Report No. UM-HSRI-78-54

Analytical Study of Mathematical Models of the Motor Vehicle System: Phase III

Final Report

Barbara C. Richardson

Kent B. Joscelyn

The University of Michigan
Highway Safety Research Institute
Policy Analysis Division
Ann Arbor, Michigan 48109

November 1978

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Analytical Study of Mathematical Models of the Motor Vehicle System - Phase III Final Report		5. Report Date November 1978
		6. Performing Organization Code
7. Author(s) Barbara C. Richardson and Kent B. Joscelyn		8. Performing Organization Report No. UM-HSRI-78-54
9. Performing Organization Name and Address Policy Analysis Division Highway Safety Research Institute The University of Michigan - 2901 Baxter Road Ann Arbor, Michigan 48109		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Motor Vehicle Manufacturers Association 300 New Center Building Detroit, Michigan 48202		13. Type of Report and Period Covered Final Report 7/77 - 11/78
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This document is the final report on Phase III of the "Analytical Study of Mathematical Models of the Motor Vehicle System." This study consisted of four basic tasks: the collection and inventory of mathematical models of the motor vehicle system, the analysis of selected models used in policy analysis, the computer implementation of models being analyzed, and research into the use of a model as a tool in policy formulation. The subject of in-depth study was the Wharton Econometric Forecasting Associates Automobile Demand Model. This report summarizes the technical approach and research results of the tasks undertaken in this study.

17. Key Words Model Econometric Computer Model Motor Vehicle Automobile Demand Policy Formulation		18. Distribution Statement Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 32	22. Price

ACKNOWLEDGMENTS

The efforts of many people were involved in performing this study and producing this report. Their assistance and cooperation are gratefully acknowledged.

This document is one of the workproducts of a study of mathematical models relating to the motor vehicle transportation system. The general research design was developed by Kent B. Joscelyn and Barbara C. Richardson, the co-principal investigators of the project.

Other members of the HSRI Policy Analysis Division performed substantial portions of the research. D. Henry Golomb and Michael M. Luckey performed the analysis of the Wharton EFA Automobile Demand Model. James H. Saalberg implemented the study of the use of that model. James M. Deiman also participated in that task. D. Henry Golomb performed the computer implementation task, and was assisted by Lawrence D. Segel who also assisted in all other aspects of the project. All of the above-named individuals in addition to Howard M. Bunch, Beverly K. Roth, and James D. Tomola participated in the model inventory effort. Murray Greyson, D. Henry Golomb, Michael M. Luckey, James H. Saalberg, Lawrence D. Segel and the co-principal investigators reviewed and critiqued the text of this report.

The report was produced under the supervision of Jacqueline B. Royal. Anne L. VanDerworp served as lead typist and was assisted by Jackie L. Stadler. The report was edited by Natalie H. Lenaghan and James E. Haney.

Lawrence E. Slimak and Christian van Schayk of the Motor Vehicle Manufacturers Association (MVMA) provided useful comments and suggestions, as did members of the MVMA Ad Hoc Committee on Federal Simulation Models that served as an advisory committee to this project. Committee membership included Richard H. Shackson, chairman, Samuel M. Zentman, Jack H. Merritt, and James F. Marquardt. Alternate committee members were Neil E. South and Irene E. Szopo.

Many individuals provided information for this study. Particular thanks go to the personnel of the U.S. Department of Transportation, the Department of Energy, the Office of Technology Assessment, the International Trade Commission, Mathtech, Inc., and Wharton EFA, Inc.

Without the cooperation provided by these individuals the study would not have been possible.

The responsibility for any errors in this report lies with the authors.

Kent B. Joscelyn
Co-Principal Investigator

Barbara C. Richardson
Co-Principal Investigator

CONTENTS

1.0 INTRODUCTION

This document is a report on Phase III of the "Analytical Study of Mathematical Models of the Motor Vehicle System" being performed by the Highway Safety Research Institute (HSRI) of The University of Michigan under the sponsorship of the Motor Vehicle Manufacturers Association (MVMA).

The period of performance of Phase III of this project was July 1, 1977 to June 30, 1978.

1.1 Background

The use of complex mathematical models to estimate, forecast, and evaluate the impacts of existing or proposed public policies has become common in recent years. Given the complexity of the real world, decision-makers face great difficulties in arriving at important policy decisions because many interrelated factors must be taken into account to produce a "best" solution. Mathematical models attempt to distill the significant relationships among various factors into a systematic and explicit reflection of the real world and to reduce large masses of data to key numbers and statistics. Because of this they have obvious attractions to policymakers.

One sector that has been the subject of extensive development of models is the motor vehicle transportation system. Models have been developed to assist in resolving a series of complex national issues heavily involving the motor vehicle and the motor vehicle industry. These issues have included the development of a viable national transportation system, problems of highway safety and environmental pollution, and most recently the energy crisis. The extensive use of models in the Project Independence studies (Jack Faucett Associates and Interagency Task Force on Energy Conservation 1974) and by the 1975 Federal Task Force on Motor Vehicle Goals Beyond 1980 (U.S. Department of Transportation 1976) to produce forecasts of automobile demand, vehicle miles traveled, and gasoline consumption are among the more notable examples of recent applications.

Recognition that models are proliferating and that they are increasingly being applied in federal efforts to solve critical problems of national policy led the Highway Safety Research Institute in 1976 to initiate a preliminary inquiry into the use of models in policy formulation. This study identified approximately thirty models dealing with vehicle production and resource accounting, vehicle miles traveled, automobile sales and pricing, simulations of vehicle fleet attributes, and energy factors. This effort became Phase I of a larger multiphase project entitled, "Analytical Study of Mathematical Models of the Motor Vehicle System."

By the end of this preliminary inquiry it was apparent that the universe of relevant models related to the motor vehicle transportation system was considerably larger than was possible to encompass in the initial effort. Furthermore, the number of relevant models was continuing to grow. Early consideration of how to evaluate models effectively led to the conclusion that it would be necessary to exercise or operate models if definitive conclusions about their capabilities and limitations were to be made.

