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Publication of this paper sponsored by Committee on Ride Quality and Passenger Acceptance.

Resource Impacts of Alternative Automobile Design Technologies

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Automobile production and operation consume energy, materials, capital, and labor resources. Alternative automobile design concepts are examined in terms of their aggregate resource impacts. A computer-based model was developed for generating the resource requirements of alternative automobile technologies. The model goes beyond previous tools in its scope, level of impact disaggregation, and flexibility. It projects the annual energy, materials, capital, and labor requirements of the passenger automobile fleet through the year 2000. The methodology integrates a family-tree technique with an input-output approach that generates the capital and labor information. It tracks 24 major materials, with supply disaggregated among primary and recycled materials, imports, and domestic sources. Net energy consumption is derived, along with capital and labor impacts disaggregated by 90 industries. The model was used to examine a broad range of scenarios, encompassing various automobile design technologies and constraints imposed by safety and emissions regulations. All the scenarios show fleet fuel consumption declining through 1985, as the gains in fleet fuel efficiency outweigh the growth in distances traveled. With a few exceptions, the weight-conscious designs and innovative structures result in a significant reduction in consumption of the major materials used in automobile production. Finally, increased capital expenditures in the automobile industry are offset by capital savings in other sectors of the economy.

As a major consumer of petroleum, the automobile has been the subject of much recent attention. Various techniques have been proposed for improving automobile fuel economy, ranging from simple retrofit devices to advanced engines and innovative structures. Unfortunately, the focus of this attention has been exclusively on petroleum consumption and has tended to ignore the other vital resources consumed by the automobile fleet. Automobile production and operation require energy, materials, capital, and labor resources in delivering a level of service that is usually measured in terms of vehicle distances traveled, or vehicle miles traveled (VMT). Aggregate demand for any of these four resources can be reduced through the substitution of the others. Thus, the selection of fuel-efficient automobile designs should be viewed and evaluated in terms of the trade-offs in aggregate resource requirements that they represent. The increased use of aluminum in automobiles, which would displace materials such as cast iron and sheet steel, is an example of these concepts.

Due to its light weight, aluminum substitution would lower the overall weight of the vehicle and improve fuel economy. However, aluminum production is very energy intensive. Whether or not there is a net energy savings would depend on whether the reduction in propulsion fuel consumption exceeds the changes in automobile fabrication and materials processing energy. Going further, it can be shown that similar trade-offs exist among the other resource categories; additional capital requirements are needed for motor vehicle and aluminum production facilities, but these are offset by investment savings in such areas as refineries, petroleum distribution, and steel manufacturing.

The aluminum example suggests the broad range of options available in the selection of future automobile design concepts and the large number of consequences. There are substitution possibilities within resource categories (e.g., between materials or between energy forms) and trade-offs between resource sectors (e.g., capital displacing energy). These trade-offs raise several critical issues:

1. In the process of lowering petroleum imports, are we creating a vulnerability in another area to a potential cartel?

2. Is the implementation of the design concepts feasible or constrained by supply bottlenecks?
3. To what extent do the direct energy savings exceed any increase in the indirect energy requirements?

In order to address these questions, a computer-based model was developed for generating the resource impacts of alternative automobile technologies and constraints imposed by safety and emissions regulations. The model derives the aggregate energy, materials, capital and labor requirements for automobile production and usage from 1975 through 2000. Functionally, the simulation is usually operated as an accounting model and not as a predictive model. In this mode, consumer behavior is exogenously specified, in terms of fleet size, new car sales, sales mix, and fleet VMT. Data on the attributes of alternative automobile design concepts are another input to the model.

The object of this paper is to present and discuss representative results showing the resource impacts of alternative automobile design technologies. To facilitate this goal, the paper first presents an overview of the methodology, including a description of the component submodels and the manner in which they are tied together. Next, a series of scenarios is described, encompassing a broad spectrum of automobile design options and constraints associated with meeting safety and environmental goals. The resource impacts of these cases are summarized and their energy, materials, capital, and labor implications discussed. Those readers interested in a more detailed description of the methodology and results are directed to Rubinger and Prensky (1).

