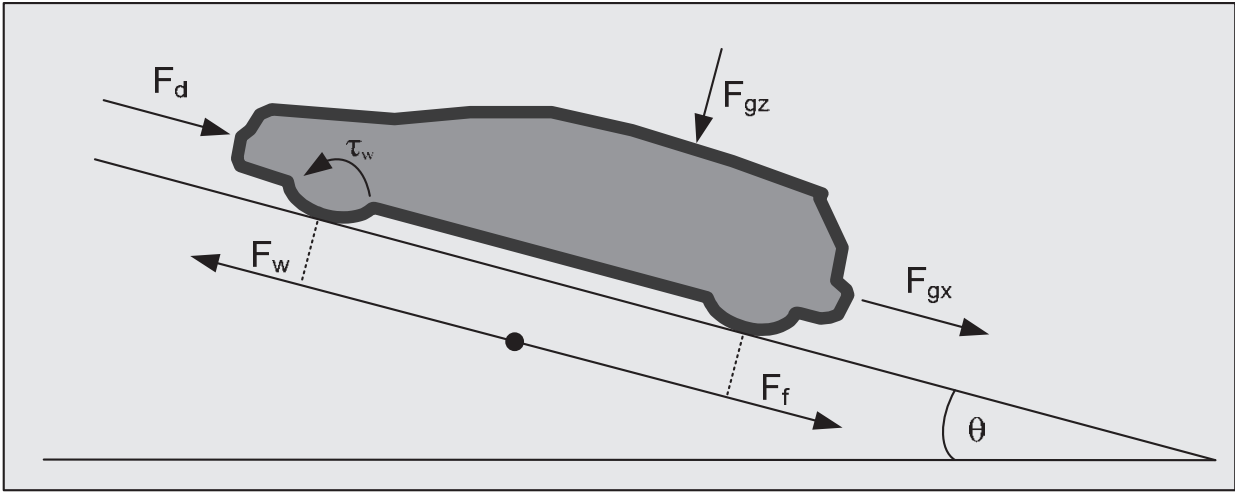


Fig. 12. Applied Forces to the EV

The earth’s gravitational force imposes a force F_g on the vehicle. F_g is derived from Newton’s second law where a body of mass m endure an acceleration a resulting in an applied net force F .

$$F = mg \tag{4}$$

The gravitational normal force applied to the vehicle shall take into consideration the slope angle θ , when vehicle is moving uphill or downhill.

$$F_{gz} = mg\cos\theta \tag{4.1}$$

$$F_{gx} = mg\sin\theta \tag{4.2}$$

In order to move the vehicle a wheel force F_w is applied on the wheel. F_w is the resulting force from the generated torque in the electric motor applied to the vehicle’s wheels through a gear box with a fixed differential ratio. F_w is then represented as the ratio of the torque applied to the wheel τ_w to the wheel radius, r_w .

$$F_w = \frac{\tau_w}{r_w} \tag{4.3}$$

When vehicle is moving the aerodynamic drag force F_d is created. F_d depends on the air density ρ , the vehicle frontal area A_v , the drag coefficient C_d , and the vehicle velocity V_v .

$$F_d = \frac{1}{2}C_d\rho V_v^2 A_v \tag{4.4}$$

The contact surfaces between the vehicle's wheels and the road results into a friction force F_f . The product of the friction coefficient μ_f and the vehicle's gravitational force F_g results in the corresponding frictional force F_f .

$$F_f = \mu_f F_{gz} \quad (4.5)$$

The total force acting on the vehicle F_t is the sum of all applied forces on the vehicle in the driving direction.

$$F_t = F_w - F_{gx} - F_d - F_f \quad (4.6)$$

The acceleration of the vehicle is determined by the torque applied to the wheels. The wheel torque τ_w is the product of the E-motor torque τ_{em} the gear box ratio G_b

$$\tau_w = \tau_{em} G_b \quad (4.7)$$

The acceleration of the vehicle a_v through the application of Newton's second law is the ratio of the total force acting on the vehicle to the mass of the vehicle

$$\begin{aligned} F_t &= \frac{F_w - F_{gx} - F_d - F_f}{m} \\ &= \frac{\tau_w}{r_w m} - g \sin \theta - \frac{1}{2m} C_d \rho V_v^2 A_v - \mu_f g \cos \phi \\ &= \frac{\tau_{em} G_b G_i}{r_w m} - g \sin \theta - \frac{1}{2m} C_d \rho V_v^2 A_v - \mu_f g \cos \phi \end{aligned} \quad (4.8)$$