Because the Motor Vehicle Manufacturers Association recognized the importance of studying this new type of policy analysis tool, it agreed to sponsor a more extensive effort aimed at expanding the original inventory of models and undertaking detailed analyses of selected models. Phase II of the study followed and was performed between 15 March and 30 June 1977. It involved three basic tasks: expanding the model inventory initiated in the first phase, selecting for analyses models of particular interest identified in the inventory, and developing a plan of work for the third phase of the study.

As a result of the efforts in Phase II of the study, the Wharton EFA Automobile Demand Model (Schink and Loxley 1977) was selected as the initial model to be the subject of a detailed analysis. This choice was made because the Wharton EFA model had gained the reputation of being a state-of-the-art analytic tool and because it was known to be in use for policy analysis purposes. The complete program of the model was obtained from the Transportation Systems Center along with the necessary data files. An extensive study was undertaken of the conceptual, structural, and operational characteristics of the model, and the model was tested in actual operation. The report of this analysis is in preparation (Golomb et al., pending).

In the course of the research for the inventory and the early stages of the Wharton EFA model analysis, it became evident that a full treatment of the model subject ought to include assembly of information on model applications and a critical evaluation of the ways in which models and their outputs were being used in policy formulation processes. In late 1977, plans were developed to parallel the technical analysis of the Wharton EFA model with an investigation of the applications of this model in policy studies. A report on this task conducted between February and June 1978 is currently in preparation (Saalberg, Richardson, and Joscelyn, pending).

By the end of June 1978, some seventy-eight models had been selected and summarized for inclusion in the first published version of the inventory of models related to the motor vehicle transportation system (Richardson et al. 1978).

Phase III of the study, then, included continued expansion of the inventory of models, analysis of a selected model, and an investigation of the use of models in policy formulation by the federal government through a case study approach.

Phase IV of the study is currently underway and is described briefly in Section 4.0.

1.2 Project Objectives

The general objective of the overall study is to examine and describe mathematical models that could be used in formulating policy related to the motor vehicle transportation system. Specific objectives are to:

- identify existing mathematical models of the motor vehicle transportation system;

- provide the capability for exercising selected models via computer;
- analyze selected models;
- modify and integrate models in response to specific requirements; and
- investigate the use of models in policy formulation through a case study approach.

1.3 Report Organization

Section 1.0 of this report, the Introduction, presents background information and lists the study objectives. Section 2.0 presents the technical approach and research results for each task of the project. Section 3.0 is the report summary. Section 4.0 presents the planned approach for fiscal year 1979. The Appendix lists the members of the advisory committee to this study, the MVMA Ad Hoc Committee on Federal Simulation Models.

2.0 TECHNICAL APPROACH AND RESEARCH RESULTS

This section presents a general overview of the project, the technical approach, and the results of each of the research tasks.

2.1 Overview of Project Activity

The sequence of activity in the project has been as follows. First, mathematical models relating to the motor vehicle transportation system were identified, and the documentation on each collected. The documentation was reviewed, and models were selected for inclusion in the inventory. A summary report on each selected model was then written.

Next, models were chosen for analysis. The primary criterion for selecting models for analysis has been the potential each model has for use in policy analyses, as determined from the information assembled during the inventory effort. On this basis two models have thus far been chosen for analysis: the Wharton EFA Automobile Demand Model and Faucett Automobile Sector Forecasting Model (Jack Faucett Associates, Inc. 1976).

The selected models were then analyzed. In the case of the Wharton EFA and Faucett models, both of which are complex, it was necessary to implement them on a computer.

As a first case study, the Wharton EFA model was examined as an example of a model that has been used extensively in federal policy analysis.

Project activities have been divided into seven distinct tasks. Task 1000, Project Planning and Control, is to plan, develop, and implement the project in a timely manner. It includes project management, liaison with the project sponsor, and reporting the results of research.

Task 2000, Model Assessment, consists of identifying and reviewing models to compile a model inventory and establish priorities for further analyses of selected models. It includes the preparation of the inventory of models and related material, the necessary file management, and the development and application of the criteria for selecting models for analysis.

Task 3000, Model Analysis, is the analysis of selected models to determine their structure and operational characteristics. In addition to model analysis, this task includes the acquisition of the models and the necessary data bases, as well as comparison of models as appropriate.

Task 4000, Computer Application, is designed to support the analysis of models. Activities include the implementation of model programs on The University of Michigan computer, the provision of computer access to the models by the sponsors and other interested parties, and the maintenance of the models placed on the computer.

Task 5000, Exercise Models, is the development of the capacity to conduct analyses, using the models to meet specific requirements that arise during the course of the study.

Task 6000, Model Development, is to modify or integrate existing models to meet specific needs.

Task 7000, Use of Models in Policy Formulation, is to investigate how and in what contexts selected high-priority models are being used to plan, formulate, and evaluate policies affecting the motor vehicle transportation system.

The following sections describe in greater detail the technical approach and research results for each substantive task. Task 1000, which is essentially administrative is omitted, and descriptions of Task 5000, Exercise Models, and Task 6000, Model Development, have not been included, because no activity on these tasks has occurred within the time period covered by this report.

2.2 Task 2000: Model Assessment

The objectives of this task include preparation of an inventory of models and selection of models for analysis.

2.2.1 Technical Approach. The term "model" has been broadly used in the inventory task. Any system of equations may be called a model. Taking this into account, the inventory includes models consisting of single-equation regressions that were not intended to be used as policy evaluation tools when they were developed, as well as sophisticated programs with large data bases that have been developed specifically for policy analysis. The complex models are included because they are used in research and policy making, especially by the federal government. The simple models are included because they are representative of research that has advanced economic theory as it applies to automobile demand, fuel or energy consumption, market share, vehicle miles traveled, or similar aspects of the motor vehicle transportation system.

To compile the inventory, the following steps were performed: the models were found, screened, and collected; reviewed for their relevancy and classified by type; and, finally, reviewed in depth to extract the information necessary for the inventory report.

2.2.1.1 Identification of Models. Four methods were used to find the relevant models: a search of library catalogs for pertinent literature, a search of computer files for additional models, personal contacts with people in the field, and a follow-up of references made in the reports on various models.

For the library search in this task, the catalogs of the libraries of The University of Michigan were searched by topic for titles suggestive of suitable literature. The materials stored at the Highway Safety Research Institute Information Center were also searched in this way.