MODEL OVERVIEW

An overview of the analysis process is presented in Figure 1. The Resource Accounting Model is comprised of three component submodels with an integrated data flow: the Fleet Attributes Model, the Aggregate Materials and Energy Consumption Model (ARAM), and the Capital and Labor Impacts Model (INFORUM). Figure 1 also identifies the exogenous scenario-specific information required by the model. These data fall into three general categories: automobile design data, marketing and mobility projections, and scenario descriptors.

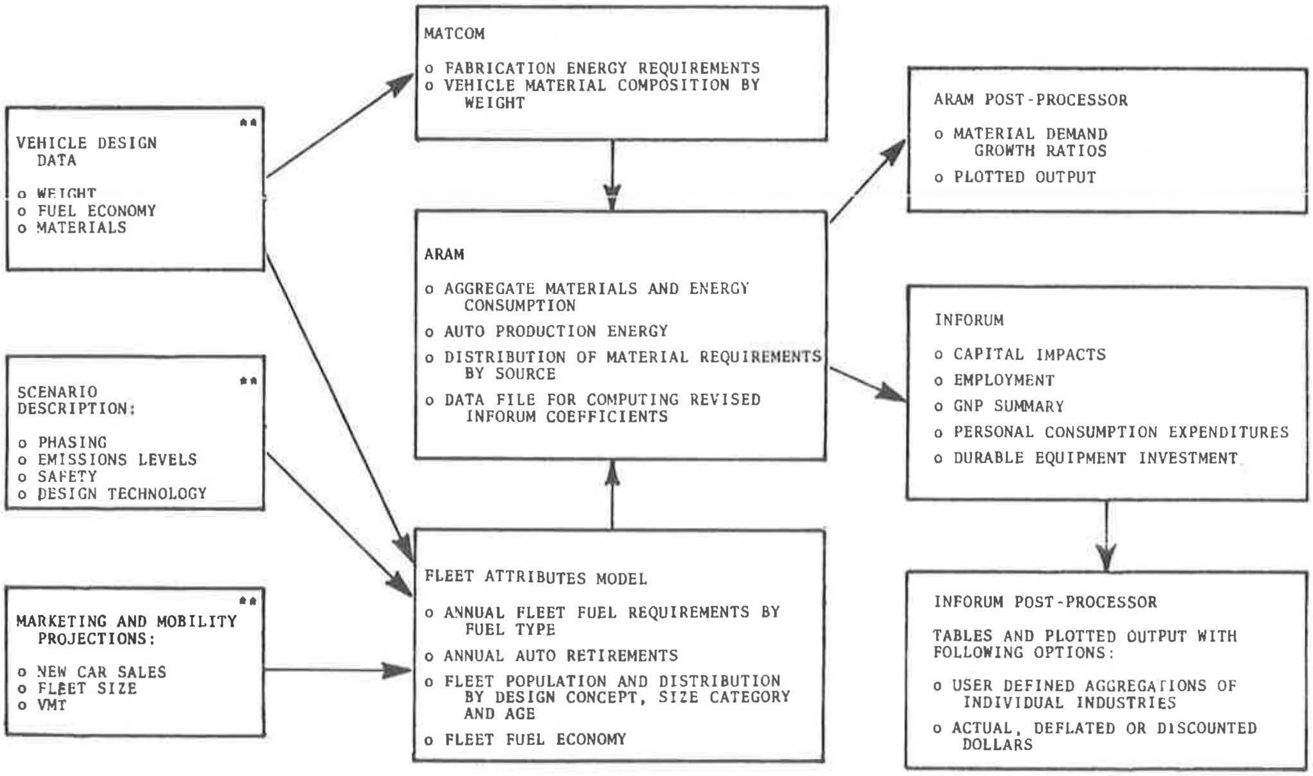
The impact analysis process is initiated by the specification of a scenario. Each scenario involves the selection of a series of automobile design technologies that are to be phased into production, along with schedules for implementing safety and environmental goals. The scenarios examine various combinations of automobile structure, engine, and drive train (each designated an automobile design concept); these rely on vehicle design data developed by the Auto Design Panel of the Federal Task Force on Motor Vehicle Goals Beyond 1980 (2). The specific automobile design concepts considered appear in Table 1. For each of these concepts, the value

Table 1. Automobile design concepts examined.

