ASSESSMENT OF GHG MODELS
FOR THE SURFACE TRANSPORTATION SECTOR

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1. INTRODUCTION

A working group of the Organization of Economic Cooperation and Development (OECD) is assessing the capabilities of models to estimate greenhouse gas (GHG) impacts of climate change strategies. This paper is a survey of several models used in the U.S. to estimate the impact of GHG control strategies in the surface transport sector. The models chosen for review were selected to represent both the state-of-the-art, and the state-of-the practice. While this paper does not attempt to review all possible models in the U.S., it is quite comprehensive in its coverage of models that are widely used, or ones widely acknowledged as the state-of-the-art by leading researchers in the field.

The categorization of models and the types of strategies that can be analyzed is necessary to provide a good comparative picture of modeling capabilities and model sophistication. Section 2 provides a description of one possible classification scheme that allows common descriptors to be used across of a variety of models and their capabilities to analyze different types of control strategies.

Broadly speaking, the forecasts of surface transportation related GHG emissions need models capable of forecasting vehicle stock, fuel use, and travel. These topics are the subjects of Sections 3, 4,5 and 6, respectively. The travel models are discussed in two sections, one that deals with travel at a national level and the second that deals with travel at a local and regional level. Freight travel models have not been traditionally coupled with personal travel models and are discussed separately in Section 7.

Section 8 describes models that integrate information on all vehicles, fuel and travel to estimate total fuel demand and GHG emissions. Section 9 summarizes the capabilities of the different models reviewed to analyze alternative GHG control strategies.

1.CLASSIFICATION OF MODELS AND CONTROL STRATEGIES

2.1 OVERVIEW

The modeling of GHGs from the transportation sector can incorporate or exclude many different aspects of the entire complex transportation system of the U.S. Models can scale from the micro-simulation level of a household and its transportation demand to very aggregate representation of the entire on-highway transportation system is the U.S. All GHG models have some common elements: an estimate of (1) the stock of vehicles, (2) the activity or travel by each vehicle and (3) the GHGs produced by the vehicle per unit of travel. However, models differ by the level of disaggregation of each of the three elements, and the sophistication with which changes to the three elements over time, or with policy changes, can be represented.

The level of disaggregation and sophistication are two descriptors of models, as is the scale national or regional (metropolitan area) type models. A survey of the different types of models reveals a curious dichotomy, in that the structure and assumptions of national scale models are typically completely different from those of regional models. Key variables and inputs to national models are usually default assumptions or constants in regional models, and vice-versa. Regional models focus on travel patterns, mode choice, the local road network and other similar local factors in their detailed representation of travel. National level models, however, focus on the vehicle fleet technology and composition, the type of fuel used, new vehicle sales and old vehicle scrappage, while travel demand is typically modeled simply as a function of macroeconomic forces. In contrast, regional models take fleet technology and fuels as inputs, or as an invariant.

The broad structure of the two types of models are shown in Figure 2-1 and 2-2, respectively. Most of the modeling efforts in national level models are concerned with vehicle attributes, vehicle choice modeling, alternative fuel supply and infrastructure, and vehicle sales and

FIGURE 2-1

National Transportation GHG Model Structure

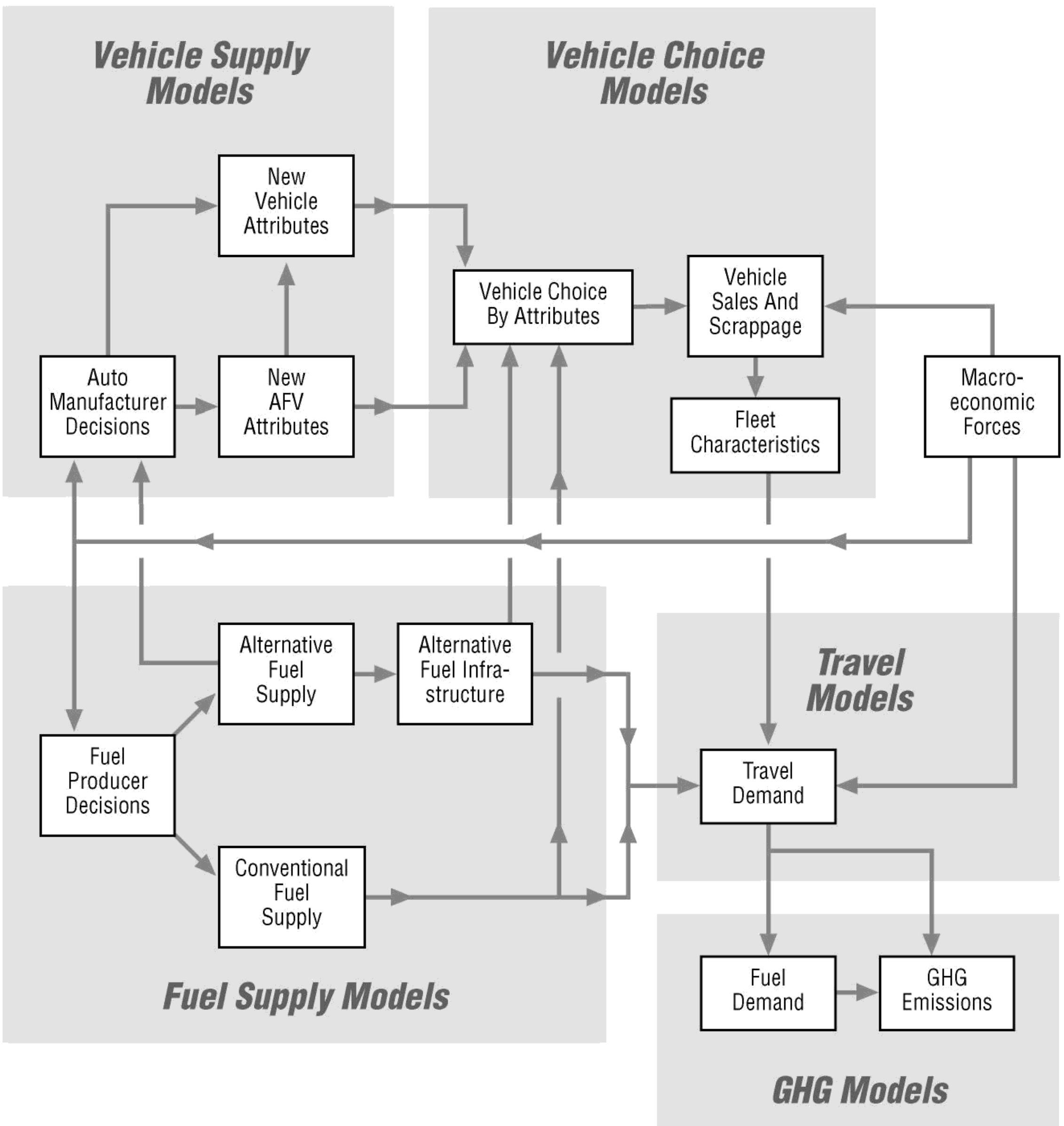
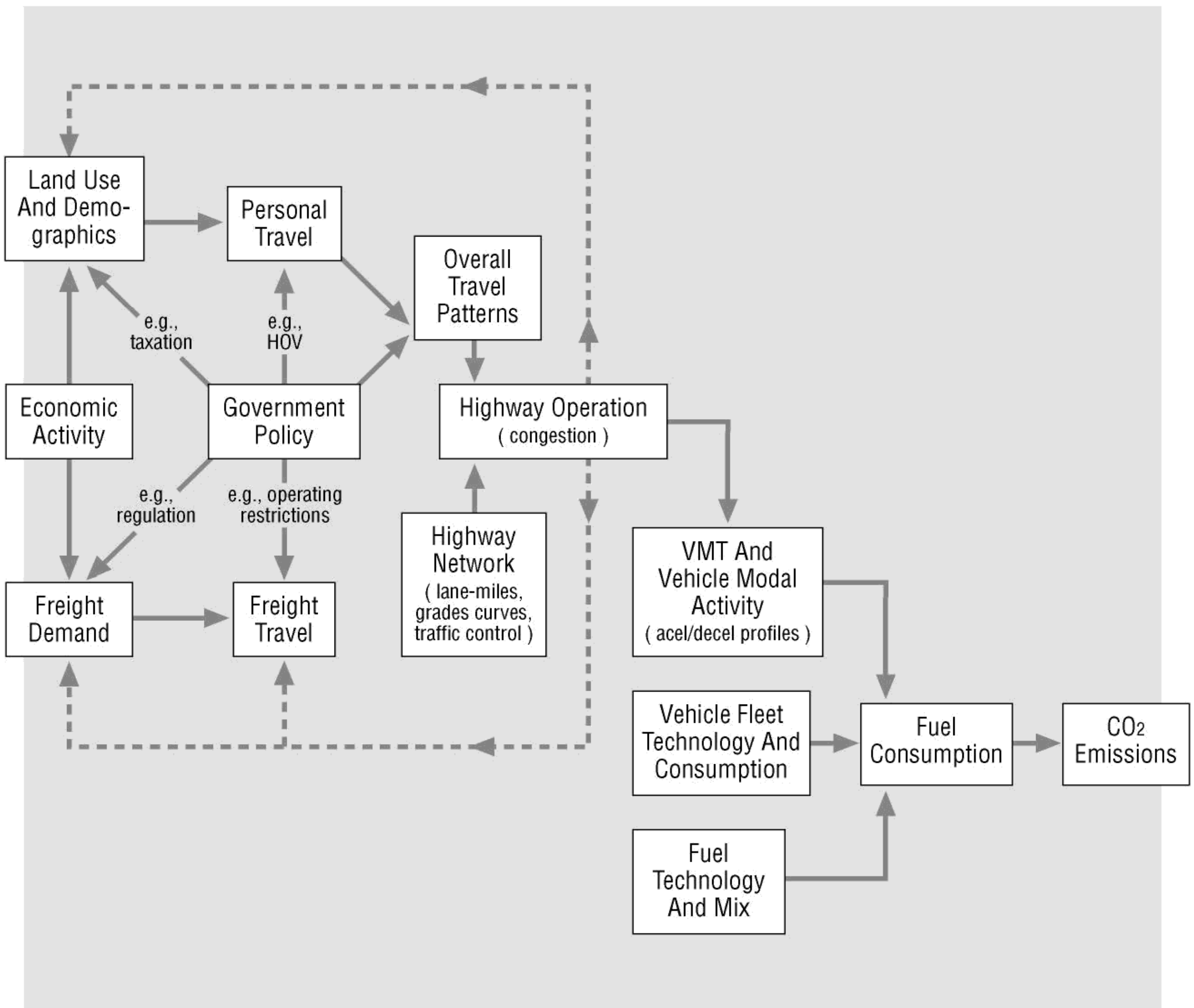