The second search method used was the periodic search of three computer-based files of literature: (1) the Transportation Research Information Service (TRIS) data base, sponsored by the U.S. Department of Transportation and the Transportation Research Board; (2) the National Technical Information Service (NTIS) data base; and (3) the Compendex data base (Engineering Index). (The latter two are accessible through the Lockheed DIALOG Retrieval Service.) To find all the relevant models, broad key research terms were used for the computer searches. Even so, some models known previously to be significant were not included in any of the citations produced by the computers.

Personal contact was the third method of finding models. Authors, sponsors, and users of some of the models were contacted by telephone, personal visits, or both, to elicit additional information about the models. The personal contacts included individuals in key divisions within the Department of Transportation, the Environmental Protection Agency, the Department of Energy, and other federal organizations.

Reports on the models found by one of these methods often refer to other models, including models typical of the state of the art, models that provide input to or use output from the subject model, and models upon which the subject model was built. The fourth method used in compiling the inventory was to assemble additional information related to the models mentioned in reports already in hand and, if the new models seemed germane, to add them to the list.

Although every effort was made to be as comprehensive as possible, some models were likely overlooked in the search process. Moreover, information obtained from representatives of sponsoring or model-using agencies or from authors was likely not always accurate and comprehensive because of staff turnover, unpublished modification or uses of models, or lack of disclosure of proprietary information.

2.2.1.2 Initial Screening and Collection. The models found by these search methods were screened for their appropriateness to the project by title and, when available, by abstract of the report in which the model was originally presented. Models relating to the motor vehicle transportation system (econometric, physical, accounting, etc.) were considered appropriate if they describe an effect on society or the environment, and if they have the potential for use in policy-related analyses or advance the development of models pertaining to the motor vehicle transportation system. The project staff made every effort to be as inclusive as possible at this stage of identifying the models for collection.

In general, the efforts of the staff focused on models built after 1970. Although the study includes some older models to illustrate the state of the art before 1970, no effort was made to compile a complete file of models built before that time. Also, the models included are generally of national rather than local applicability. However, several models which are based on local area data were included primarily because they may be used in analyses of regions other than those upon which they were based. Therefore, for example, while travel demand models are included in the inventory, local modal split models have not been considered since they are generally calibrated for specific regions and are generally not used in national policymaking. The model types included in this study are listed in Table 1.

The models were collected primarily in two ways: (1) by employing the usual acquisition procedures of the Highway Safety Research Institute library and (2) by contacting authors and sponsors of models and requesting that the reports on the models, their programs, or whatever form of documentation was available be sent to the project staff. The first method was used more extensively, since it is possible to obtain documentation on most models by this means. On occasion, authors and sponsors sent the documentation relevant to their models directly to the HSRI project staff.

2.2.1.3 Initial Model Review. After receiving the documentation, HSRI staff reviewed each model twice. The first review checked the relevance of the model to the project and classified the model by type. During this initial model review, if a model did not appear to be relevant to the study, it was eliminated from further consideration. If it did appear relevant, it was assigned an accession number and cataloged by model type.

2.2.1.4 Completion of Inventory Forms. Once it was decided to include a model in the inventory and an accession number was assigned, the model was reviewed in depth to extract information to be included on inventory forms designed by the project staff. The inventory forms are the substance of the inventory report.

TABLE 1

MODEL TYPES

Accidents

Air Pollution/Air Quality

Automobile Demand

Automobile Design

Automobile Emissions

Automotive Industrial Financial Performance

Energy Consumption

Fleet Size

Fuel Consumption

Fuel Economy

Market Share

Modal Split

Motorcycles

National Economic Impact

Noise Pollution

Pricing

Scrappage

Trucks

Vehicle Manufacturing Resource Utilization

Vehicle Miles Traveled

Vehicle Operating Performance

Vehicle User Costs/Vehicle Operating Costs

Weight

2.2.2 Research Results. The primary output of this task is the report, An Inventory of Selected Mathematical Models Relating to the Motor Vehicle Transportation System (Richardson et al. 1978). This report lists each relevant model and gives significant information about each of the 78 models included. The information for each model in the inventory is organized by the following categorical terms: name, sponsor, author, type, objective, relationship to other models, historical background, assumptions, validation, limitations and benefits, structure, data requirements, documentation, and computer requirements.

Besides collecting and reporting on the relevant models, the HSRI project staff collected a set of background materials pertaining to the historical development of models, use of models, and other related topics.

2.3 Task 3000: Model Analysis

On the basis of information gathered for the inventory report two models were chosen for implementation and analysis--Task 3000 of the project. They are the Wharton EFA Automobile Demand Model and the Faucett Automobile Sector Forecasting Model. The purpose of this task was to analyze the models to determine their structure and operational characteristics.

Thus far, the project staff has conducted an in-depth analysis of the Wharton EFA model, an analysis that will be presented in a report currently in preparation (Golomb et al., pending). An analysis of the Faucett model is now taking place and will be reported when completed.

2.3.1 Technical Approach. Four steps were followed in the analysis of the Wharton EFA model. These are: model structure analysis, equation reconstruction, submodel evaluation, and full model evaluation.

2.3.1.1 Model Structure Analysis. The general purposes of model structure analysis are to provide the theoretical background necessary to understand the results that are generated by the model and to provide a broad overview of the structure of the model. The Wharton EFA model is an econometric model, a type of model which is often viewed as a "black box" that somehow generates numerical results. The intent of model structure analysis was to examine the basic structure and logic of the model so that its results could more easily be understood and interpreted.

The theoretical structure of the model was examined on two levels. First the theory underlying individual equations or particular sets of equations was examined. Second, the basic logic of the entire system of equations was investigated with the aid of flow diagrams that display the essential relationships contained in the model.

2.3.1.2 Equation Reconstruction. The purpose of equation reconstruction was twofold. First, by reconstructing the model on an equation-by-equation basis, i.e., reestimating the primary equations of the model, the accuracy of the model results contained in the model report could be checked. Second, equation reestimation provides statistical information that can be used in evaluating the equations of the model.

The key time-series equations of the model were replicated on an equation-by-equation basis, using a multiple linear regression package (1). The signs of the estimated parameters were checked against the predictions of the theory. The statistical significance of the parameter estimates was tested. The overall goodness of fit of each equation as reflected in the coefficient of determination ($\bar{R}^2$) was tested (2). The Durbin-Watson statistic was used to test for first-order autocorrelation of the residuals (3).

2.3.1.3 Submodel Evaluation. The basic purpose of submodel evaluation was to analyze the dynamic properties and forecasting behavior of submodels of the full model. All models have certain groups of equations or individual equations, i.e., submodels, that "drive" the full model. That is, these submodels strongly influence the dynamics of the entire system of equations. The examination of the dynamic properties and forecasting behavior of selected submodels provides invaluable insights into these properties of the full model. Such an analysis on the full model alone can be extremely difficult since the interactions between equations can be very complicated. In fact, it is often necessary to decompose submodels into smaller groups for these same reasons.

The dynamic properties of a submodel were analyzed by examining the response of the submodel to specified changes in the independent variables or estimated parameters. An example would be to formulate an experiment in which a submodel simulation would be run over some time period, with one of the independent variables increased by one percent for each year of the time period. These simulation results would be compared with those of a simulation over the same period with no change in the independent variable. If the independent variable is present in more than one equation of the submodel, it may be necessary to decompose the submodel into smaller submodels to isolate the impact on the submodel of the change in that independent variable.

The results of the simulation experiments to examine the dynamic properties of submodels were displayed in tabular arrays or in graphs. These displays permit an examination of period-by-period impacts, i.e., changes, on the variables of the submodels.

The forecasting behavior of submodels was also studied. This was done by examining the simulation results of the model over an historical period. Generating simulations over historical periods permits a comparison of the predictions of the model with actual known values. Thus, errors in the predictions can be examined for each year of the simulation period. Also, various error statistics that indicate average error over the simulation period can be produced.

The error analysis served not only in evaluating the accuracy of the model in predicting the levels, e.g., known values, of the model variables, but also in examining whether the model can predict changes in the variables. A model can be rather accurate in predicting levels, but it may have a tendency to predict poorly the turning points of variables--that is, the points in time when a variable changes from an upward trend to a downward trend, or vice versa. For example, the model may have a tendency to predict a turning point a year or two after it occurs. On the other hand, a model can be relatively accurate in predicting changes in variables and inaccurate at predicting levels.

2.3.1.4 Full Model Evaluation. The purpose in evaluating the full model was to analyze the dynamic properties and forecasting behavior of the model as a whole. These characteristics of the full model were studied by using the same principles of analysis discussed above for submodels.

One additional task performed in the full model analysis was to test whether the model has a tendency to accumulate forecasting errors over time. The model was examined for this tendency by a procedure that compares the forecasting errors generated by the model in one-period-ahead forecasts with those generated by the model in two-period-ahead forecasts, and so on. If the forecasting errors of the model increase as the forecasting horizon lengthens, the model displays a tendency to accumulate errors.

2.3.2 Research Results. This section summarizes the results of the analysis of the Wharton EFA Automobile Demand Model.

2.3.2.1 Model Structure Analysis Results. The Wharton EFA Automobile Demand Model is a very large and complex system of interrelated mathematical equations which in its original version simulates long-term automobile demand. A revised version of the model, soon to be released, will treat light trucks and vans separately, thereby permitting a more detailed analysis of the motor vehicle transportation system. The present version of the model contains almost 400 mathematical statements involving about 600 variables. Of its mathematical statements, about 300 are identities, and over 80 are statistically derived within the model.

The paramount output of the model is a forecast of what the size and composition of U.S. automobile demand (sales) and total stock is likely to be in the future, given the vehicle characteristics and economic and demographic conditions and/or assumptions that may be fed into the model at the beginning of a simulation. Other significant outputs that result directly or may be derived with additional assumptions include forecasts of fuel consumption, industry employment, and tax revenues flowing directly from sales and vehicle operations.

Although the model is complex and contains a number of innovations, much of the basic theory underlying it is typical of auto-demand models constructed over the last twenty years. The central concept underlying the model is that the automobile market operates by a stock adjustment process. Fundamental to the working of a stock adjustment is the assumption that gross expenditures on a commodity such as automobiles, measured in units sold, can be calculated from the difference between a "desired" stock and the stock already in existence, taking into account the need to replace old stock as it wears out. Desired stock, which is the key concept in a stock adjustment model, refers to the long-run "steady state" or equilibrium (in economic terms) number of units that would exist if all factors that affect automobile demand, such as demographics, sales taxes, and the like were held constant from a current time into the infinite future, allowing any existing discrepancy between supply and demand to be resolved by normal market forces.

The desired stock of automobiles and the desired shares within the total stock for each delineated class of vehicle (five size classes in the current version of the model) are, essentially, the numbers of vehicles that would be in existence if the consuming public owned and operated all the automobiles it needed, wanted, and could pay for under existing price and income conditions. With this as a logical basis, desired stock and desired shares by type of car are derived within the model from historically determined relationships between key demographic, household income, and vehicle cost variables on the one hand and the number of vehicles in operation on the other. The demographic variables include the number of households and the number of licensed drivers per household. Household income refers to disposable real income. Vehicle costs include both the costs of initial purchase and the stream of operating costs that occur over the average useful life of a vehicle. Without reference to any particular formulation, it appears eminently reasonable that the number of cars desired by the public should be directly proportional to the actual or projected number of licensed drivers and to the ability to pay, represented by income, and inversely proportional to the cost of owning and operating a vehicle. Given this idealized target and a number of vehicles already in being, with vehicles that are wearing out or being scrapped for other reasons (e.g., accident) substracted, a difference calculated represents likely new car sales, other things being equal. In simplest terms, this is what the Wharton EFA model does. Its complexities come from the fact that the relationships involved are not simple, most of the key variables are directly or indirectly reciprocally related, and other things generally are not equal or constant.

The Wharton EFA model is divided into six large computational blocks of equations:

- Block A, in which miles per gallon or fuel efficiency estimates are generated for each class of new cars and for the total fleet of new cars.
- Block B, in which new car prices are estimated.
- Block C, in which the cost of operating a typical car in each size class is estimated, taking into account both purchase costs and the stream of operating costs over an average ten-year lifespan, discounted back to current dollar values.
- Block D, in which the desired shares for class of car and for the total stock are estimated.
- Block E, in which actual demand, essentially total new car sales, is estimated, along with total scrappage and used car sales and scrappage.
- Block F, in which actual (as opposed to desired) stock and stock by class shares is updated and estimated.

Detailed flow diagrams of each of these computational blocks are included in the model structure section of the Wharton EFA model analysis report currently in preparation by HSRI. These flow diagrams were drawn according to the computer program of the Wharton EFA model that HSRI received from the U.S. Department of Transportation's Transportation Systems Center. In addition, the exogenous model input and major output of each of the blocks are listed.

2.3.2.2 Equation Reconstruction Results. In reconstructing the principal time-series equations of the model, the project staff obtained mixed results. Some equations were exactly reproduced, others closely reproduced, and still others were poorly reproduced.

In the exactly—or almost exactly—reproduced equations, the coefficient estimates and summary statistics obtained by the project staff differ from Wharton EFA's by less than one percent. Examples include the equations for new car registrations and vehicle miles traveled.

For the closely reproduced equations the HSRI staff obtained coefficient estimates and summary statistics that differ from Wharton EFA's by one to three percent. Examples are the equations for auto scrappage and new car registrations shares (combined subcompact and compact, subcompact share of combined subcompact and compact, mid-size and full-size).

For the poorly reproduced equations, coefficient estimates and summary statistics obtained by the project staff differ from Wharton EFA's by a substantial amount—five to fifteen percent. Equations in this category include luxury new-car-registrations shares and domestic new-car-registrations shares (subcompact, compact, and luxury).

The HSRI staff were able to reproduce, exactly or closely, approximately 75% of the key time-series equations of the model. Data series revisions by Wharton EFA are a likely cause of the differences found in both the closely and poorly reproduced equations. For example, in the domestic new-car-registrations share equations, the variable that measures the number of people 20-29 years of age relative to the number of family units was revised substantially by Wharton EFA in the course of building the model (4). Apparently the version of the series that was used in estimating the domestic share equations was different from the one delivered to the Transportation Systems Center.

2.3.2.3 Submodel Evaluation Results. In the submodel evaluation, analyses of the forecasting behavior and dynamic properties of selected submodels of the full model were made. Three sets of submodels were examined. The first set includes the equations for desired stock, new car sales, scrappage, and vehicle miles traveled. The second set includes the equations for desired shares and new car market shares. The third set contains the equations for capitalized cost per mile by type of vehicle. These submodels were chosen because they contain equations central to the operation of the model.

In examining the dynamic behavior of the submodels, the project staff paid particular attention to the dynamic relationships of the equations of the submodels--the effect of a one-percent increase in vehicle miles of travel per family, for example, on the solution of the scrappage equation. Such examinations assist in understanding the dynamic behavior of the full model.

In examining the forecasting behavior of the submodel, the staff placed emphasis on how the estimates for desired stock affect the predictions of new car sales and scrappage and how the desired share estimates affect the new-car market-share predictions. A brief discussion of Wharton EFA's approach in the development of these equations follows. Both the desired stock and desired shares equations were estimated by Wharton EFA based on 1972 state cross-section data. This was done, as Wharton EFA argues, because according to classical economic theory the determinants of these desired variables cannot be estimated with time-series data. Once equations for these desired variables have been estimated, the desired variables must be translated into time-series data so that the new car sales, scrappage, and new-car market-share equations may be estimated. The translation involves setting the right-hand independent variables of the desired equations equal to their historical values to determine an estimated historical value of the dependent desired variable.

Wharton EFA found that the translation process did not produce reasonable values of the desired variables, especially the desired shares variables. This was due to income distribution differences between 1972, from which the desired equations were estimated, and the majority of years to which the desired values were translated. Also, the 1972 offering of cars was substantially different from the offerings over most of the translation period. Wharton EFA had to adjust the historical series of desired estimates to obtain reasonable estimates of the equations of new car sales, scrappage, and new-car market shares that are dependent on the desired estimates. Similar adjustments cannot reasonably be made when the model is used to forecast into the future.

To evaluate the submodels, the staff examined them with the adjusted and unadjusted estimates of the desired variables over the historical period. The staff found that:

- The unadjusted desired stock estimates, which would be used in a forecasting application of the model, generate substantial errors in the new-car-sales and scrappage predictions. However, the trends in new car sales and scrappage are reasonably predicted.
- The unadjusted desired-share estimates produce substantial errors in the new-car-market share predictions.
- Since the cross-section estimates do not translate well into the historical time domain, similar errors will almost certainly occur in forecasting applications of the model.

2.3.2.4 Full Model Evaluation Results. The dynamic properties of the full model were analyzed using multiplier experiments. A multiplier experiment involves changing one or more exogenous variables to determine the impact on the endogenous variables of the model. The following nine multiplier experiments were conducted:

1. One percent increase in nominal personal income.
2. One percentage point increase in the sales tax rate on new cars.
3. Ten percent increase in gasoline price.
4. One percentage point increase in the unemployment rate.
5. Ten percent increase in the insurance cost index.
6. Ten percent increase in the repair cost index.
7. Ten percent increase in the production input cost index.
8. One percent increase in the number of licensed drivers.
9. One percent increase in the number of individuals aged 20-29 years.

In general, the results indicate that the model is rather insensitive to changes in the exogenous variables listed above. This is particularly true in the long run, although in some cases there can be a substantial short-run impact which then quickly declines over the long term. (Recall that the Wharton EFA Automobile Demand Model was built to do long-term forecasting.) The effect on new car sales of a permanent one percent increase in current dollar income provides a good example of this type of behavior. New car sales in the first year experience a substantial increase of approximately 5.2 percent (470,000 units) as a result of the one percent increase in income. Over the longer term, however, the change in new car sales fluctuates between very small positive and negative values. For practical purposes, this implies a long-run income elasticity of zero. This result is inconsistent with previous work which has shown that there is a long-term positive elasticity of new car sales with respect to income.

The forecasting behavior of the full model was studied by using simulation experiments over the period 1960-1974. The first experiment was designed to study the tendency of the model, if any, to accumulate forecasting errors as the length of the forecasting horizon is increased. It was found that no clear trend existed in terms of error accumulation for the eight key time-series variables of the model except for vehicle miles of travel, which did display a tendency to accumulate errors as the length of the forecasting horizon was increased.

The second simulation experiment was intended to study the forecasting accuracy of the model over the sample period 1960-1974. On the basis of root-mean-squared error (RMSE) statistics and computer-generated plots, it was concluded that the model predicts the trends in new car sales, scrappage, and vehicle miles traveled fairly accurately, but that the actual levels of these variables are not forecast with much precision. For new car sales by market class, the results clearly showed that the model produces very inaccurate forecasts of these variables. In fact, the forecasting accuracy of the Wharton EFA model was compared to that of a naive alternative model (sample mean), and on a root-mean-squared error basis, the naive model out-performed the Wharton EFA model for all five market classes. Indeed, for four of the market classes (subcompact, compact, mid-size, and full-size) the differences were quite substantial, with the RMSE of the naive model being on the order of four to eight percentage points lower.

The final two experiments studied the forecasting behavior of the model over the first and second halves of the full sample period (1960-1967 and 1968-1974). In general, it was concluded that the model does a better job of tracking the historical record over the second half (1968-1974) of the full sample period than the first half. This is to be expected, given that the desired stock and desired share equations were estimated with cross-section data for the years 1971 and 1972.

Thus, the analysis of the Wharton EFA model conducted during Phase III of the study indicates that the model has some serious shortcomings, particularly with regard to its ability to forecast accurately levels of key variables. These shortcomings will be discussed at length in the HSRI report on the analysis of this model now in preparation.

2.4 Task 4000: Computer Application

The purpose of this task has been to support the analysis of the two highest priority models, the Wharton EFA and Faucett models. The task includes three basic activities: internal implementation, external implementation, and system maintenance. Thus far, the project effort on this task has concentrated on internal implementation. To implement the models, the computer programs of the models and their supporting data had to be obtained in a format suitable for computer processing at The University of Michigan.

2.4.1 Technical Approach. Internal implementation requires that the models be put into computer form for analysis. For each model either a computer tape or a deck of cards containing the model program must be obtained from the model author or sponsor. A tape of the Wharton EFA model was obtained from the Transportation Systems Center, and a card deck of the Faucett model was obtained from the Federal Energy Administration (now part of the Department of Energy). The data base necessary to run and analyze the Wharton EFA model was included on the tape, but the Faucett data were obtained in printed form. Several changes were made in the computer program of the Wharton EFA model to facilitate model analysis, and a program entitled, HSRI Econometric Model Simulator (HEMS), was developed to facilitate the analyses of econometric models.

2.4.2 Research Results. As each step of analysis of the Wharton EFA model occurred, it was necessary to perform some modification to the model program. The following modifications were made:

- Using simulations directly from the model as input, a program to generate graphs of submodel analysis showing actual versus predicted values was written.
- The programming necessary to adjust switches in the program to allow the choice of alternative forms of equations was performed.
- Modifications were made for running the baseline scenario.
- Programming was performed to provide greater compatibility with MTS (The University of Michigan computer system).
- Programming was performed to print out simulation results, multiplier results, and error statistics for lists of requested variables.
- Options were added to enhance the analysis of desired shares. These deal with the normalization of the desired shares.
- A program to read in the Wharton EFA exogenous variables (necessary to run the baseline forecast and the multiplier runs) was written.
- A program was written to allow for more sophisticated full model and submodel evaluation (the HEMS program).

Note that none of these modifications change the basic model in any way.

2.5 Task 7000: Use of Models in Policy Formulation

The purpose of this task was to undertake a preliminary inquiry into the use of models in policy formulation within the federal government by assembling information on the use of one model--the Wharton EFA Automobile Demand Model. The specific objectives of the task included:

- identification of major federal users of the Wharton EFA model;
- determination of how the model is used;
- identification of policies affected by use of the model; and
- assessment of the technical appropriateness of the use of the model and its output, to the extent possible.

2.5.1 Technical Approach. The technical approach of this study was framed within the relatively short time allowed for this preliminary effort. The primary method employed was to contact personally the users and potential model users, both governmental and private. Most of the contacts were by telephone, although a number of key users were visited for more extended discussions. In addition to making personal contacts, relevant literature and reports describing used of the Wharton EFA model were assembled and reviewed.

Approximately sixty persons in more than twenty-five federal agencies and eight private research groups were contacted. Significant documents by the National Highway Traffic Safety Administration, the Office of Technology Assessment, the Senate Finance Committee, and Mathtech, Inc. were reviewed. They contain analyses based in part on the Wharton EFA model's output. Table 2 lists the agencies and groups where at least one person was contacted and provided information.

2.5.2 Research Results. This section presents a summary of the findings of the study of the use of the Wharton EFA model in policymaking. The full report is in process of preparation (Saalberg, Richardson, and Joscelyn, pending). Below are summarized the major users of the Wharton EFA model identified to date, the significant policy issues that have been addressed using the Wharton EFA model, and several key findings concerning how the model has been used.

TABLE 2

ORGANIZATIONS CONTACTED

Federal Governmental Contacts

Congressional Budget Office

Congressional Research Service

Council of Academic Advisors

Department of Commerce
- Bureau of Domestic Commerce
- Bureau of Economic Analysis (3)
- Office of the Chief Economist
- Transportation and Capital Equipment Division, Bureau of Domestic Business Development

Department of Energy
- Energy Division, Oak Ridge National Laboratories
- Energy Information Administration
- Office of Conservation and Solar Applications (2)
- Office of Energy Research
- Office of Policy and Evaluation (2)

Department of Transportation
- Federal Aviation Administration
- National Highway Traffic Safety Administration (9)
- Office of Intermodal Transportation (6)
- Transportation Systems Center (3)
- Urban Mass Transportation Administration

Department of the Treasury (2)

Environmental Protection Agency
- Motor Vehicle Emissions Laboratory (5)
- Noise Abatement Office
- Office of Economic Analysis
- Office of Mobile Source Air Pollution Control
- Research Center, North Carolina

General Accounting Office (2)

International Trade Commission (2)*

TABLE 2 (Continued)

Joint Congressional Committee on Internal Revenue and Taxation

Office of Technology Assessment (2)*

Senate Finance Committee

Other Contacts

Energy and Environmental Analysis, Inc.

Massachusetts Institute of Technology Energy Laboratory

Mathtech, Inc.

Michigan Energy and Resource Research Association

Operations Research, Inc.

SRI International, Inc.

Technology and Economics, Inc.

Wharton Econometric Forecasting Associates, Inc.*

Numbers in parentheses indicate number of individuals contacted if more than one within the organization.

Asterisks (*) indicate in-person visits; all other agencies contacted only by phone.

2.5.2.1 <u>Major Users of the Wharton EFA Model.</u> The most extensive use of the Wharton EFA model or its output has been within the Department of Transportation (DOT). This finding is not surprising inasmuch as the model was developed by Wharton Econometric Forecasting Associates under a contract from the Department's Transportation Systems Center. Those divisions within DOT that have used the Wharton EFA model are the National Highway Traffic Safety Administration, the Office of Intermodal Transportation within the Office of the Assistant Secretary for Policy and International Affairs, and the Transportation Systems Center itself.

The policy questions that have been addressed within DOT using the Wharton EFA model or its outputs for at least part of the analyses have included the 1981-1984 passenger automobile fuel economy standards, the president's proposed gasoline tax related to fuel consumption, the proposal to impose a gas guzzler tax and companion fuel economy rebate, the passive-restraint air bag, and the potential impact of introducing electric vehicles. Incomplete attempts have also been made to use the model to estimate the impact of the fifty-five mile-per-hour speed limit and the imposition of fuel economy standards on nonpassenger light vehicles (trucks and vans). With respect to this last, it should be recalled that the Wharton EFA model is currently being developed further to encompass explicitly this segment of the motor vehicle population .

Outside of DOT, significant applications of the Wharton EFA model have been identified in work done for the Senate Finance Committee by the economic staff of the International Trade Commission, in the Congressional Office of Technology Assessment, in the Department of the Treasury, and in the Council of Economic Advisors. The Wharton EFA model would have been used for analytic work by the staff of the Joint Congressional Committee on Taxation and Revenue, but the cost of doing so exceeded the budget then available.

In the cases of the Senate Finance Committee, the Council of Economic Advisors, and the Treasury Department, the uses of the Wharton EFA model have involved one or more facets of the president's energy proposals related to the motor vehicle. The most extensively documented application is in an analysis of the probable impact of the fuel efficiency incentive tax proposal and the gas guzzler tax proposal prepared by the International Trade Commission staff for the Senate Finance Committee. The Wharton EFA model output was reviewed by the staff of the Council of Economic Advisors in the preparation of the president's National Energy Plan. In the Treasury Department, the model's output was used to estimate the impact of revenue that would occur from the imposition of the president's proposed gasoline tax.

The Office of Economic Analysis of the Environmental Protection Agency used the Wharton EFA model to analyze the probable impact of proposed vehicle emission standards on the economy and on fuel consumption. In the case of the Office of Technology Assessment, SRI International employed the Wharton EFA model in an investigation of three alternative scenarios depicting potential futures for automobile uses. Within the Department of Energy, the model has been used in analyses of the potential economic impact of introducing turbine and sterling automotive power plants.

Outside the federal government, the most notable use of the model identified to date has been in a study of the impact on the demand for electricity that would come from the introduction of battery-powered automobiles. The study was done for the Electric Power Research Institute by Mathtech, Inc. Even this study has had government implications. The Transportation Systems Center's electric-vehicle analysis was an extension of this major work, and the results of the Mathtech work are reported to have been reviewed by the Department of Energy.

2.5.2.2 Summary of Key Findings Concerning the Use of the Wharton EFA Model

The Wharton EFA model has been used in policy-related studies by significant units of the federal government in both the executive and legislative branches. The most frequent use occurred in the Department of Transportation, which sponsored the development of the model. Outside DOT use of the model was reported in the Department of Energy, the Environmental Protection Agency, the President's Council of Economic Advisors, and the Senate Finance Committee.

A variety of major policy issues, dominantly related to energy questions, has been analyzed using the model to project key economic impacts. The specific energy policies analyzed included proposed automobile fuel economy standards, several versions of the so-called "gas guzzler" tax, and the president's gasoline conservation incentive tax. Other types of policy subject to analysis have included vehicle emission control standards and safety proposals, such as the passive restraint air bag.

Opinion among several respondents is divided concerning whether or not the analytic results of the model were given significant weight in those policy studies where the model was used. Model results are prominent in several of the reports reviewed, and in one case, the Senate Finance Committee, there was a credible report asserting major influence of results based on the model. The evidence is sufficient to indicate that model results have been prominent and appear to have exerted notable influence on conclusions in some of the applications studied. A more definite conclusion cannot be drawn.

With respect to how analysts worked with the model, the study indicates the dominant mode was to employ computer output produced by sources outside the analysts' agency. Only in two cases did the analysts involved in a study operate the model directly.

Few analysts who used the Wharton EFA model results appear to have had a deep understanding of the model and particularly of some of its significant limitations. This appears to be especially true for the majority who did not directly operate the model. In most instances, the press of time was given as a reason for not being able to study even the model documentation in detail. It is also the case, however, as the HSRI analysis of the model showed, that the documentation, while voluminous, was also incomplete.

Lack of familiarity with details of the model appears related to inappropriate and inadequately qualified prominence being accorded to some model results. This is particularly true for studies that placed emphasis on projections of market sales by car type and on projected splits between foreign and domestic car sales. The HSRI analysis of the model showed that the former projections were subject to large error. The foreign and domestic shares were actually set exogenously and were not computed by the model, a fact stated, but only obscurely, in the Wharton EFA documentation. It is notable that in the two reported cases where analysts operated the model directly, ie.e., the studies by Mathtech, Inc., and SRI International, Inc., limitations of the model were recognized and discussed in reporting several results.

The general lack of adequate attention to the question of how accurate were the forecasts produced by the model constitutes a major weakness in the applications studied. Sensitivity analyses were used in some studies to indicate how much forecasts, e.g., of sales, would vary if key exogenous assumptions, like the growth rate of gross national product, were changed. This is only a partial answer to the question of how much variability was inherent in the point estimates generated by the model. Without some measure of accuracy, there is little basis for judging whether or not forecast differences in the impacts of two or more policy alternatives are large enough to be meaningful either in statistical or practical terms.

In summary, it has been found that the Wharton EFA model has been in widespread use in the federal government, that its primary applications have been in the area of energy-related policies, and that users, in general, have not had a deep understanding of the model or its limitations. This has apparently led, in some cases, to unwarranted confidence in the model output.

3.0 SUMMARY

This section summarizes the results of project activity during Phase III.

As part of the activity on Task 2000, Model Assessment, seventy-eight models have been reviewed in depth. Summaries of each of these were prepared and included in the Inventory Report which was published in September 1978.

Model Analyses, Task 3000, has focused on the Wharton EFA Automobile Demand Model, with some analysis of the Faucett model also having taken place. The structure and theory of the Wharton EFA model have been analyzed; the key time-series equations of the model have been reconstructed; submodel evaluation has occurred for three sets of important submodels; and evaluation of the full model has been performed. The specific results of the analysis will be included in the project analysis report currently in preparation.

The model implementation activity of Task 4000 has focused on the internal implementation of the Wharton EFA and Faucett models, both of which are operational on The University of Michigan computer system, and on activities necessary for the analysis of the Wharton EFA model. Many modifications to the computer program of the Wharton EFA model were made to facilitate model analysis.

In Task 7000, the use of the Wharton EFA model by the federal government in the formulation of policies relating to the motor vehicle system has been studied. The model has been used most extensively by the Department of Transportation. It has also been applied by the Environmental Protection Agency, the Department of Energy, the Senate Finance Committee, the Council of Economic Advisors and the Department of the Treasury. The primary uses of the model by the government have been in analyses related to the energy policy issues, most notably the 1981-1984 passenger automobile fuel economy standards and the president's proposed gas guzzler tax. It has also been applied in analyses related to vehicle emission standards, safety standards, and new engine technology. The complete findings of this task will be included in the report on the use of the Wharton EFA model currently in preparation.

4.0 SUMMARY OF FY 1979 APPROACH

This section summarizes the proposed approach for fiscal year 1979.

The technical approach will follow the work plan presented for FY 1978. During FY 1979 the following areas will be emphasized:

- continued assessment and, where appropriate, analyses of models,
- HSRI's exercising of priority models in response to established needs,
- development and implementation of software to provide external users direct access to the models, and
- study of actual applications of models to federal policies.

Project plans include analyzing three models: the Faucett model, the upcoming version of the Wharton EFA model (which includes light trucks and vans), and the integrated Wharton EFA/Faucett model planned by the Department of Energy.

One change in the model assessment task will be a two-tier approach in reviewing the models. This includes preparation of abstracts for all models and background reports reviewed, and preparation of complete inventory reports for only those models considered to be of great interest to the motor-vehicle-system community.

Study of the use of the Wharton EFA model in federal policymaking will continue, and investigation of the use of the Faucett model will begin.

APPENDIX

MVMA Ad Hoc Committee on Federal Simulation Models

Membership
July 1977 - June 1978

CHAIRMAN:

Richard H. Shackson
Environmental Research Office
Ford Motor Company

Dr. S.M. Zentman
Manager
Engineering Computer Center
American Motors Corporation

J.H. Merritt
Market Planning
Chrysler Corporation

James F. Marquardt
Environmental Activities Staff
Auto Safety
General Motors Technical Center

Alternates:

Neil E. South
Environmental Research Office
Ford Motor Company

Dr. I.E. Szopo
Economic Studies
General Motors Corporation

FOOTNOTES

1. An attempt was made to reproduce only the time-series equations of the model. Poor documentation for the cross-section data and limitations in scope forced us not to attempt to replicate the cross-section equations of the model.
2. $\bar{R}^2$ is the coefficient of determination adjusted for degrees of freedom. The purpose of $\bar{R}^2$ is to facilitate comparisons of the goodness of fit of several regression equations that may vary with respect to the number of explanatory variables and the number of observations.
3. Autocorrelation occurs when the error terms of the model are correlated. If the equation contains a lagged dependent variable (a variable set to its value in a previous year), it is well known that the standard Durbin-Watson statistic is an unreliable measure to use to test for first-order autocorrelation. In fact, it is biased toward the value of 2.0, which indicates no autocorrelation. Durbin has developed a large sample test for autocorrelation in the presence of a lagged dependent variable. This test is used with equations that contain a lagged dependent variable (Durbin 1970).
4. Information based on a conversation with Colin Loxley at Wharton Econometric Forecasting Associates, Inc.

REFERENCES

Durbin, J. 1970. Testing for serial correlation in least-squares regression when some of the regressors are lagged dependent variables. Econometrica 38:410-421.

Jack Faucett Associates, Inc. 1976. Automobile sector forecasting model documentation, Final report, Submitted to the Federal Energy Administration report no. JACKFAU-76-137-7.

Jack Faucett Associates, Inc. and Interagency Task Force on Energy Conservation. 1974. Project independence blueprint. Final task force report. Project independence and energy conservation: Transportation sectors. Volume II. Washington, D.C.

Golomb, D.H.; Luckey, M.M.; Saalberg, J.H.; Richardson, B.C.; and Joscelyn, K.B. (pending). An analysis of the Wharton EFA Automobile Demand Model. Ann Arbor, Michigan: The University of Michigan.

Richardson, B.C.; Joscelyn, K.B.; Golomb, D.H.; Luckey, M.M.; and Segel, L.D. 1978. An inventory of selected mathematical models relating to the motor vehicle transportation system. Report No. UM-HSRI-78-28. Ann Arbor, Michigan: The University of Michigan.

Saalberg, J.H.; Richardson, B.C.; and Joscelyn, K.B. (pending). Applications of the Wharton EFA Automobile Demand Model in federal policy analysis. Ann Arbor, Michigan: The University of Michigan.

Schink, G.R., and Loxley, C. 1977. Final report - An analysis of the automobile market: Modeling the long-run determinants of the demand for automobiles. Wharton Econometric Forecasting Associates, Inc.

U.S. Department of Transportation. 1976. Interagency Task Force on Motor Vehicle Goals Beyond 1980, The report by the federal task force on motor vehicle goals beyond 1980, Draft.