Fleet No.	Automobile Design Concept			Fleet Fuel Economy (km/L)
	Structure	Engine	Drive Train	
1	Current	Current	Current	6.9
3	Weight conscious	Top 1975	Current	9.7
4	Weight conscious	Top 1975	Improved transmission	10.5
5	Innovative	Top 1975	Improved transmission	11.7
7	Weight conscious	Diesel	Improved transmission	12.4
8	Innovative	Diesel	Improved transmission	13.5
10	Innovative	Advanced	Improved transmission	13.5

Note: 1 km/L = 2.47 mpg.

Figure 1. Overview of the Resource Accounting Model (RAM).



**Exogenous scenario-related data required by the model.

of such key vehicle attributes as weight, fuel economy, and material composition was required. Three size classes were used—small (four-passenger), midsize (five-passenger), and large (six-passenger).

The Fleet Attributes Model integrates marketing and mobility projections with automobile design characteristics to produce the scenario-dependent data required (a) to generate fuel consumption projections, (b) to run ARAM, or (c) to conduct a refinery impact study. In addition, it generates information on composite fleet emissions and the distribution of fleet VMT by age, automobile concept, safety level, and emissions standard. Projected fuel requirements are disaggregated into leaded and unleaded gasoline, diesel, and broadcut fuel. Since the Btu content of fuels differs, total fuel consumption and average miles per gallon statistics are calculated in gasoline equivalent measures (where 1 gal of diesel fuel is assumed to have the same energy content as 1.1 gal of gasoline or broadcut fuels). [The models were constructed using customary units; therefore SI equivalents are not given.]

The materials and energy consumed by the production and operation of automobiles are tracked by ARAM. A total of 24 major materials used in the production of automobiles are followed, and the total demand disaggregated among primary production, secondary production, and imports; this allocation is based on projections for future shipments and reflects a changing import ratio plus increased use of recycled materials.

ARAM also tracks the energy requirements, disaggregated by energy form (i.e., coal, natural gas, and so on) for materials production and processing, automobile fabrication, and automobile fleet operation.

The sequence of operations followed by ARAM is illustrated in Figure 1. Scenario-dependent data are supplied by the Fleet Attributes Model and Materials Composition (MATCOM). ARAM also includes an extensive internal data file containing all the nonscenario specific parameters. The values of the internal data coefficients and additional information on ARAM may be found in DeWolf and others (3).

Aggregate capital and labor requirements for the scenarios are generated by INFORUM, a dynamic model of the interindustry flows within the U.S. economy developed by the Interindustry Economic Research Project of the University of Maryland (4). The INFORUM input-output model was modified so that each scenario is translated into a new set of demands on the motor vehicle, producers durables, construction, and fuel supply sectors. For example, increased automobile industry investment requirements are converted into purchases from the producers durables and construction industries (3, 5). In addition, corresponding to the automobile design requirements, technical coefficients are modified to reflect the new pattern of purchases by the motor vehicles sector from supplier industries such as steel, aluminum, and plastics. Under these scenario-imposed constraints, INFORUM determines the gross national product (GNP) summary, personal consumption expenditures for the products of 200 industries, employment (disaggregated by 90 industries), durable equipment investment by each of 90 industries, and structures investment.

RESOURCE IMPACTS: REPRESENTATIVE RESULTS

The Resource Accounting Model provides the framework for examining a broad range of scenarios. For each case, the results will, of course, reflect the input assumptions regarding such factors as the rate of technology inplementation, the weight and fuel efficiency of the design configurations, new car sales, and fleet VMT projections. It is important to recognize that the validity of the methodology is independent of the choice of exogenous data. If other input assumptions were preferred, the simulation would be rerun with the alternate data. A useful application of the model is the examination of the sensitivity of the results to the input assumptions; this knowledge puts the significance of changes in the input data and the value of additional information into perspective.