FIGURE 2-2

Regional Transportation Model Structure



scrappage. The fleet characteristics are then a computational outcome of vehicle sales/scrappage. At the national level, travel demand is usually represented by a series of relationships that increase base year travel activity at a growth rate that is an input or may be determined by demographic and/or economic forces. Total travel is then apportioned to the fleet using historical relationships between annual VMT, and vehicle type and vintage. Fuel demand by fuel type and GHG emissions are purely mathematical outcomes of travel by vehicle type and vintage, and vehicle efficiency.

Regional transportation models have a different set of key drivers as illustrated in Figure 2-2. Regional models can be classified as those that predict future demand (travel demand forecasting models; TDFs) and those that estimate detailed highway performance impacts (traffic operations models). A third category, post-processors for travel demand forecasting models, provide more detailed operational assessments than TDFs, but not as detailed as traffic operations models. Separate TDF models have been developed for estimating personal and freight travel demand. In both formulations, travel demand is a function of the regional layout in terms of population density, land use and the roadway network. These local and regional models are widely used for regional planning, and the entire structure in Figure 2-2 is popularly referred to as “four-step” models for their four distinct processes they replicate. Their primary purpose is to forecast future demand for highway, transit, and freight travel. Travel demand estimates in these models are based on forecasts of land use and demographics in the region. However, forecasts of land use and demographics are derived from a variety of methods that are far less standardized than the “four-step” process including: judgment-based adjustments to regional level forecasts, static land use prediction models, and dynamic urban growth simulation models. The “feedback loop” in Figure 2-2 indicates the interaction between land use and transportation that is sometimes addressed, most notably in the urban growth simulation models.

Post-processors and traffic operations models use TDF model forecasts to predict the impacts of alternative transportation investment strategies on system performance. Typical impact categories include delay, criteria emissions, safety, and fuel consumption. However, it is noteworthy that the vehicle fleet composition and fuel supply, availability and price issues are not significant modeling concerns in these types of models, but are usually simple representations of outputs from national level models. On the other hand, VMT estimates from regional TDF models account for the underlying processes that determine VMT in far greater detail than do national models. Also, even with their limitations with regard to vehicle and fuel technologies, traffic operations models are capable of determining the impact of highway conditions (most notably congestion) on fuel consumption, a factor that is essentially fixed in national-level GHG models.

2.2 CLASSIFICATION OF MODELS

Few, if any models, have a comprehensive and detailed representation of all facets of the transportation chain. The state-of-the-art is typically developed in one sector at a time, while the state-of-the-practice may lag in incorporating the state-of-the-art, as many of the supporting elements in more comprehensive models will be incapable of linkage with the state-of-the-art model input/output specifications.

For national level models, we have subdivided the framework into five areas:

- Vehicle technology and supply
  — conventional and alternative fuel vehicles;
- Fuel supply and infrastructure
  — conventional and alternative fuel;
- New and On-Road Fleet Composition
  — new vehicle choice
  — sales and scrappage
  — vehicle type and fuel type mix;
- Travel models
  — personal vehicle travel
  — freight travel;
- Total fuel demand and GHG models
  — vehicle related GHG models
  — full fuel cycle models.

The modeling approaches that are common to national level models are briefly discussed below, and address the issues of sophistication and disaggregation.

A very common form of GHG model is the "accounting" model, where the methodology contains logical identities. Such models track new vehicle sales by fuel type, vintage and fuel economy; as vehicles are scrapped, the model simply recalculates the revised fleet mix and its characteristics as a summation of the different vintages present. Fuel demand is then a mathematical outcome of *vehicles x travel x fuel efficiency*. While such models require extensive exogenous inputs for all factors, they can be useful in determining the effect of "target driven" policies, i.e., fuel efficiency standards or an alternative fuel vehicle sales target.

The second type of model is the "input-output" model where the forecast is driven by a set of equations relating a specific factor to an economic or policy input, but the actual process is not physically represented. For example, new vehicle fuel economy can be predicted as a function of fuel price and per capita income using a regression equation of historical response of fuel economy to these inputs. However, such models do not have any detail on the technological composition of fuel economy changes and implicitly assume that past relationships will define the future. The models characterize specific aspects as a "black-box" so that structural changes cannot be incorporated.

The third type of model is a "process" model that contains a detailed representation of the mechanism by which input is related to output. In the vehicle technology example, such models will have a representation of the actual technological improvements available to vehicles in the future. In a travel model, there would be a representation of the travel demand at the household level. Such models are capable of providing more richness to the output, and can often provide information on distributional effects whereas models with aggregate representation cannot.

Of course, models could have elements of all approaches incorporated, but typically, at the submodel level, these classifications provide a useful method to group available models.

A particularly useful consideration in the analysis of models is their ability to represent the effects of specific policy measures to control fuel demand, or more specifically, GHG control measures. Broadly, the measures can be classified as:

- Command and control;
- Voluntary responses;
- Pricing strategies;
  - — taxes and tax rebates,
  - — R&D support,
  - — subsides and payments,
  - — investment credits.

For this analysis, the pricing strategies have been subdivided into different categories, since some can easily represented in most models, while others such as “R&D Support” require models of greater complexity.

The level of disaggregation is also quite important in the ability to track policy effects and forecasts. For vehicles, separation of the commercial truck fleet and personal travel fleet is an essential requirement, but many models further disaggregate the fleet by size and weight class. For fuels, the number of alternative fuels represented is an issue, as is the capability to distinguish between conventional fuel types (diesel, gasoline, reformulated diesel, and gasoline alcohol blends).

The representation of consumer types and distinguishing between fleet and private buyers can be critical in evaluating programs oriented towards fleets and commercial vehicles or different types of vehicle users. Travel models need to distinguish between freight and personal travel, while very detailed dis-aggregation by freight type or household type is also possible. These factors establish the depth and sophistication of the modeling effort.

2.3 SUMMARY

The classification of models to estimate U.S. GHG emissions can consider may dimensions but a very general scheme can encompass:

- topic area (vehicles, fuels, travel);
- scale (national/regional);
- methodology (accounting, input/output or process);
- level of disaggregation (vehicle types, fuel types, consumer types);
- types of measures that can be modeled (command-and-control, voluntary, pricing).

3. VEHICLE ATTRIBUTE AND SALES FORECASTING MODELS

3.1 OVERVIEW

Models to forecast new vehicle attributes and new vehicle sales by market class for both conventional and alternative fuel vehicles usually treat vehicle attribute forecasts and sales forecasts separately. Models to forecast vehicle attributes of size, performance, range, price and fuel efficiency are usually distinct from models that predict sales volume and market shares by type and size. The only exception to this occurs for the forecast of alternative fuel vehicle price that, in some models, is sensitive to sales volume (to simulate economies of scale in production). The de-coupling of sales and attributes for conventional (gasoline) vehicles and for diesel vehicles is due to the fact that the vehicle "supply curve" is essentially flat in the anticipated range of sales variation. A separate class of vehicle <u>availability</u> models has been developed for use in urban area and statewide transportation planning.

This section describes the vehicle supply and demand models, that (with certain minor exceptions) rely primarily on macroeconomic inputs related to crude oil price, GNP growth, unemployment rates, etc. to forecast vehicle sales by vehicle attributes such as size, weight and fuel economy. In addition, vehicle availability models are also discussed.

3.2 VEHICLE ATTRIBUTE MODELS: CONVENTIONAL FUEL VEHICLES

The primary attribute of interest to GHG modeling efforts is the vehicle fuel efficiency and fuel type. However, consumer vehicle choice models are based on consumer demand for vehicle interior room, luggage space, acceleration performance and ride quality, and other less quantifiable attributes such as brand image and quality.

Economic studies of changes in conventional fuel economy have usually used an elasticity based approach where vehicle fuel economy changes were empirically related to fuel price changes using historical data. Studies in the early 1970s funded by the US DOT were the first to characterize the "supply" function for fuel economy on the basis of vehicle technology changes and their costs. The study by Menchen et al. (1974)[1] identified fuel economy improvements and tier costs, and presented a supply curve of miles per gallon (mpg) versus retail price increase. This study may be the first one publicly available using a detailed approach.

The technologically based approach has since prevailed, and the Technology/Cost Segment Model (TCSM) by EEA[2] in the early 1980s has served as the prototype for all such modeling since. The TCSM has been updated and expanded since that time and applies primarily to light-duty vehicles (cars and light trucks). This model has also been adopted in slightly modified form as a module called the Fuel Economy in the National Energy Modeling System (NEMS). The approach begins by defining a set of fuel economy technologies. This set is usually well known since all of the sources of inefficiency in the gasoline internal combustion engine, and the inefficiency in vehicle body design have been extensively studied over the last 50 years. Five data inputs describe the technology to the model:

- the impact on fuel economy;
- the impact on cost;
- the interactions with other technology;
- the effects on other vehicle attributes of interest to the consumer; and
- the date of first availability.

Typically, the technology models use this information to predict fuel economy changes over time and the resultant impact on vehicle price, using a model of auto industry behavior, while holding <u>vehicle attributes of size and performance constant</u>. The models of industry behavior result in a limit to technology market penetration based on the industry's product life cycle and tooling constraints, and assume that technologies that are "cost-effective" to the consumer are adopted. Cost–effectiveness is typically modeled as the ability of a technology to pay for itself in reduced fuel consumption, so that fuel prices are key input to the calculation. EEA's TCSM uses this approach, and the cost technology to fuel saving ratio determines the technology market penetration as subject to product life cycle constraints. The TCSM structure is very detailed for light-duty vehicles, and a similar detailed model for the heavy-duty commercial truck fleet is not available. NEMS incorporates a less detailed technology model for heavy-trucks. Recently, two other models of vehicle technology change and net fuel economy/price change for light-duty vehicles have become available. Both models use methodologies conceptually very similar to the TCSM, but have different cost/fuel economy data associated with technologies. One is from the American Council for an Energy Efficient Economy (ACEEE)[3] and is generally more optimistic in its fuel economy predictions relative to the TCSM. The second is from a study conducted by Sierra Research[4] sponsored by the American Auto-Manufacturers Association, which is somewhat more pessimistic. The study has not been released in the U.S. but a similar version has been released in Canada. Newer versions of the TCSM (as embedded in NEMS) and the Sierra Research study also incorporate negative or positive hedonic costs with technology costs to quantify the "cost" of more noise, vibration and harshness or the "value" of very high acceleration performance.

The net output of these models is a time based fuel economy/price forecast associated with a specific fuel price forecast or a regulatory requirement of fuel economy standards, for each vehicle size class at constant attributes. These models, therefore, directly provide the most important variable (mpg) for forecasting the vehicle GHG emissions per unit of travel under any input scenario of fuel price; alternatively, the models can provide a cost for meeting a desired mpg target. These models usually also provide other vehicle attributes such as weight and horsepower, which serve as inputs to vehicle choice models.

3.3 ALTERNATIVE FUEL VEHICLE ATTRIBUTES

The projections of alternative fuel vehicle (AFV) attributes are available from a number of models, mostly dating from the early-to mid-1990s. These include models by SAIC[5], EA-Muller[6], DeLuchi[7] and EEA[8], that estimated the attributes of AFVs using compressed or liquefied natural gas (CNG/LNG), methanol, ethanol, propane (LPG) and alcohol-gasoline blends. By and large, the assumption is that such vehicles will be derived from conventional vehicles, and attribute changes have been generally specified in percentage terms. For example, CNG vehicles are forecast to have fuel economy that is lower by five percent (on an energy basis) relative to a gasoline vehicle of similar size and engine displacement, and the weight is forecast to be three percent higher. Since all the fuels mentioned above are capable of being used in gasoline engines with modifications to the fuel system, this is a reasonable approach for what is likely a low sales volume product. This assumes that manufacturers will not develop special purpose AFVs that are not derived from conventional vehicles, and the market has shown this assumption to be true.

Most of the AFV attribute models were derived from an engineering analysis of cost and performance, but also have assumed price declines over time due to a combination of learning and increased sales. These assumptions have been included with no actual feedback from sales forecasting models that predict sales volume. Hence, assumed price declines have actually resulted in forecasts of increasing sales of AFVs, rather than the other way around. The only model that solves interactively for both vehicle price and sales volume is the Transitional Alternative Fuel Vehicle Model[9] (TAFVM), that is described in Section 4.

In the last few years, the three domestic manufacturers have introduced AFV models so that actual vehicle specifications are now the basis for near term forecasts of AFV attributes; these specifications are documented in GREET[10] as one example, but are also usually available in manufacturer product literature.

The only AFV types where the “derivative” approach has not been used are electric cars and fuel cell vehicles. Electric vehicle attributes have been forecast by the California Air Resources Board[11], OTA[12] and more recently, by UC-Davis[13], but these forecasts also suffer from the assumption of learning and sales volume driven price decreases in the future. The same organizations have also developed costs of fuel cell vehicles, which also have assumptions about the pace of fuel cell technology improvement as an additional input that lead to price declines and performance improvement in the forecasts.

A special point to be noted is that the AFV analysis is not conducted at “constant attributes” but explicitly specifies attribute losses for performance, range, interior room and refueling time. These factors have been forecast based on current AFV specifications and the known limitations of the technology, such as battery storage capacity.

3.4 VEHICLE SALES AND SALES MIX

Total vehicle sales and the sales mix by vehicle size class and type (car/light truck) have not been successfully forecast by any of the available methods. These variables are dependent on macroeconomic variables that are themselves quite difficult to forecast, such as economic growth, unemployment, interest rates and consumer confidence. The most widely used method to forecast total sales is in conjunction with large macroeconomic input-output models of the U.S. economy. Total vehicle sales are forecast on the basis of several econometric outputs of the models. Sales forecasts are available from DRI[14] and Chase Econometrics[15] that maintain large input-output models representing the entire U.S. economy.

Sales mix by vehicle type (car/light truck and heavy truck) and size (small intermediate, large, etc.) have proved very difficult to forecast due to changing consumer taste in the light vehicle market. DRI and Chase also provide forecasts of sales mix based on regression models of historical demand using vehicle price, personal disposable income, fuel price, and demographics as inputs. Similar regression models are employed by the NEMS Fuel Economy Module; however, none of these models have been successful in forecasting new trends such as the boom in sport utility vehicle sales in the U.S. (Models of sales mix by fuel type for AFVs are treated in Section 4).

Vehicle horsepower or performance level has not been forecast publicly (the auto manufacturers may have confidential models to estimate performance demand). The NEMS Fuel Economy Module incorporates a horsepower demand function that is based on personal disposable income and the fuel cost per mile, calibrated to historical data, and developed by EEA. However, the model assumes constant marginal utility for all levels of performance, which may not be true at very high levels of performance.

As the above discussion shows, vehicle sales, sales mix and attribute demand functions are largely the province of input-output models that are based on regressions of historical data. This area of modeling is potentially the least sophisticated and least advanced in the entire GHG modeling sequence. However, they are capable of modeling the effects of many GHG policies that affect operating costs or vehicle prices by size or efficiency class.
The only "process" model of sales and vehicle attribute demand that is in a developed form is one by Train.[16] The system uses micro-simulation; it starts with a database of representative household and commercial fleets, and then simulates vehicle transactions at the individual unit, including new vehicle purchases and sales and scrappage of existing cars. Forecasts for a region or the nation are derived by aggregating results across households and fleets, and the entire population can be represented by a relatively small number of "synthetic" households. It is a behavioral model that is estimated from surveys of households, and each household's choices depend on both vehicle characteristics and household characteristics. This model has been improved and expanded, and is used by the California Energy Commission[17] for its modeling of the California fleet.

While the model is conceptually superior to input-output models, it requires a large amount of survey data to be accurate. Moreover, the data must be periodically updated as household structure and preferences change over time. At present, there are no models available using this structure to represent the U.S. as a whole.

3.5 VEHICLE AVAILABILITY

Vehicle availability is a particularly critical variable in both trip generation and mode choice models, and also can have important indirect effects on trip distribution and on household location choices. Because vehicle availability is an important factor in travel forecasting, and thus on vehicle miles of travel and emissions, it typically is modeled explicitly as part of an urban area's and state's travel forecasting process.

Within the transportation planning process, the term auto ownership sometimes is used by travel modelers and forecasters in its strict sense to include only a consideration of the number of automobiles actually owned by household members. At other times, it is used in a more generic sense to include additional motorized vehicles, such as pickup trucks and motorcycles as well as leased and other vehicles available to household members but owned by others. The term vehicle availability is defined for purposes of this discussion to include each of these types of vehicles explicitly.

A number of approaches have been taken to vehicle availability modeling by transportation planners and researchers at metropolitan planning organizations, state departments of transportation, and academic research units. Although the number of vehicles available to a household is not always predicted explicitly as part of the regional travel forecasting process by MPOs, when it is, the most common approach is to forecast it as a function of other socioeconomic variables. The most common variables used are household income, size, and location; but additional household characteristics and locational descriptors are also often used. Models of this type represent the *state-of-the- practice* adopted by MPOs at the current time; they typically are developed using either Census or travel survey data and using a number of model estimation methods: linear-in-parameters regression using zonally aggregated data; cross-classification analyses of data sets with individual households as the basic unit; and choice models, typically with a logit structure, based on individual household observations. Models of these types are relatively easy to develop; their major limitation is that they provide no explicit representation of differences in transportation services and their impacts on vehicle availability, and thus are not directly applicable for estimating responses to alternative GHG policies.

The distinguishing characteristic of *advanced practice* vehicle availability models is their increased policy sensitivity. Advanced vehicle availability models include not only household socioeconomic and locational variables, but also variables which are related to the ease of pedestrian travel and/or the transportation facilities and services available to each household. Pedestrian environment variables typically reflect factors such as the ease of street crossing, building setbacks, sidewalk continuity, street connectivity, and topography at the zonal level. Models which include these variables show the negative relationship which exists between the quality of the pedestrian environment and the level of vehicle availability. Variables related to highway and transit system characteristics typically are accessibility measures such as the percentage of regional total employment or of regional retail employment that can be reached by a stated mode of travel within a specified number of minutes. Alternatively, accessibility measures can be derived from mode choice models. Because these additional variables depend on both zonal and transportation network characteristics, they complicate the vehicle availability model development and application process, but they also provide a means of including the observed linkage between transportation levels of service and vehicle availability. These models reflect the increases in vehicle availability with improved highway systems, and the decreases with improved transit systems.

With the new activity-based travel demand forecasting systems now being introduced into the transportation planning process, more detailed household-level vehicle availability models are being developed that include greater detail on vehicle availability, vehicle type choice, and vehicle usage. The Train model described in Section 3.4 is an example of such a model. These vehicle type choice models deal not only with the number of vehicles available to a household, but also with the characteristics of these vehicles. They provide a means of forecasting the impacts of future changes in vehicle technology such as electric-powered automobiles and smaller, more fuel-efficient vehicles.

As an alternative to estimating how many vehicles are available to a household at a given point in time, models can be developed to predict how households will change their vehicle availability as the household changes, its vehicles get older, the transportation system changes, and both vehicular operating costs and purchase costs change. Models of this type require time-series data for estimation, and typically also include vehicle type considerations as in the Train model. Household panel surveys, conducted at two or more points in time, are required for these models. In addition, because dynamic models are often concerned with how auto ownership patterns will change as new vehicle types become available, information may also be required on how households will respond to new vehicle types. Stated-preference surveys are designed to obtain information on hypothetical choices in experimental designs which facilitate the determination of tradeoffs between jointly varying characteristics of these not-yet-available choices. An example of a dynamic model of vehicle availability and vehicle type choice is the model development plan presented in a 1994 paper by Brownstone, Bunch, and Golob.

The newest forms of vehicle availability models, such as those represented by the work of Train and Brownstone, et al, present new challenges in terms of their data requirements and model complexity. They also provide the ability to answer new kinds of questions concerning household activity and travel behavior, and the impacts of this behavior on GHG emissions from the operation of future transportation systems.

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4. CONVENTIONAL AND ALTERNATIVE FUEL SUPPLY AND INFRASTRUCTURE

4.1 OVERVIEW

Since the market for conventional fuels (gasoline and diesel) is so highly developed, there are almost no models of conventional fuels supply and infrastructure. Indeed, world fuel (crude oil) prices are often an input into most models, while the current retail infrastructure is assumed not to need any modifications to meet future demands. Such assumptions are clearly not feasible for most alternative fuels under consideration. As demand for such fuels increase, existing supply sources will be inadequate for the transportation fuels market, and new production facilities will be needed. The retail infrastructures, which are currently almost non-existent for most alternative fuels, will also need significant investments. If alternative fuels displace conventional fuels, prices of conventional fuels will fall, as a secondary effect.

The demand for alternative fuel vehicles (AFVs) and, hence, for alternative fuels is dependent on both AFV attributes and the price and availability of the fuel itself. For this reason, models of AFV sales and fuel choice (for bi-fuel vehicles) are discussed in this section.

4.2 ALTERNATIVE AND CONVENTIONAL FUEL SUPPLY

There is a range of primary resources used to manufacture alternative fuels. Methanol, LPG and other alcohols/ethers used as blending agents are derived from natural gas. Several fuels, such as ethanol or bio-diesel, are derived from corn, grain, rapeseed, or even cellulosic materials such as woody wastes or corn stover. In the late 1980s, the U.S. Department of Energy (DOE)[1] undertook a systematic study of the supply curves for a range of alternative fuel feedstocks, and estimated the costs of production on an international basis by dividing the world into a number of regions. The supply curves for a variety of alternative fuels have been recently updated in another major study for the DOE conduced by Oak Ridge National Laboratory, EEA and J.E. Sinor.[2]

The world supply curves for crude oil and natural gas have also been developed for the DOE. A 1993 DOE study conducted by EEA[3] developed gas supply curves based on detailed marginal cost of production on a field-by-field basis. There are also crude oil supply curves for two types of crude (light and heavy) developed by DOE for the Oil Trade Model. However, the existence of price cartels in the crude oil market (OPEC) has made crude prices difficult to model on a resource cost basis. There have been attempts to model the crude oil market as a ‘Stackelberg’ monopoly, (where a subset of suppliers have a dominant share of the total market and behave jointly as a price leader), with some limited success. However, conventional fuel supply curves are generally not used in the context of most transportation fuel demand and GHG models.

These market interactions and the ultimate consequences for energy supply, demand, prices, and U.S. economic welfare can be partially assessed by examining the long-run market balances with an integrated model. The Alternative Fuel Trade Model (AFTM)[4] examines these interactions using an approach often called "long-run comparative statics." It compares long-run static pictures of the energy economy under alternative scenarios or policies, without explicit consideration of the intermediate adjustment process needed to reach those long-run balances. The approach focuses on:

- prospects for fuel substitution (in motor fuel, switchable boiler, and basic petrochemical markets);
- long-run effects of alternative motor fuel use on oil and gas demand, refining, imports, and fuels prices;
- ramifications of possible monopolistic responses by oil and gas exporters (specifically the OPEC countries).

AFTM determines prices and quantities of fuels which balance the inter-related world oil and gas markets, given a set of assumptions regarding supply, demand, and costs. It estimates changes in prices, supplies, and demands of conventional fuels if alternative motor fuels are made available to the U.S. market. It reports the level of alternative fuel use, and tracks the market clearing geographic trade in world energy supplies. The market costs and benefits of introducing these substitute fuels are also assessed, based on a standard "social surplus" analysis. Social surplus is defined as net economic benefits (or costs) of a particular market outcome, measured as the total benefits of fuel consumption minus the cost of domestic fuel production, fuel processing and distribution, fuel imports, and incremental vehicle capital costs.

The AFTM is a numerical simulation of regional fuel supplies, production processes, demand, and transportation. Each component of fuel supply, production and transport is assigned a cost for use in the model's optimization calculations. An additional "utilization cost" quantity is introduced into the optimization in markets that choose fuel supplies based on market share (or logit choice) functions. Demand is assigned a value based on the price consumers are willing to pay for each product; this becomes the model's valuation of the "benefit" of demand. The model seeks to minimize the sum of the costs and benefits of fuel supplies and demands under whatever constraints have been set up to describe a scenario of interest.

The AFTM balances supply and demand for a variety of conventional and alternative fuels in a world divided into six regions, using an optimization method. As a result, fuel prices and demand can be endogenously forecast through this model.

4.3 ALTERNATIVE FUEL VEHICLE AND FUEL CHOICE MODELS

Substantial development of alternative fuel vehicle choice models has occurred in the early to mid-1990s. The modeling methods that have been developed are of two types: the first based on stated preference from surveys of consumers, and the second, based on a "welfare maximizing" model of consumer choices which utilizes valuations of consumer time and revealed preference for vehicle attributes.

Stated preference models have been the focus of research at the Institute of Transportation Studies (University of California) with continuing model development by Ren, Brownstone, Bunch and Golob.[5] The model is similar to the approach used by Train in modeling conventional vehicle choice, in that it is a micro-simulation approach at the household level. The key inputs to the model are vehicle technology, fuel prices, fuel infrastructure and incentives to purchase AFVs. The newest version of this modeling approach combines data from revealed preference and stated preference into a single structure. The models are largely based on surveys of a panel of over 5,000 households in California conducted in the early 1990s with the survey repeated in the mid-1990s. The multi-nominal nested logit specification of vehicle choice is consistent with the approach used by Train, and many of the AFV choice specifications have been now included (in modified form) in the California Energy Commission model called CALCARS, described in Section 3.

Studies have found that stated preference models tend to be very optimistic in how much consumers are willing pay for fuel efficiency and reduced emissions. Some results from stated preference surveys have shown that consumers will pay $2,000 for a one cent reduction in cost per mile, implying an undiscounted payback period of 200,000 miles of driving. As a result, the models have historically tended to forecast high levels of AFV penetration.

More recent surveys have been conducted by Argonne National Laboratory[6] to recalibrate these coefficients. These surveys are also been designed by ITS and are of a national panel, so that the co-efficients derived are more representative of the U.S. as a whole. The analyses of the survey data have also attempted to correct for the consumer insensitivity to first cost on stated preference surveys. It remains to be seen if the newly developed model coefficients provide a more reasonable forecast of AFV market penetration.

The other type of model based on economic analysis has been developed by Dr. David Greene of Oak Ridge National Laboratory, and is called the Alternative Fuels and Vehicles Choice (AFVC) model.[7] The philosophy underlying the AFVC is to maintain a direct linkage between assumptions about fuels, vehicles and consumer behavior. This type of model also uses a multi-nomial logit specification, where all recognized factors that enter consumer choice of AFVs are represented in an utility function. The model considers cost, performance, size, value of having a multi-fuel option and range on the vehicle side, while also considering fuel cost, refueling time, refueling convenience in terms of availability, effect on performance, and social benefits of emissions and oil dependence reductions. All of these factors are evaluated in terms of net present value to the consumer and are represented in a utility function. Hence, the model is capable of recognizing the "disbenefits" associated with having a fuel that is sold only in some locations, or requires a long time to refill the tanks. The model's derivation also makes it possible to calibrate it to the real world experience, e.g., by using data from other countries where AFV penetration is significant. The main drawback is that it is static equilibrium model, in that the processes of introducing new AFV models or expanding infrastructure for alternative fuels whose market-share is growing are not represented in this model.

4.4 ALTERNATIVE FUEL/INFRASTRUCTURE EXPANSION

As described above, most of the existing models use static descriptions of AFVs and infrastructure, but do not describe the process by which such vehicles and fuels can enter the market. The one exception is the Transitional Alternative Fuels Vehicle (TAFV) Model.[8] The TAFV Model simulates the use and cost of alternative fuels and alternative fuel vehicles over the time frame of 1996 to 2010. As the name suggests, the TAFV model is designed to examine the transitional period of alternative fuel and vehicle use. That is, the model is a first attempt to characterize how the United States' use of AFVs might change from one based on new technologies available only at a higher-cost and lower-volume, to a world with more mature technologies offered at lower cost and wider scale. It also seeks to explore what would be necessary for this transition to happen, and what it would cost.

Previous studies are limited in that they examine AFVs in a single year. They present a 'snapshot' of AFV use given assumptions about technological maturity and price. The AFTM, for example, assumed mature vehicle technologies produced at large scale and a well-developed alternative fuel retail sector. Most studies, which examine AFVs in a multi-year, dynamic setting take technologies and prices as exogenously given. That is, fuel and vehicle prices are determined outside of the model. In particular, they do not examine the important linkages between investments in alternative fuels and vehicles, investment in alternative fuel retailing infrastructure, and the prices and availability of those technologies.

The TAFV follows up on the long-run equilibrium analysis done with the AFTM, which was a partial equilibrium model, used for long-run comparative static analyses. By making endogenous the scale of alternative vehicle and fuel production and the retail availability of alternative fuels, the TAFV model fills a gap in alternative fuel analysis. Vehicle and fuel prices are determined within the model based upon underlying supply and demand curves. In contrast to the AFTM, the TAFV model specifically characterizes the time path of investment and adjustment, in order to consider whether some of these transitional issues may be important. The results from the TAFV model do, necessarily, reflect its many primary assumptions such as the prices for vehicle and fuel production capital, the costs of raw materials, and input-output assumptions that describe the productivity of a unit of capital in its respective employment.

More generally, the TAFV model provides a methodology for simulating the introduction of new technologies where economies of scale and endogenous feedback effects are important. Explicitly modeling these dynamic effects is very important and cannot be ignored for a wide variety of economic and environmental questions that involve either fixed investment in capital or pollution stocks such as greenhouse gas emissions.

There are a variety of transitional phenomena at work in AFV markets, which might be influenced by policy. As alternative vehicle and fuel producers gain cumulative experience, some cost reductions through learning and economics of scale are expected. If vehicle manufacturers are encouraged to design and introduce new AFVs, the number of vehicles models offering AF capability rises, and consumers value this greater choice. Incentives or programs leading to the earlier development of fuel distribution infrastructure can increase fuel availability. Programs calling for the purchase of AFVs by fleets lead eventually to the sale of used fleet vehicles to private consumers, making AFVs available to used-vehicle buyer, increasing demand for alternative fuels and AFVs. Each of these possible linkages may work slowly, as investments are made and vehicle and capital stocks adjust. The TAFV model characterizes, in varying degrees of detail, interactions among the major stakeholders, and uses an optimization routine to determine a dynamic market equilibrium. Of the different models, it is perhaps the most sophisticated effort at estimating future AFV penetration and fuel infrastructure expansion simultaneously.

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5. NATIONAL TRANSPORTATION PERFORMANCE MODELS

5.1 INTRODUCTION

The National Transportation Performance Models reviewed are the "Car Talk" VMT model developed by the U.S. Department of Transportation's Volpe National Transportation Systems Center, the procedure used in the Transportation Research Board's (TRB) "Sustainable Future" project, and the Highway Economic Requirements System (HERS),. The "Car Talk" and TRB models are relatively simple in terms of analytic processes and input data, and both were developed specifically for estimating the effects of GHG strategies at the national level. HERS is substantially different in purpose and structure than the "Car Talk" and TRB models. HERS is essentially a national level traffic operations model that is used to gauge the effect of highway conditions and investment on system performance. Its procedures are not as detailed as some traffic operations models applied at the local level (e.g., traffic simulation models) but it nonetheless produces similar results. HERS uses the Highway Performance Monitoring System (HPMS) data as input, a detailed inventory of selected highway sections. The importance of the HPMS data and the HERS model to this discussion is that they represent a reliable and widely used source of national-level estimates of vehicle miles of travel and commonly serve as the source of highway transportation data used in national-level GHG analyses and other national models of transportation behavior.

The "Car Talk" and HERS models can be classified as an "input-output" models while the TRB model can be thought of as essentially an "accounting" model, although it does use some elasticities.

5.2 "CAR TALK" NATIONAL VMT FORECASTING PROCEDURE

The Volpe Center's "Car Talk" VMT Model[1] is a three-stage procedure for estimating VMT at the national level. The basic model (first stage) relates annual nationwide VMT to licensed drivers, vehicles per licensed driver, and annual VMT per vehicle in a straightforward multiplication. The explanatory variables in the basic model are estimated through a series of log-log regression equations (second stage) that include the explanatory variables of:

- Gross Domestic Product per capita;
- fuel price per gallon;
- fuel price per mile driven (a function of average fuel efficiency {mpg} and fuel price per gallon);
- new vehicle price index;
- labor force participation rate;
- road miles per licensed driver; and
- vehicles per capita.

In turn, these variables are developed from exogenous forecasts published by government agencies, consensus of experts, and historical trends (third stage). Since the first two stages are fixed, the key to application of the model is the ability to forecast the explanatory variables in the regression equations. The model's authors note that forecasts of future population growth and fleetwide fuel efficiency are particularly uncertain and have applied the model for several different forecasts of these variables. In a recent application of the model,[1] VMT growth between 2000 – 2020 is expected to average 2.5 percent per year under a high population growth, increasing fuel economy scenario and 2.0 percent per year under a low population growth, decreasing fuel economy scenario. By comparison, the growth factors in the 1997 HPMS sample indicate a growth rate of around 2.0 percent per year for the 1997 – 2017 period.

The "Car Talk" model is sensitive to national trends in fuel price, fuel efficiency, and vehicle prices and thus can be used to gauge the effects of GHG strategies targeted at these items. Because these factors are related to the primary VMT components through historical regression equations, the ability to account for future changes in the underlying processes is limited. The inclusion of the "road miles per licensed driver" variable is problematic for studying the effects of GHG strategies aimed at transportation system improvements, both capital and pricing. The authors suggest that this variable is a surrogate for the available supply of highways in terms of the general speed of trips (and was selected because of lack of data for speeds and lane-miles), but unless totally new roads are constructed, it does not change. Therefore, highway reconstruction, Intelligent Transportation Systems (ITS) deployments, and pricing/market strategies will show no effect in the model. Finally, the use of exogenous forecasts of explanatory variables makes the "Car Talk" model dependent on these sources for basic input data.

5.3 "SUSTAINABLE FUTURE" ANALYSIS PROCEDURE

The Transportation Research Board (TRB) utilizes a simple model in its "sustainable future" analysis to forecast CO_2 emissions at the national level.[2] It is similar to the "Car Talk" model in that it is based on national VMT and fuel efficiency forecasts. However, it carries the analysis a step further in that it applies a CO_2 emissions rate (pounds per VMT) to the VMT estimates to derive total CO_2 emissions. (The base CO_2 emissions rate is calculated by dividing "pounds of CO_2 per gallon of fuel" by fuel efficiency.) The effects of GHG strategies are thus estimated through changes in VMT, fuel efficiency, and the CO_2 emissions rate of vehicles.

For forecasting a baseline condition from 2000 to 2040, VMT is assumed to increase 1.5 percent per year. This value is lower than HPMS or "Car Talk" values but the forecast horizon is much longer for the TRB procedure. The model is then applied in three scenarios of general GHG strategies:

- Reduction in Motor Vehicle Demand – the combined effect of various transportation demand management strategies (e.g., ridesharing, transit, parking restrictions) and land use/growth management strategies is accounted for by reducing the VMT growth rate.
- Increase in Motor Vehicle Fuel Economy – the procedure was applied assuming an increase in fuel efficiency of 1.5 percent per year.
- Higher Motor Fuel Prices – the effect of higher fuel prices is addressed through elasticities for both VMT and fuel efficiency.
- Development of Low GHG Emitting Vehicles – the CO_2 emissions rate is varied as these vehicles enter the market.

Note that for each general category of GHG strategy, the assumed effect on the procedure's explanatory variables are developed "off-line" through simplified procedures. Therefore, the main purpose of the TRB procedure is to provide bounds on the problem rather than to study the effect of individual GHG strategies in detail. Like the "Car Talk" model, the TRB procedure relies on exogenous forecasts of explanatory variables. However, some of the basic relationships – such as fuel price elasticities and the CO_2 emissions rate may be useful for inclusion in other models. If GHG strategies beyond the four noted above are to explored with this model, additional relationships between them and model's primary factors (VMT, fuel efficiency, and CO_2 production rate of vehicles) would have to be developed. The effect of alternative fuels could also be studied if the CO_2 content of the fuel and the fuel efficiency of vehicles using that fuel were known.

5.4 HIGHWAY ECONOMIC REQUIREMENTS SYSTEM (HERS)

The HERS[3] model was developed by FHWA to determine the effects of highway investment and management strategies on highway system performance. It uses FHWA's Highway Performance Monitoring System (HPMS) data as a basis for its calculations. The HPMS data describe the physical characteristics of a sample of highway sections from all the States. Each section is selected as a stratified random sample based on functional highway class and traffic volume. Data include geometrics, pavement condition, and traffic characteristics. HERS simulates the highway improvement process by identifying deficient highway sections and instituting improvements. In doing so, it cycles through all the sections in the underlying HPMS data and keeps track of improvement costs and the effects the improvement has on several impacts categories: travel time, vehicle operating costs, accidents, and criteria emissions (CO, VOC, and NO_x). The impacts on the sample sections are then expanded as representative of the entire highway system.

Improvement types considered include traditional "capital" improvements (lane additions, shoulder widening, curve flattening, signal upgrades) as well as several categories of transportation demand management (TDM), including transit service/fare improvements, parking pricing, ridesharing, employer trip reduction, congestion pricing, and fuel taxes). The effect of TDM strategies is calculated by applying VMT reduction factors derived from the literature. The effect of Intelligent Transportation Systems (ITS) strategies is limited to ramp metering and signal coordination. The effects of capital improvements are estimated directly through relationships between the impact categories and highway conditions. Speed is estimated through functions that incorporate the traffic and physical characteristics of the section. The speed models include the effect of queuing in over-capacity traffic conditions. Criteria emissions are modeled as a direct function of average speed on the section using simplified relationships extracted from the MOBILE5a emissions factor model, the national model developed by the U.S. Environmental Protection Agency (EPA) for estimating emissions of volatile organic compounds (VOC), carbon monoxide (CO), and oxides of nitrogen (NOx). Fuel consumption is modeled directly as a function of seven vehicle types, average speed, grade, and speed-change cycles. However, fuel consumption is not reported as output from the model; it is imbedded into total vehicle operating costs, which are generated as a model output. Further, the fuel consumption relationships are outdated and based on a sample of vehicles with fixed technologies.

HERS uses traffic growth factors in the HPMS data to simulate the effects of improvements over a forecast period, usually 20 years into the future. During the analysis period, HERS identifies deficiencies on the HPMS sample sections, implements improvements targeted at those deficiencies, develops costs for the improvements, and estimates the system performance impacts of both the improved and unimproved sections. The HERS model is applied at the national level by FHWA and is used to produce the biennial *Highway Conditions and Performance* report to Congress. In addition, many states also use HERS to make state-specific estimates, although the sample size of the underlying HPMS data must be considered when performing state-level analyses.

The basis of HERS' analytic capabilities is the HPMS sample data. Therefore, it is tied to the data reported for the individual sample sections. It is highly sensitive to strategies that affect the sample section directly (e.g., capital improvements) but strategies that affect the demand for travel or the characteristics of vehicles making that travel are only crudely addressed. Current year VMT in the HPMS data, which are based on current traffic counts, form the basis for official reporting of VMT by FHWA. Because the data are based on a disaggregated sample, VMT estimates for many different levels of aggregation are possible.

VMT growth in future years are based on state-supplied growth rates for individual sections. These growth rates are developed from a variety of sources by the states and do not follow any single convention; sources include urban travel forecasting models and historical growth rates. These sources for VMT growth do not (to our knowledge) include the effects of vehicle- and fuel-related GHG strategies. HERS has a procedure for adjusting traffic growth based on estimated user costs for each section: as user costs increase, VMT growth is suppressed. Because section user costs are estimated only as a function of highway and traffic characteristics, VMT forecasts are not currently adjusted to account for the effects GHG strategies that deal with vehicle attributes/sales, alternative fuels, and land use/growth management; the effect of pricing strategies is limited to a crude estimation of the VMT reductions due to fuel tax increases. However, elasticities from national-level vehicle attribute/sales and fuel models could theoretically be applied to HERS' VMT forecasts. Finally, because HERS is based on assumptions about overall future traffic growth, it is insensitive to changes in freight demand and movements.

HERS' main advantages for GHG analyses are its abilities to estimate VMT, especially at the national level but also for levels smaller than the national level, and the fuel consumption impacts of highway conditions and transportation investment strategies (including demand management and transit). Because the impacts are "built up" from individual highway segments, analyses directly include the effects of variability in highway conditions. However, because the fuel consumption in HERS is not directly reported as output, changes to the model would have to be made. Also, the underlying relationships are outdated and insensitive to vehicle- and fuel-related GHG strategies.

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6. METROPOLITAN TRANSPORTATION MODELS

6.1 INTRODUCTION

Metropolitan Transportation Models are used to guide state and local investments in transportation. Their intended purposes are to forecast future demand for transportation and to estimate the impacts of alternative investment strategies. Travel demand forecasting (TDF) models provide the most detailed estimates of VMT of any model available – because they account for the processes determining travel demand – but are limited in scope to the particular metropolitan region being studied. TDF models have been developed at the state level, but the existence of statewide models is limited and are not as ”standardized” as metropolitan models. Also, state level TDF models tend to focus on major intercity routes and do not provide the detail in road system coverage offered by metropolitan models.

Since the 1970s, Metropolitan Transportation Models (including TDF and traffic operations models) have been used to estimate fuel consumption as one of the impacts of transportation conditions and investments. However, the underlying relationships are based on a limited number of test vehicles and many have not been updated. They relate vehicle activity (which is determined by congestion level and highway features) to fuel consumption, but do not account for changes in underlying vehicle and fuel characteristics. For estimating the relative change in fuel consumption due to transportation investments, this limitation is not particularly germane, but it does severely restrict the models’ ability to estimate GHG strategies aimed at vehicles and fuels. However, the ability to account for VMT under different driving conditions is an important feature that might be tapped in the future. Many – if not most – of the models discussed in Chapters 3 and 4 are insensitive to this factor: they assume that the driving conditions (congestion and road features) under which VMT occurs will remain constant into the future. This assumes that transportation investments will match increases in travel demand in about the same balance as experienced historically. Although these assumptions are reasonable for the vehicle and fuel models' purposes, it understates the contribution to GHG control that transportation investments can have.

6.2 TRAVEL DEMAND FORECASTING (TDF) MODELS

TDF models have a long history of development and application within metropolitan areas, dating back to at least the early 1950s. They were originally designed to forecast future year highway traffic (typically 20 years into the future) for the purpose of identifying deficient road sections. They were expanded in the 1960s to produce estimates of future demand for fixed-route transit and later to include demand estimates for other nontraditional modes of travel (e.g., ridesharing). TDF models are based on a network typology meant to be an abstract representation of the region's highway and transit system. The network is composed of individual links and nodes that correspond roughly to major intersections and interchanges in the actual road and transit network. Their formulation has been continuously improved over the years and TDF software has migrated from mainframe to microcomputers. Examples of current TDF model software[1] packages used in the United States include EMME/2, TP+, URBAN/SYS, MINUTP, and TRANSCAD. Despite their slightly different features, the same basic four steps, run in sequence, typify TDF models:

- Trip Generation – determining the number of trips originating and terminating in small geographic areas ("traffic analysis zones") throughout a region;
- Trip Distribution – determining the number of trips traveling from an origin zone to multiple destination zones;
- Modal Split – determining what percent of trips between zones use the various modes of travel that are available; and
- Traffic Assignment – determining the specific routes in the network taken by trips between zones.

In addition to depictions of highway and transit networks, TDF model inputs include forecasts of population, employment, and household characteristics at the traffic analysis zone level. These forecasts are derived from regional forecasts and trends, and incorporate the effect of expected land use changes and growth management policies. Metropolitan areas use a variety of methods to develop TDF input forecasts at the geographically small traffic analysis zones. These methods range from simple allocation of expected growth through judgment or Delphi techniques to the application formal land use models, sometimes in an iterative fashion with preliminary TDF model results. The most sophisticated models in this latter category are the so-called urban simulation models, which replicate the growth of metropolitan areas for small time intervals (typically year-by-year). Urban simulation models include the effect of the transportation system on urban growth as well as growth management and land use policies. In all cases, the effect of expected land use changes and growth management policies are considered.

Typical outputs from TDF models include link specific estimates of traffic volume and associated vehicle speeds and a "trip table", the estimated number of trip interchanges between zones. Network-wide estimates of VMT can be obtained by summing the product of link volumes and lengths. Because average link speeds are also output, network-wide delay estimates can be made. However, TDF-produced speeds have been criticized as being too crude for detailed emissions and fuel analyses. Some TDF models make estimates of fuel consumption from these speed estimates by applying simple relationships relating average link speed to fuel consumption. But even with very accurate speed estimates, fuel consumption and emissions are in part a function of vehicle operating mode (acceleration, deceleration, access ramps, hills, etc.) and the treatment of vehicle operating mode is not yet incorportade in TDF modeling.

6.3 POST-PROCESSING MODELS AND PROCEDURES

The main purpose of TDF models is to produce demand estimates, usually in terms of highway network volumes (link-by-link), transit ridership, and number of trips between origins and destinations. Speed and delay estimates that are output are often unrepresentative of actual highway conditions. However, speed/delay estimates are a key indicator of transportation system performance and are used in modeling emissions related to air pollution, congestion management, and benefit/cost analyses of transportation investments. To obtain better speed/delay estimates and to develop these analyses fully, TDF model outputs are often post-processed. Examples of formal TDF post-processing models include:

- Surface Transportation Efficiency Analysis Model (STEAM)[2] – developed by FHWA and Cambridge Systematics, Inc. and used to assess the impacts of highway capital and transit investments;

- Intelligent Transportation Infrastructure Deployment Analysis System (IDAS)[3] – Currently under development by FHWA, Oak Ridge National Laboratory, and Cambridge Systematics, Inc., IDAS is designed to assess the impacts of ITS strategies; and

- Post Processor for Air Quality (PPAQ)[4] – Developed by Gary Davies of Garmen Associates, PPAQ develops improved estimates of vehicle operating conditions by highway functional class and translates these into emissions using characteristics contained in the Environmemntal Protection Agency's MOBILE5A model. PPAQ has been widely applied within the northeast United States and currently is being adapted for use in New York City.

All post-processors take TDF model outputs and make speed and delay estimates independent of those produced by the TDF model. Various equations have been developed for this purpose, including modified versions of those used by TDF models as well as equations that incorporate vehicle queuing analysis and traffic signal operation. The STEAM and IDAS models have the capability to use the revised speed estimates to make a revision of the initial TDF model outputs; the effect of future travel conditions on travel demand can be made in a way not possible with static applications of TDF models. (The use of this type of "feedback" has been tried by using TDF models only, but the process for doing so is extremely cumbersome and manual in nature.)

Some post-processor models then make estimates of fuel consumption based on the revised speed and delay estimates; these tend to use straightforward relationships between average speed and fuel consumption. Because their speed estimates are thought to be more reliable – due both to better fundamental relationships and (in some cases) the use of feedback – post-processor models' fuel consumption estimates are also thought to be more reliable. However, for GHG strategy analysis, the limitations of TDF models in accounting for vehicle- and fuel-related policies remain.

6.4 TRAFFIC OPERATIONS MODELS

Traffic operations models encompass a wide range of analytical techniques aimed at developing estimates of the operating characteristics of the highway system. Techniques include highway capacity analysis, queuing analysis, and shock-wave analysis. Models include macroscopic and microscopic traffic simulation. All of these methods produce estimates of vehicular speed and delay as their basic measures of highway performance, although many other measures also can be produced depending on the method's capabilities; these include density, queue length, number of stops, and various subcomponents of delay. For the purpose of GHG strategies, we will focus on traffic simulation models.

Like TDF models, traffic simulation models work with a representation of the actual highway network. However, much more detail on network characteristics is required for simulation models. Both macroscopic and microscopic simulation models attempt to replicate traffic flow on the abstracted network. Macroscopic models use aggregated traffic flow relationships, sometimes including queuing analysis and shock-wave analysis, to simulate traffic flow. Macroscopic models may be either simulation models (used to study specific conditions) or optimization models (used to determine "ideal" operating parameters such as signal timing. Microscopic models are simulation-oriented and are much more detailed and replicate the movements of individual vehicles for small time intervals, usually second-by-second. In microscopic models, vehicles interact with the characteristics of the network and with each other; the speed and acceleration of each vehicle is tracked and system performance measures are accumulated from these "microscopic" statistics. Microscopic models require more detailed data and have much longer run times than macroscopic models and are typically applied to study relatively small networks. Examples of traffic models currently in use include:

- Macroscopic Traffic Simulation[5] – FREQ, CORFLO;
- Macroscopic Traffic Optimization[6] – PASSER II, MAXBAND, TRANSYT-7F;
- Microscopic Traffic Simulation[7,8] – CORSIM, INTEGRATION, PARAMICS.

Traffic operations models of all types usually include features to make estimates of fuel consumption. In all cases, the relationships were built by examining a limited number of vehicles (usually passenger cars only) without regard to vehicle or fuel technologies. Much of the underlying fuel consumption data are many years old. However, the primary purpose of such estimates within traffic analyses is to measure the *relative* change in fuel consumption due to different improvements and operating policies. In macroscopic formulations, the fuel consumption relationships are based on aggregated traffic performance measurements such as delay, average speed, and number of stops. In microscopic models, fuel consumption is built up from instantaneous (second-by-second) fuel consumption based on vehicles' speeds and accelerations.

6.5 SUMMARY

As the basic analytical tool of transportation planners in metropolitan areas, travel demand forecasting, or TDF, models were developed initially to support the planning and construction of major new highways. Subsequently, TDF model systems were adapted to support the planning and construction of rail transit systerms. Most recently, they have also been adapted for a variety of uses for which they were not originally intended, including air quality analysis, high occupancy vehicle (HOV) lanes, and other forms of congestion management. Their primary advantage for GHG strategy analysis is that they can produce regional-level VMT estimates that are sensitive to transportation system improvements as well as some forms of pricing, travel demand management, and land use policies that potentially could be applied within a metropolitan region, especially when these model systems are linked to formal procedures for forecasting future land use and growth patterns. Fuel consumption estimates using TDF model outputs are extremely crude. They are not sensitive to GHG strategies aimed at vehicle- and fuel-related changes in policy and technology. In terms of geographic scale, TDF model systems are typically applied at the level of a single urbanized metropolitan area, or for an individual corridor or subarea within a larger metropolitan area. TDF model systems only recently are being extended to cover an entire state. Rural and exurban areas located between separate metropolitan areas normally are not represented in TDF models. Thus, TDF model systems are not applicable for either national-level analyses or even regional-level policy analyses covering several neighboring states.

Traffic operations models, in contrast to TDF models, are focused on evaluating highway system performance at a detailed level and assume travel demand as a given input. The primary purpose of traffic operations models is to evaluate: specific geometric design treatments (e.g., signal spacing, freeway ramp configuration); control strategies (e.g., signal timing, ramp metering); and operating policies (e.g., high-occupancy vehicle lanes). Microscopic models provide the most accurate depiction of traffic conditions that result from these strategies, followed by macroscopic models, then the other analytic methods. However, they can not produce travel demand estimates and must rely on exogenous sources. This means they are not capable of directly determining the effects alternative modes and noncapital transportation improvements without demand estimates first being made separately. Although they provide the most detailed estimates of traffic performance measures -- including fuel consumption -- for transportation analyses, they do not account for changes in vehicle and fuel technologies. Finally, their use has been limited to relatively small geographic areas within a metropolitan area: subregional analyses and extended corridors are typical for macroscopic model applications while highly focused corridors and highway segments are the typical scope of microscopic model applications.

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8. # 7. NATIONAL, URBAN, AND STATEWIDE FREIGHT MODELS

7.1 OVERVIEW

Increased attention has been given in recent years to the movement of freight within, between, and through metropolitan areas, with particular focus on intermodal ports and intercity corridors. Three factors are motivating this concern: the effect of freight movements on overall performance of the transportation system, the critical role of freight in promoting a strong economy, and the contributions of freight vehicles to urban area and regional air quality emissions, especially fine particulate matter and oxides of nitrogen.

A result of this increased effort being given to the analysis of freight movements is the emergence of improved freight analysis models.[1] While these modeling capabilities have not yet been utilized to estimate emissions of greenhouse gases, this emissions capability easily could be added to the outputs of truck, and rail where existing, vehicle miles of travel.

Freight transportation models have been developed at the national, urban area, and statewide geographic levels which potentially could be applied for greenhouse gas calculation purposes. The national model described, ITIC, represents an extension of an Intermodal Competition Model. Three freight models are described that have been applied primarily at the urban area level. The Quick Response Freight Manual illustrates the systematic application of factors and tables for forecasting commercial vehicle travel. Two modeling approaches, Truck Trip Forecasting Methods and Matrix Estimation Methods for Truck Trips, can be viewed as freight equivalents of the traditional urban transportation person-oriented travel models. Commodity Flow Models have been developed for both urban areas and states, and represent a more economically rigorous form of modeling freight. The final modeling approach described, the use of an Integrated Land Use/Freight Transportation Model System, represents an attempt to capture the interactive effects between transportation and land development.

7.2 INTERMODAL TRANSPORTATION AND INVENTORY COST MODEL

The Intermodal Transportation and Inventory Cost Model (ITIC) was developed by USDOT as part of its Comprehensive Truck Size and Weight Study.[2] ITIC provides estimates of truck-to-truck, rail carload-to-truck, and rail intermodal-to-truck diversion caused by changes in costs for long haul (i.e., over 200 mile) truck shipments. The primary focus of ITIC during its development was capturing the effects of changes in truck size and weight limits on truck costs, and the extent to which changes in truck costs would cause shippers to use truck instead of rail or to modify the types of trucks they use. However, ITIC could also be used to estimate diversion impacts for other policies affecting truck costs, such as changes in fuel taxes or other highway user charges.

The outputs of the ITIC modeling process are truck VMT (by type of truck and operating weight) and tonnage diverted to or from rail. Using ITIC to analyze the effects of freight policies on greenhouse gas emissions would require post processing of ITIC outputs with truck and rail energy consumption rates and factors for converting energy consumption to greenhouse gas emissions. The ITIC model grew out of research conducted for the Association of American Railroads' (AAR) proprietary Intermodal Competition Model. ITIC is currently maintained by the Federal Highway Administration's Office of Transportation Policy Studies.

ITIC examines sample truck and rail shipments. The model determines whether a sample shipment will divert by estimating the total logistics cost (transportation plus inventory) to move the shipment by the various available modes and truck configurations. "Inventory cost" is the cost of maintaining stock for either a manufacturing process or to meet customer demand. Inventory costs include ordering cost, holding cost (for safety stock, cycle stock, and in-transit stock), and claims cost (for loss and damage). Transportation costs include all costs to the shipper of moving goods from origin to destination. For rail shipments, this includes not only rail linehaul costs but also truck drayage costs at the origin and destination of the shipment. In calculating rail costs, ITIC recognizes that rail prices may be significantly above the variable cost to the railroad of carrying an additional shipment and that, to avoid losing a shipment, railroads may reduce their rates.

ITIC uses truck data from the AAR's North American Transportation Survey (NATS), which was last conducted in 1993 and 1994. NATS is a survey of long-haul over-the-road shipments conducted at truck stops.[3] It provides information on origin, destination, truck body type, and commodity. For rail shipment data, ITIC uses the Surface Transportation Board's Waybill Sample.[4] Waybill database fields used by ITIC include shipment origin and destination, commodity shipped, type of rail equipment used, shipment weight, and shipment revenue.

Limitations of the model, which are discussed further in the description of the ITIC model in the Comprehensive Truck Size and Weight Study Final Report[5], include the following:

- An "all-or-nothing" rule is used in determining if a sample shipment (and all the shipments represented by the sample shipment) will divert.

- Some service considerations, such as spoilage, are not included in the model.
- The commodity descriptions may be too generic, leading to difficulties in establishing densities and other potentially important shipment characteristics.

7.3 QUICK RESPONSE FREIGHT MANUAL

The *Quick Response Freight Manual*[6] (QRFM) provides procedures for incorporating trucks and other commercial vehicles into the four-step travel demand modeling process used by most medium and large metropolitan areas. The procedures produce trip tables for three classes of commercial vehicles: (1) four-tire commercial vehicles, including delivery and service vehicles, (2) single unit trucks with six or more tires, and (3) combinations consisting of a power and one or more trailing units. The procedures are designed to be quick and easy to implement, using data that should be readily available for most metropolitan areas. The QRFM provides extensive sets of default data for developing the trip tables for each of the three classes of vehicles, including trip generation equations, average trip lengths (for trip distribution), and traffic distributions by vehicle class for different types of highways.

The QRFM contains other information of use to state and metropolitan area transportation planners in understanding and modeling freight demand:

- A discussion of factors affecting freight demand, including factors that influence the demand for goods and services as well as the costs and service levels associated with freight transportation.
- A discussion of simple growth factor methods that can be used to forecast growth in freight demand based on predicted changes in levels of economic activity.
- A discussion of primary and secondary data collection activities that might be undertaken to improve the accuracy and reliability of the freight planning process.

Separating commercial vehicle traffic from all traffic and breaking commercial vehicle traffic into the three classes used in the QRFM is useful in analyzing greenhouse gas strategies because (1) greenhouse gas emissions per vehicle mile differs greatly across the classes and (2) most transportation policies would have very different effects on the classes.

7.4 TRUCK TRIP FORECASTING METHODS

These methods are the analogue to the traditional four-step process used in passenger travel demand forecasting models. They have been developed and used extensively in various metropolitan area contexts as well as for regional and statewide planning.[7,8,9] Truck trip ends are estimated as a function of zonal variables such as households and employment by industry. Gravity models are typically used to distribute these trips, and then a variety of traffic assignment techniques can be used to route the truck trips over the highway network. If these procedures are combined with those for passenger cars, total vehicular flows and highway speeds can be estimated.

The resulting truck flows and speeds can then be used in post-processors to obtain estimates of freight vehicle highway emissions and fuel consumption.

The main advantage of these methods is that they are well understood by practitioners. