Evaluation of the optimal performance of passenger vehicle by integrated energy-environment-economic modeling

H. Farzaneh; Y. Saboohi

1Department of Energy Engineering, Graduate School of Environment and Energy, Science and Research Campus, Islamic Azad University, Tehran, Iran
2Sharif Energy Research Institute, Sharif University of Technology, Tehran, Iran

ABSTRACT: Analysis of multi dimensional interactions of flow of energy in passenger vehicle is a complex task that necessitates development and utilization of analytical tools. Development of analytical tools with high complexity is usually based on conclusions of many concepts and theories from different scientific disciplines. In this approach, Passenger vehicle is supposed to be organized in the form of a firm and appears in the market that oriented towards establishing an effective energy supply system which may be identified as delivering the product (person kilometer or tone kilometer) with minimum operation costs. To this end, an optimization model named power software founded on theory of firm of microeconomics has been developed using technique of mathematical programming. Base on this theory, the car owner tries to minimize the total cost of the system subject to the satisfaction of the required transport services and technological, economical, environmental and institutional constraints. The approach and the application of the model shall be demonstrated with the help of a case study. The result of this study shows the extent of optimal energy usage subject to meeting the required certain urban transport service.

Key words: Passenger vehicle, energy flow optimization, mathematical programing

INTRODUCTION

Urban passenger transport is a major energy consuming sector and it has tremendous impact on the environmental pollution. The effect of urban passenger transport on the energy consumption and environmental pollution is more acute in developing countries than in industrialized countries, which may be due to the lack of reliable and effective mass transport infrastructure in these countries. Contribution of private passenger vehicles to the transport services is, therefore, considerable. Improvement of energy efficiency and regulation of emission of pollutants from passenger vehicles could provide effective means of easing the negative economical and environmental impact of urban transport systems. Technology assessment and efficiency evaluation of passenger vehicles have been pursued with the help of analytical tools that have been developed and implemented in the last two decades (DOE Report, 2005), (Hoffman and McInnis, 2004) and (MAP Engineering, 1993). Many of the available analytical tools are based on the heuristics and experimental data (Markel, et al., 2002). But there has been little effort on concluding the theoretical background of analysis and developing respective energy models according to the optimal behavior of the system. Based on this conclusion, integrated energy-environment-economic modeling approach is developed to study of the performance of passenger vehicle as major component of the urban passenger transport.

In this investigation, passenger vehicle is supposed to be organized in the form of a firm and appears in the market as a supplier of goods and commodities. Activity of a producer is usually oriented towards establishing an effective supply system which may be identified as delivering the product with minimum costs. To this end, power software is designed and development for energy flow optimization in passenger vehicle that created in Fortran/Visual Basic programming. Fortran codes provide matrix-base programming environment for performing calculation based on concept of model while Visual Basic code is used to represent user friendly interface for a usual
user. Power uses graphical user interface screens to guide the users through the modeling process. With the interface section, the user can iteratively evaluate the impacts of vehicle parameters and drive cycle requirements on the vehicle performance, economy, environment, traffic and institutional conditions. This research has been done in Islamic Azad University, Science and Research Campus during 2002-2005.

MATERIALS AND METHODS

Approach of the model

In this approach, the vehicle is composed of various sub-systems and control volumes provide basis of structural development of the system of vehicle. Development of the vehicle system may be studied through analysis of functions of control volumes and the interactions between them. It is therefore necessary to define the dimensions and functions of the control volumes and relationships between them. Conversion processing depicts the flow of material/energy through an open system and its behavior is conditioned by the basic laws of physics and thermodynamics. In addition, development and operation of vehicle undergo various technical, economical and institutional constraints. Control volumes are open system and thus energy and material flows through them. Three main categories of open control volumes are defined in the software structure. They represent processing/conversion components (Engine, Gearbox, Differential, Radiator, Air filter, Intake manifold, injector or carburetor, outlet manifold and wheels), header (fuel linkage, electric network and lubrication system) and storage (fuel storage and battery). When the actual vehicle is composed of a collection of boundary, environment, technologies and input to plant data, it can be stored in the database of the model. The collection data can be inserted into the model to connection of the defined control volumes to establish of energy flow from one component to the next. The model library approach allows the same component model to be reused in multiple vehicle configurations. It also allows the impacts of different models to be evaluated within single vehicle architecture. After processing of data, the library linked to Fortran codes (Matrix generator and optimizer) and then optimal results will be observed through the output reports as mass and energy balances in different control volumes, supply and demand match, optimal energy flow and capacity profile of each control volume, storage profile in each load zone, energy flow networking and distribution in total site of vehicle total system and marginal cost of vehicle movement, energy intensities and effectivities and pollution in different scenarios.

Theoretical concept of the model

The economic rationality of a producer and activity of a firm has extensively been developed as a branch of micro economics and it has been utilized for explaining the development of production technology. It is clearly stated that a firm strives towards establishing a system of production and delivery with minimum costs subject to satisfying the demand and other technical, economical and institutional constraints. This concept may be formulated as below (Henderson and Quandt, 1985):

\[
\begin{align*}
\text{Minimized } &\quad Z = f(X_1, X_2, X_3, ..., X_n) \\
\text{Subject to: } &\quad g_i(X_1, X_2, X_3, ..., X_n) \leq b_i \\
&\quad X_j \geq 0 \quad i, j = 1, 2, 3, ..., n
\end{align*}
\]

Present value total costs of the vehicle operation including fuel price, maintenance and the cost of time of the traveler is depicted by Z as objective function of system. \(X\) is multiple product of price and consumption of production factor at operation time point with consideration of discount rate. \(b\) is demand for product that in this model is the passenger-kilometer on tone kilometer. The application of this concept to design and operation of a vehicle may provide a useful concept for developing analytical tool. It is therefore intended to segregate the whole passenger vehicle system into sub systems and elements in order to substitute the production function (which would be the transport service in this case) and replace it with a set of simultaneous equations. Such a formulation would enable to solve the behavioral model of the production firm explicitly.

Level of segregation is usually determined by the ability to introduce the basic laws of physics, engineering and economics. Changes in the state of the control volume is of general form and basic laws of physics and technical rules may be formulated accordingly and include them in the set of constraints of the system. Therefore, set of simultaneous equations would be developed that represent the laws governing the flow of material and energy through different equipments and devices at different stages of total passenger vehicle system.