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## **GREEN TRANSPORTATION CORRIDOR**

## **RAMALLAH – JERUSALEM – BETHLEHEM**

## **HYBRID BUS RAPID TRANSIT**

### **Proposal for Preliminary Design**

Submitted to  
Dr. Salam Fayyad - Prime Minister of Palestinian Authority  
and to  
Mr. Haim Ramon – Vice-Prime Minister of Israel  
and to  
Peres Center for Peace

By  
Prof. Arie Lavie – CTI – Creative Technologies Israel  
and  
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## 1. INTRODUCTION

Different Transportation Authorities will be introducing new hybrid electric buses to various routes and “green traffic corridors” for Bus Rapid Transit in USA, in UK, in Europe and in Jerusalem. Such purchases are being considered because of the need to defend environment and to conserve diesel fuel, because the hybrids produce significantly less air pollution and because these buses offer savings in energy and in maintenance costs.

The authors of the proposal suggest to preliminary design and simulate a new “Green Traffic Corridor” for Bus Rapid Transit along RAMALLAH – JERUSALEM – BETHLEHEM as first step towards launching the whole project as suggested in paragraph 8.

In order to choose an optimal bus for operations in the proposed corridor, at least one such vehicle should be purchased and tested. However, there are many hybrid buses available on the market these days. As a consequence design and simulation seems to make sense in order to assist in the selection process. The design and the simulation should be based on validated code and compare well with tested vehicles. It should permit a variety of duty cycles to be employed so that various operations can be compared for these buses. This will permit the best use of funds for the potential long term replacement of most of the buses within Israel and Palestine.

The purpose of this proposal is to suggest the preliminary design of the proposed corridor and simulation software to be used, the simulations to be undertaken and the outputs that might be expected. It should be emphasized that the team proposed for this effort plans to work closely with the Israel-Palestine Transportation Authorities to be sure that needs are met.

The remainder of this proposal is outlined as follows:

- # In section 2 we propose the map of the Green Transportation Corridor; in section 3 we propose the concept of the guided hybrid bus stop station; and in section 4 and 5 we propose the hybrid buses to be simulated.
- # In Section 6 we discuss the buses to be selected for simulation, the suggested software to be used and the rationale for its use, as well as the potential outputs.
- # Section 7 provides a discussion of the various deliverables for this work.
- # In Section 8 a budget and schedule are provided.

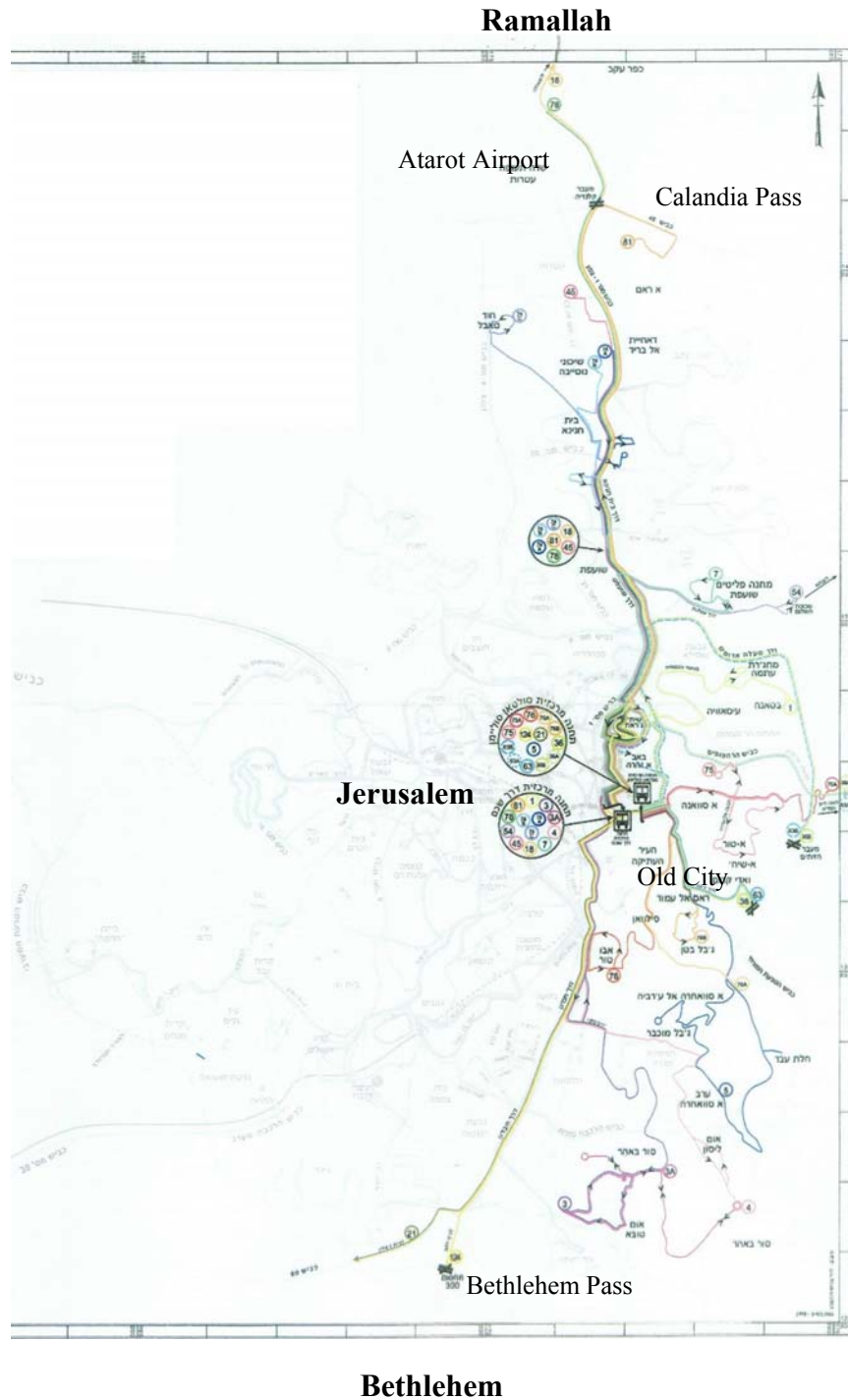
Finally it should be noted here that the project team has already presented similar simulations to some transit authorities some years ago and is conducting today simulation of hybrid bus transit for the Jerusalem Transportation Master Plan. These simulations allowed an initial evaluation of hybrids in a typical Ramallah – Jerusalem – Bethlehem duty cycle. The project team will consider to work in cooperation with a Palestinian University, possibly with Al-Quds University. The required budget for preliminary designing and simulation of the “Green Transportation Corridor” is \$600,000



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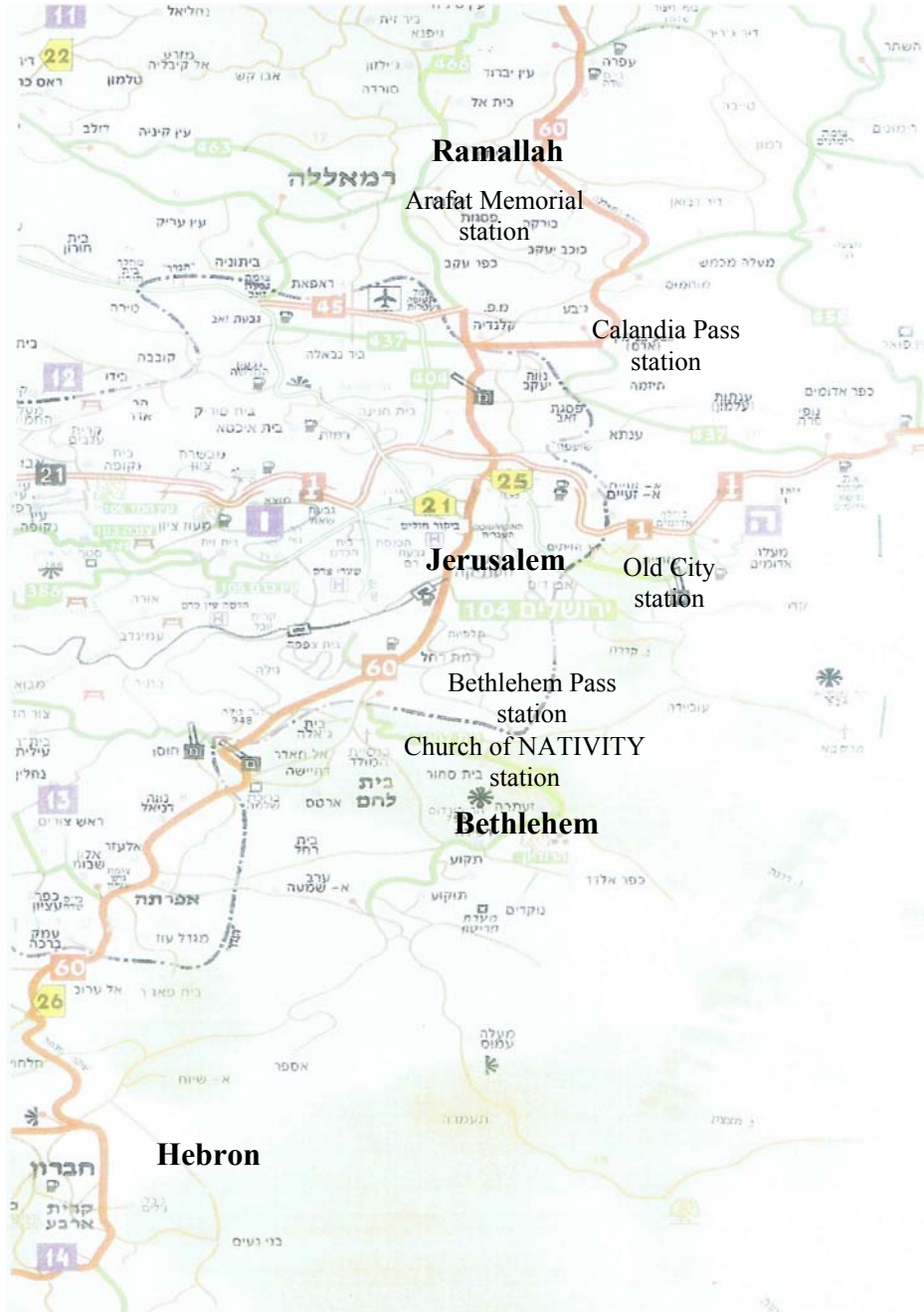
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## 2. MAP OF GREEN TRANSPORTATION CORRIDOR



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MAP (A) OF GREEN TRANSPORTSATION CORRIDOR

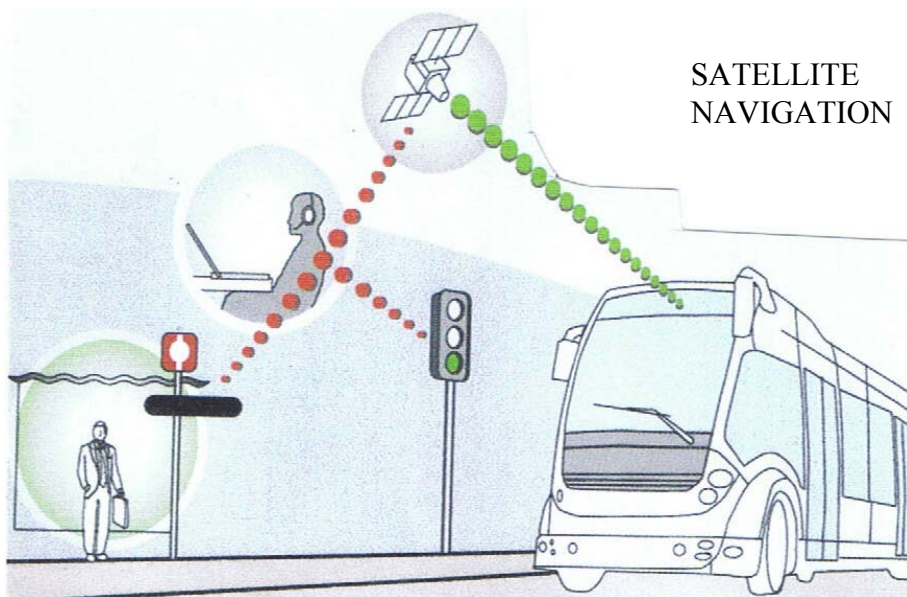




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### 3. GUIDED HYBRID BUS STOP STATIONS

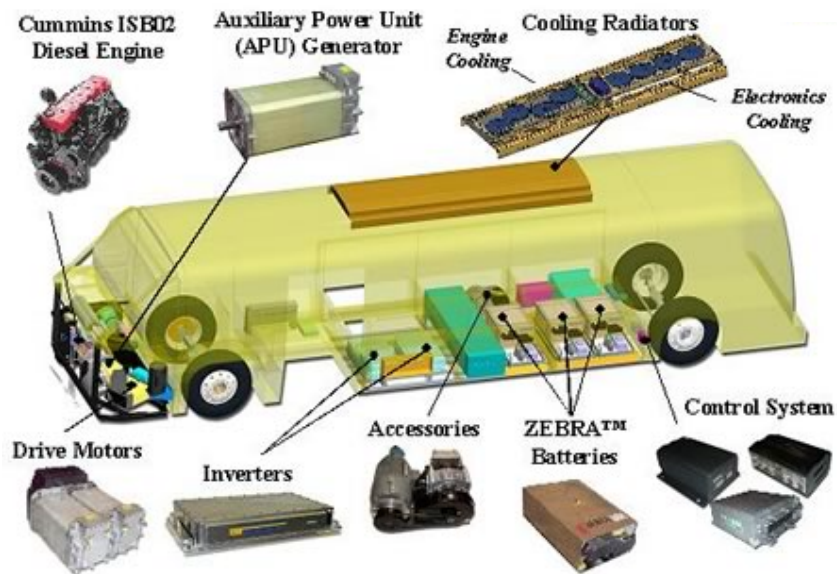


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## 4. UK “STREETCAR” HYBRID BUS FOR RAPID TRANSIT



### SIEMENS Diesel Hybrid-Electric Drive System

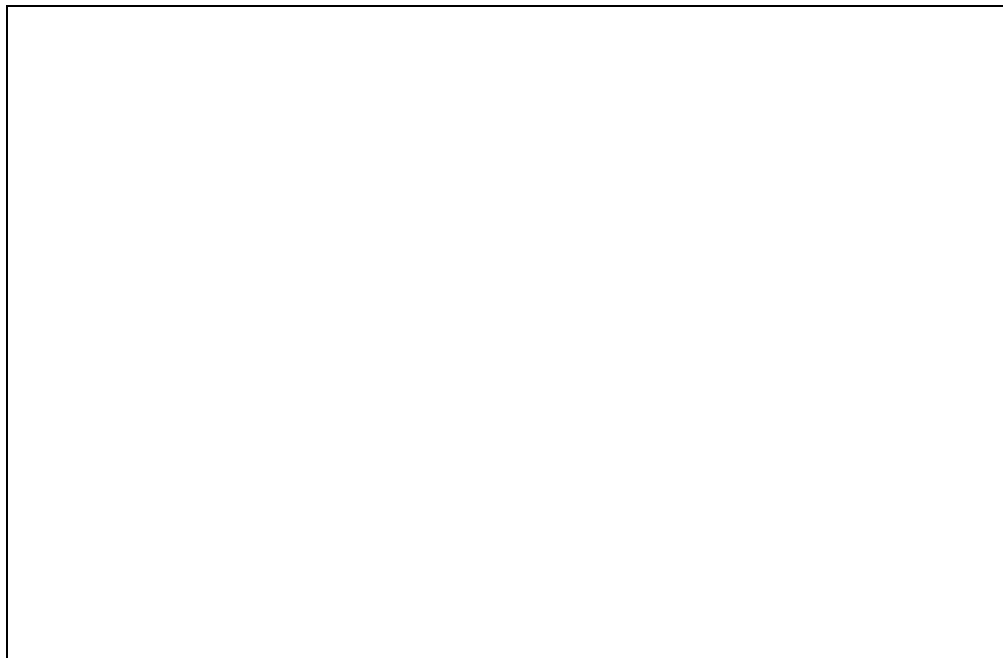




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## 5. US “NEW FLYER” HYBRID BUS FOR RAPID TRANSIT



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## 6. PROJECT DETAILS

In this section we address the vehicles to be simulated, the simulation software to be used, and the outputs to be derived. This will offer a scope of work to be delivered to the Israel Ministry of Transportation.

### 2.1 Vehicles chosen for simulation

We have selected four possible hybrid electric buses for simulation in this project. These are all 60 ft, articulated vehicles:

- # NABI 60 LFW (diesel)
- # New Flyer DE60LF (hybrid)
- # New Flyer DE60LF-BRT (hybrid)
- # Wrightbus StreetCar RTV (hybrid)

This first was chosen so that a comparison of results with straight diesel could be obtained. The others were selected as typical of those available for purchase and use in Israel. We will work with staff at the Ministry of Transportation to be sure that these are the optimal choices; others can be substituted if need be.

### 2.2 Simulation software

Over the years, two software packages have been developed and tested to be used in the sorts of simulations to be undertaken in the current work. The first, called ADVISOR, was one which the proposed team used several years ago in our original simulations for hybrid vehicles in Israel. While this package is still available, a better and more useful one has been developed in parallel and subjected to better and more accurate validation. This software, PSAT (Powertrain System Analysis Toolkit) is one chosen for this project.

It is perhaps worthwhile to look at some of the characteristics of this package here. Because of time and cost constraints, designers cannot build and test each of the many possible powertrain configurations for advanced vehicles. Thus, developing fuel cell and hybrid electric vehicles (HEVs) requires accurate, flexible simulation tools. Argonne National Laboratory of the United States Department of Energy (USDOE) undertook a collaborative effort to develop the Powertrain System Analysis Toolkit © (PSAT) under the direction of and with contributions from Ford, General Motors, and DaimlerChrysler. PSAT is sponsored by USDOE.

After a thorough assessment, DOE selected PSAT as its primary vehicle simulation tool to



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support FreedomCAR and Fuels Partnership activities. PSAT has been used for numerous studies to assist DOE in identifying future research directions regarding HEVs as well as Plug-in HEVs. In addition, PSAT received an R&D 100 Award in 2004, ranking it among the 100 best newly available products and technologies from around the world. PSAT is currently used by more than 300 researchers worldwide in more than 60 companies and universities.

PSAT is a "forward-looking" model that simulates fuel economy and performance in a realistic manner, taking into account transient behavior and control system characteristics. It can simulate an unrivaled number of predefined configurations (conventional, electric, fuel cell, series hybrid, parallel hybrid, and power split hybrid). Because of its forward architecture, PSAT component interactions are "real world."

Because of its accurate dynamic component models, PSAT can be implemented directly and tested at the bench scale or in a vehicle (using its extension for prototyping, PSAT-PRO). This ability supports an ambitious development goal for PSAT — to be transportable from the virtual world of component modeling and simulation to the emulated environment of component control in hardware-in-the-loop (HIL) testing in PSAT-PRO and then to the physical environment of full powertrain control in a vehicle in Argonne's Advanced Powertrain Test Facility.

This capability, when combined with the engineering, development, and testing resources at Argonne, substantially enhances DOE's ability to assess the potential of advanced automotive technologies and streamline the development process for promising technologies. Moreover, PSAT has provided significant benefits to industry vehicle designers and university researchers as evidenced by their growing use of PSAT for both production-oriented and research design activities.

#### Key Features

- Forward-looking model
- Written in MATLAB, Simulink, and StateFlow to ensure modularity and flexibility
- Wide range of vehicle applications including light- (two- and four-wheel-drive), medium-, and heavy-duty vehicles
- User-friendly graphical user interface written in C#
- Complete Simulink models and data sets provided
- Multiple-option component model libraries
- Designed for co-simulation environments

Prototyping HEV Components and Control Systems with PSAT-PRO Argonne contributes to technical target setting and evaluates new technologies in a vehicle systems context for a joint U.S. Department of Energy/auto industry program in hybrid electric vehicle (HEV) technology.

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In this initiative, Argonne researchers have developed PSAT-PRO, a control code based on the PSAT (Powertrain System Analysis Toolkit) model, to support component control in the Advanced Powertrain Test Facility and produce Hardware-in-the-Loop (HIL) testing. This is a technique for performing system-level tests in a quick and cost-effective manner. PSAT-PRO was designed to control any kind of hybrid powertrain systems or subsystems.

The PSAT-PRO software is integrally linked to the PSAT software, but it is still generic enough to go from modeling to prototyping for any kind of hybrid configuration. PSAT-PRO uses control strategies developed in PSAT to control prototypes in real time. PSAT-PRO can also calibrate component models.

The test methodology is based on analyzing differences between simulation results and test data. Because the toolkit is truly integrated, researchers can go back into the PSAT simulation and modify the model until the simulation results match test data. This ability would seem particularly useful in the forthcoming hybrid bus environment in Israel.

PSAT-PRO is being applied to all HIL activities at Argonne. It uses a real-time computer to directly control the components of a powertrain. PSAT-PRO also has the ability to emulate parts of the components using computer models. For example, in a previous experiment, PSAT-PRO controlled a dynamometer to simulate vehicle behavior. In this way, researchers can test a single component of a hybrid powertrain under the same configuration and conditions as if it were in a vehicle.

PSAT-PRO can be used in the following ways:

- *Real-Time Simulation.* The vehicle system controller and the HEV model are downloaded on two different electronic boards that communicate together. In this way, the vehicle model reacts in real time, exactly like an actual system. This phase can be very useful in tuning the controller.
- *Hardware in the Loop.* Researchers can test a hybrid powertrain component-by-component in the vehicle configuration by simulating the rest of the vehicle with the dynamometer.
- *Rapid Prototyping.* Researchers can integrate the system control model into the vehicle control unit. Thus, they can perform a test, analyze the results, adjust the model, and perform the same test again. The control model can be fine-tuned by taking into account results that can be provided only by test data. For instance, researchers can optimize a HEV control strategy to reduce vehicle emissions.

Previously, PSAT-PRO controlled a pre-transmission parallel HEV prototype powertrain with a continuously variable transmission and a compression-ignition, direct-injection engine. Using PSAT-PRO, researchers controlled this HEV powertrain on a test stand by emulating vehicle and



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battery behavior. The analysis identified hybridization emissions benefits and showed a trade-off between fuel economy and nitrogen oxide emissions. The results demonstrated and quantified the impact of control strategy on fuel consumption and emissions for diesel hybrid vehicles.

Argonne staff also used the PSAT-PRO control system to perform HIL testing with a series HEV using four motor-wheels. The goal was to control and optimize a variable-gap motor in an HEV application. PSAT-PRO allowed the staff to perform HIL control by interfacing the simulated vehicle and the motor/dynamometer test cell. The measured torque of the motor was used to propel the simulated vehicle model. The dynamometer speed was controlled to replicate realistic motor speed calculated with the simulated vehicle. The controlled powertrain system was actually made of both a real motor and a simulated vehicle. Therefore, the motor was being tested at a vehicle level but with the convenience of a test stand.

PSAT-PRO was also used for two DOE-funded technology validation projects. An INTegrated Electric Traction System (INTETS) and a lithium-ion battery were evaluated in a mule vehicle using PSAT-PRO to emulate a fuel cell.

PSAT-PRO is now being used for HIL projects evaluating hydrogen as a fuel for use in internal combustion engine HEV applications. For this initiative, Argonne developed the Advanced Powertrain Research Platform, a powertrain “buck” with custom instrumentation and “virtual inertia” scalable electric machine controlled by PSAT-PRO to provide the flexibility to vary the level of hybridization.

PSAT, developed with MATLAB R14, is used in powertrain development to optimize a vehicle and its components with regard to the following:

- Fuel consumption for any driving cycle or profile
- Vehicle performance, including acceleration and grade
- Drive train configuration, including conventional, electric, fuel cell, series hybrid, parallel hybrid, and power split hybrid
- Realistic control strategy development
- Component technologies
- Component sizing
- Transmission ratios

PSAT was designed to be a single tool that can be used to meet the requirements of automotive engineering throughout the development process:

- Each drive rain configuration is constructed built according to user input so that vehicle architectures can be compared and the most appropriate one selected. More than 400 pre-selected configurations are available.

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- PSAT can be used for light- as well as heavy-duty vehicles and has built-in tools for scaling the components when specific data are not available.
- Different levels of modeling (from lookup tables to high-fidelity physics based) can be used as all component models have the same number of input/output parameters.
- Control strategies and shifting algorithms options can easily be added and compared.
- HTML reports can be generated for simulations and test data. Unique driving cycles (such as an aggregation of cycles) can be created, and several cycles can be run in a row as each simulation is saved in four files.
- When used on a network, several instances of PSAT can be run simultaneously, which solves some versioning problems.
- All simulations are saved, providing the ability to reload the results or rerun the same simulation.
- Extensive post-processing allows for understanding and improving the system.
- Tests or simulations can be replayed and compared simultaneously for validation.
- Test data (from vehicle or component) can be integrated, and the test can be replayed by using an animation interface.
- A user-friendly GUI has been incorporated.
- The drivetrain configuration, component models, and data sets for the simulation can be selected. New initialization files, component models, and controls can be integrated within minutes without any code modification.
- Specific colors are used for different blocks of the component models and controls (e.g., red for input blocks, yellow for constants).
- The subsystems of the models are grouped by function (e.g., torque, speed, and inertia calculations for the transmission model).
- Extensive documentation is available.

By using test data from Argonne's Advanced Powertrain Research Facility, conventional and mild hybrid vehicles have been validated within 2% (Honda Insight, Ford P2000) and full hybrid vehicles (Toyota Prius) within 5% for both fuel economy and battery state-of-charge on several driving cycles. It seems clear that PSAT is the correct choice for the project we are undertaking.

### 2.3 Scope of work

Each of the buses selected will be modeled within the PSAT framework. Outputs will include

- # Fuel economy
- # Emissions
- # State of charge, as required
- # Operations under several duty cycles, e.g., traditional cycles used in the United States, plus those derived for application to Israeli cities
- # Additional data that might be useful as derived from application of the PSAT

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software and the feasibility study to follow the preliminary design.

## 7. DELIVERABLES

The major deliverables for this effort will include a report detailing the following typical items:

- # Details of the duty cycles selected.
- # Emission results for each bus, compared and contrasted ; note that these include particulates, CO<sub>2</sub>, unburned hydrocarbons and NO<sub>x</sub>.
- # Fuel economy for each of the vehicles compared and contrasted.
- # State of charge and requirements there for each of the buses.

Other results of the preliminary design will be developed based on discussion with the relevant transport authorities of Ramallah-Jerusalem-Bethlehem to be sure that we meet their needs.

## 8. SCHEDULE AND BUDGET

- 1) The preliminary design and simulation project will prolong 12 months. The total working effort in the preliminary design project will be \$600,000.
- 2) Thereafter a full design of the green transportation corridor and evaluation test with 3 Hybrid Buses should be initiated. It may prolong 2 years and its budget is estimated to be \$5 Million
- 3) Thereafter the development and the construction of the corridor, including operation of 100 Hybrid Buses for Rapid Transit, should be launched. It may prolong 3-5 years and its budget is estimated to be \$200 Million.