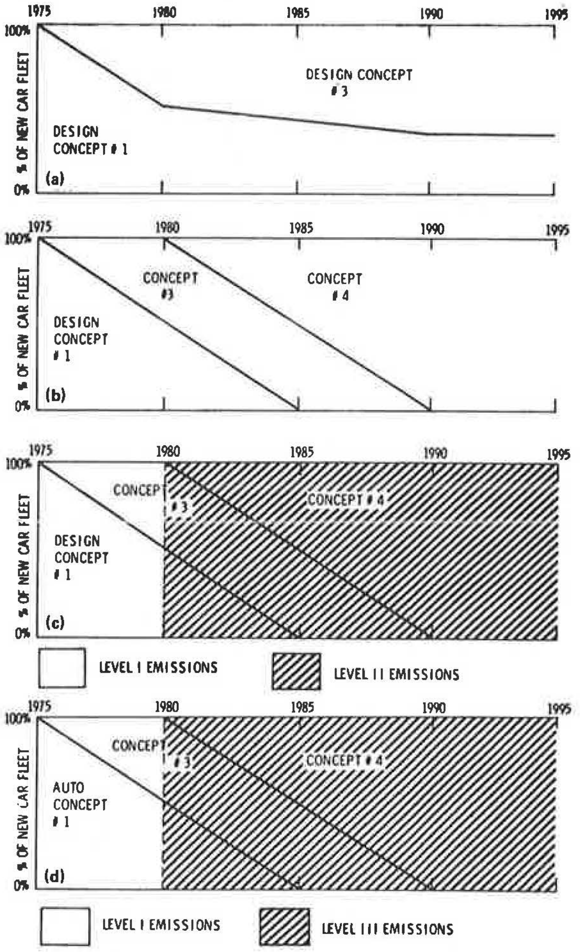
In the remainder of this paper representative results are presented and their implications for energy, materials, capital, and labor resource utilization are discussed. The cases selected focus on the resource impacts of alternative automobile design technologies and constraints related to national safety and emissions standards. To isolate these effects, the marketing and mobility projections (i.e., sales, market shares, VMT) have been held invariant between scenarios. For this purpose it was assumed that the future sales mix remains comparable to that in 1975. Furthermore, the growth in new car sales, fleet size, and VMT were based on the central projection of the Federal Task Force on Motor Vehicle Goals Beyond 1980 (6). These estimates are only dependent on the expected demographic and economic growth of the nation and not on a scenario's fleet fuel efficiency or other vehicle characteristics. Actually, some variations in sales and mobility between cases would be expected. However, a recent study showed that these perturbations are quite small (7) and can be ignored in deriving a first order approximation of the impacts. It should be emphasized that the resource accounting simulation has the flexibility of handling situations where sales, market mix, and VMT vary between scenarios; however, these results will not be presented here.

The central marketing and mobility projections assume new car sales grow from about 10 million units in 1976 to 16 million in the year 2000, an annual growth rate of about 2 percent. Simultaneously, total fleet size is expected to increase from 95.2 million vehicles (in 1976) to 161 million vehicles by the year 2000. Over this time period the corresponding growth in VMT is from 1648 to 2816 billion km (1030 billion miles to 1760 billion miles).

Four scenarios are illustrated in Figure 2. In scenario A (see Figure 2a), designated the Reference Case, 1975 begins with 100 percent production of automobile design concept 1 (see Table 1), the "average 1975" vehicle. Production of concept 1 is gradually reduced by the phase-in of automobile concept 3, which is characterized by a weight-conscious structure and top 1975 engine technology. Concept 3, which has a composite (i.e., averaged over sales mix) fuel economy of 10 km/L (24.2 miles/gal), is phased into production at the rate of 10 percent per year through 1980 and 2.2 percent per year between 1980 and 1990. This phasing assures that composite new car fuel economy in 1980 will be 8 km/L (20 miles/gal), the goal of both the voluntary fuel efficiency improvement program and the Energy Policy and Conservation Act of 1975 (8). Between 1980 and 1990, new car fuel economy improves an additional 10 percent and levels off thereafter at 8.8 km/L (22 miles/gal).

In scenario B (see Figure 2b), designated 1975 Technology Upgraded, design concept 3 is introduced into production at the rate of 10 percent per year, but production of concept 4 is initiated in 1980. This latter design concept is a weight-conscious vehicle as in concept 3, but in addition includes an upgraded transmission; its composite fuel economy is 10.5 km/L (26.3 miles/gal).

Figure 2. Scenario descriptions.



Design concept 4 is introduced into production at the rate of 10 percent per year and by 1990 represents 100 percent of new car production.

Scenario C (see Figure 2c), designated Upgraded 1975 Technology with Level II Emissions, is the first in a series designed to examine the impact of constraints associated with alternative emissions and safety standards. The emissions standards considered, identified as level I and level II, require that emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen not exceed 0.93/9.3/1.9 and 0.25/2.11/1.2 g/km, respectively. The figure for level III emissions is 0.25/2.11/0.25 g/km. Safety and damageability level II is characterized by a 64 km/h (40 mph) crashworthiness, plus antiskid brakes. Scenario C is identical to case B (see also Figures 3-5) in terms of the automobile design concepts produced. However, beginning in 1980, it requires that new cars meet level II exhaust emissions.

Case D, Upgraded 1975 Technology with Level III Emissions, is similar to the previous case except that all vehicles produced after 1979 must now meet more stringent (i.e., level III) emissions requirements (see Figure 2d). Meeting these standards requires that cars be equipped with dual or three-way catalysts. Estimates of the fuel economy penalties associated with future standards vary and range from zero to 20 percent; a penalty of about 10 percent was assumed for this scenario.

Case E, Upgraded 1975 Technology With Improved Safety, is similar to case B, except that there is an additional emphasis on safety. Automobile design concept 4, initiated into production in 1980, is assumed to meet level II safety and damageability requirements. The safety-enhanced vehicles are phased in gradually, achieving 100 percent of production in 1990.

Case F, Fuel Economy Emphasized with Level II Emissions, resembles case B in terms of phasing. However, the automobile design concept initiated in 1980 has a lightweight diesel engine, weight-conscious structure, and upgraded drive train. Automobile concept 7 is phased into production at the rate of 10 percent per year and represents 100 percent of the new car fleet by 1990. The superior fuel economy of the diesel allows the attainment by 1990 of a new car fleet fuel economy of 12.4 km/L (31.3 miles/gal, i.e., expressed in terms of gasoline equivalent gallons).

Representative results for the scenarios described here are given in Figures 3, 4, and 5. Figure 3 shows the average fleet fuel economy over the interval 1976 through 2000. It should be noted that improvements in fleet fuel economy lag behind new car fuel economy by about 10 years. This delay reflects the time it takes to scrap the older design concepts.

Total fuel consumption for scenarios and cases is compared in Figure 4. All the scenarios show fleet fuel consumption declining through 1985 as the gains in fleet fuel economy outweigh the growth in VMT. However, beyond 1985 the curves diverge, and by the year 2000 the reference case requires about 800 000 barrels/d more petroleum than the top 1975 technology case. It is also noteworthy that the adoption of the weight-conscious Otto designs allows fleet fuel consumption to be held below current levels through the year 2000, while maintaining the functional attributes of the vehicles. Viewed in terms of net energy requirements, production plus propulsion energy, the weight-conscious designs result in a savings of about 2 quads annually by the year 2000. Examination of the components that

Figure 3. Average fleet fuel efficiency.

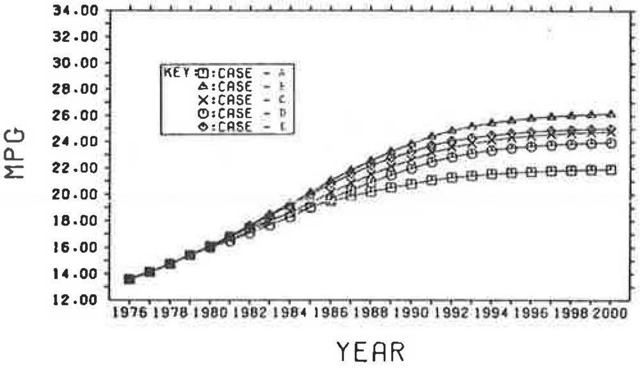


Figure 4. Comparison of annual fleet fuel consumption trends for selected scenarios.

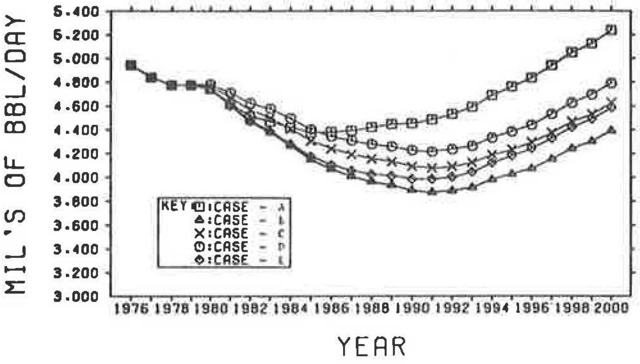
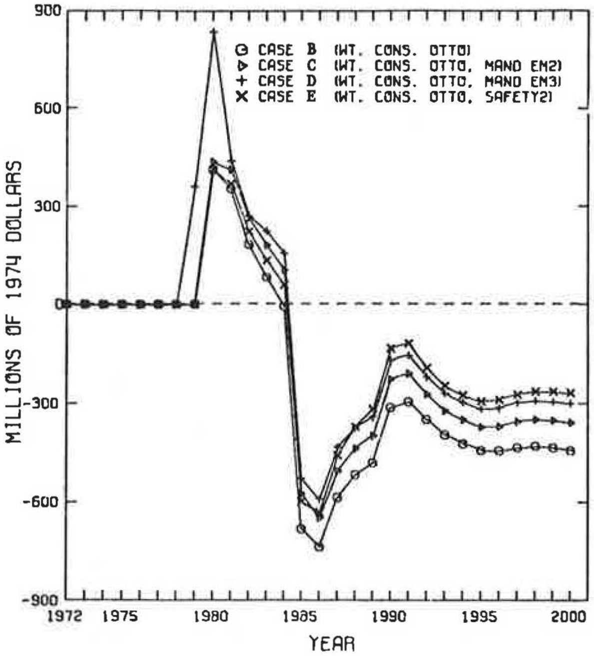


Figure 5. Total investment by case, as delta from the base case.



constitute net energy reveals that automobile production accounts for only about 9 percent of the total energy consumed by the fleet. Thus, the savings in propulsion energy achieved by material substitution (e.g., additional aluminum or plastics) overshadows the impact of any increase in vehicle production-fabrication energy.

The weight-conscious designs and innovative structures generally result in a significant reduction in consumption of the major materials used in automobile production. For example, the annual savings in steel consumption reaches about 1 million tons annually by the year 2000, while the comparable figure for cast iron is 150 000 tons. However, there are some exceptions to this trend. Increases are projected for specialty materials such as platinum, palladium, and stainless steel as a consequence of tighter emissions goals, while adoption of innovative structures leads to greater requirements for aluminum and plastics. Analysis of the material demand growth rates suggests that supply bottlenecks can be avoided with adequate planning.

The alternative design scenarios have greater investment requirements during the implementation phase, relative to the reference case, but show capital savings during the later years (see Figure 5). Whether or not there is a net capital savings depends on the discount rate used. Examination of the investment composition reveals that the capital impacts are determined by four primary effects:

1. An increase in investment requirements for the motor vehicle sector associated with the introduction of new design concepts;
2. A decrease in investment in the distribution sector due to lower levels of fleet fuel consumption;
3. Additional investments for service station conversion accompanying any shift to diesel fuel; and
4. A general decrease in capital investment requirements in the rest of the economy as a result of producing lighter vehicles (e.g., reduced demands upon the materials supply sector). A few industries run counter to these trends, most notably aluminum and the capital equipment manufacturers.

Finally, the employment impacts of the scenarios were relatively small. These impacts may be considered insignificant when compared with recent changes in the unemployment rate.

ACKNOWLEDGMENT

This work was carried out as part of the Automotive Energy Efficiency Project at the Transportation Systems Center and was sponsored by the Office of the Secretary, U.S. Department of Transportation. The Resource Accounting Model was developed by a multidisciplinary team that drew upon the advice of numerous experts in government. In particular, I wish to acknowledge the assistance of Bart DeWolf, Chris Davis, Peter Heinemann, Ron Mauri, and Alex Robb.

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Publication of this paper sponsored by Committee on Traffic Records.