The angular velocity of the E-motor ω_{em} is the angular velocity in rotation per minute (RPM) multiplied by the E-motor turnover rate 2π and divided by 60 (to transform RPM into revolution per second)

$$\omega_w = \frac{2\pi \omega_{em}}{60 G_b} \quad (4.9)$$

The vehicle speed is the product of the wheel radius and the angular velocity of the wheel. rotation per minute (RPM) multiplied by the E-motor turnover rate 2π and divided by 60

$$Vv = r_w \omega_w = \frac{r_w 2\pi \omega_{em}}{60 G_b} \quad (4.10)$$

4.2.1 Emission model

The emission model considers the emission associated with the generation and transportation of electricity in addition to the operation of the EV as illustrated in Figure 13. The EV emission model is to be based on governmental accredited agencies such as the U.S. Environmental Protection Agency's (EPA's) electric power plant emission database. The EV emission is the product of consumed electrical energy in Kilo Watt hour (KWh) and the associated emission of the electrical energy source and transmission to the EV in grams (g) per KWh according to EPA. The results are presented in g/KWh of VOC, CO, CO₂, NO_x, PM₁₀ and SO_x.

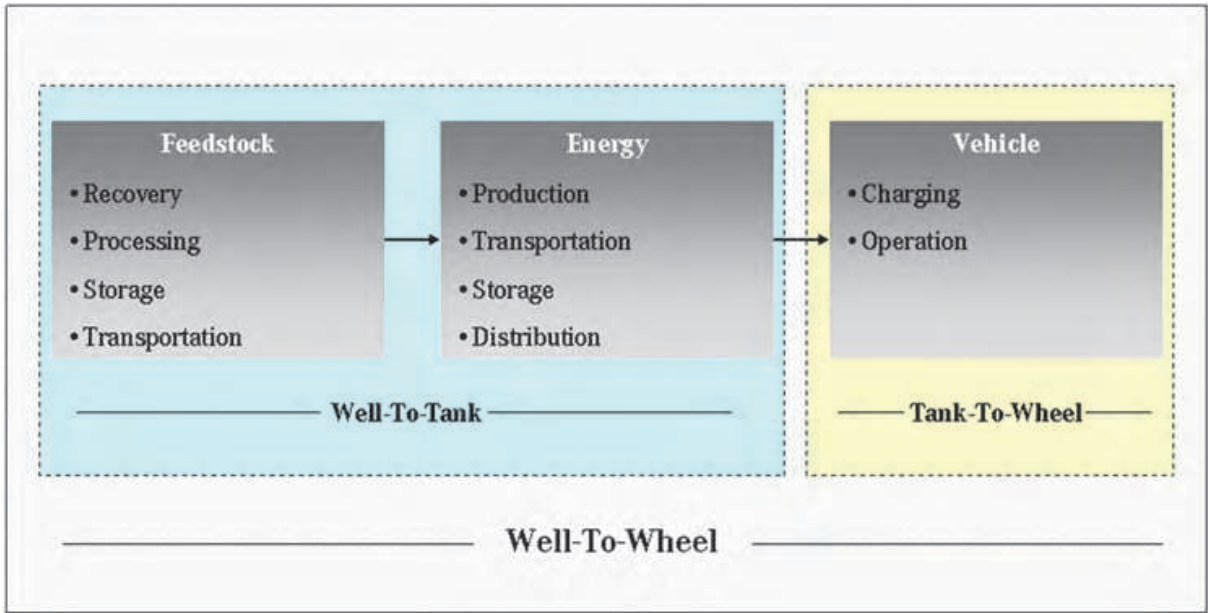


Fig. 13. Well-To-Wheel Emission Analysis Model

4.3 Network model

The roadway includes dynamic nodes such as vehicles, cyclists and pedestrians, and the static nodes such as Road Side Unit, Traffic Light Controller and Charge Point. The simulation of the nodes will require the implementation of a Vehicular ad-hoc network (VANET) capable of simulating the behaviour of the DSRC network. The network data model simulation is a discrete event simulator, implementing the protocol stack Wireless Access in Vehicular Environments (WAVE)/ Dedicated Short Range Communication (DSRC) as illustrated in Figure 14.

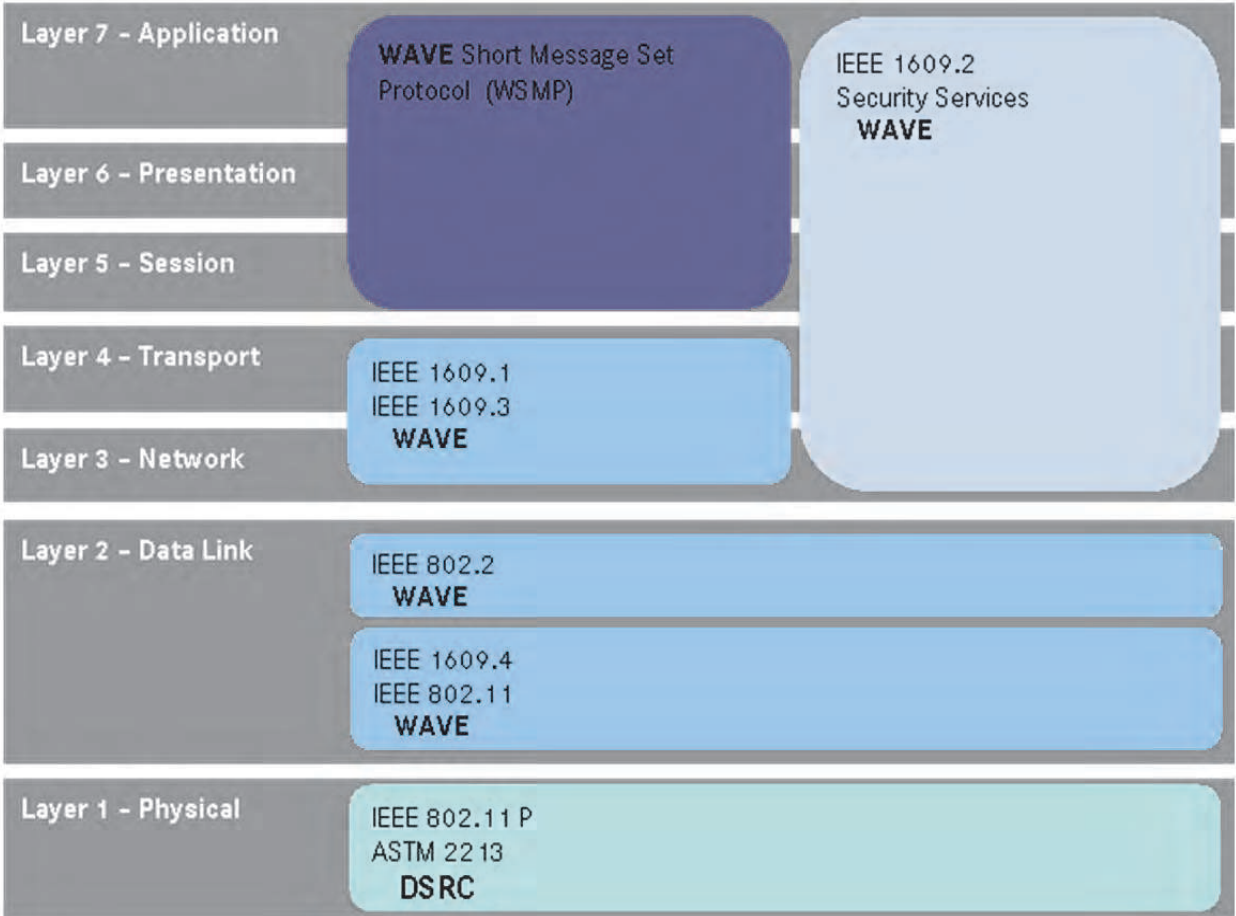


Fig. 14. Protocol Stack

5. Conclusion

Due to the single propulsion system design in the EV, the latter offers the consumers a greater reliability, simplicity of maintenance and vehicle cost compared to Plug-In Hybrid Electric Vehicle (PHEV). Further more compared with the Fuel Cell Vehicle (FCV) the EV is more advantageous relative to vehicle cost, recharging infrastructure and safety.

The automotive industry is being reshaped with the development of the EV. The new generation of automobiles are demanded to meet the market's conventional demands from vehicle space, driving range and convenience; furthermore new requirements have been shaped by the market to include energy consumption and environmental impact.

The EV will lead the way among the alternative vehicle technologies to target energy consumption and emission reduction.

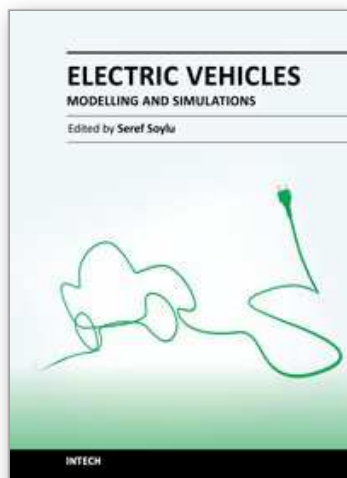
This chapter offered the conceptual framework for the PIBMS application using DSRC and GPS technologies to offer EV operators an enhanced energy efficiency and decreased emission. Furthermore the proposed framework is designed to target near future implementation for relatively negligible cost using existing equipments and technologies.

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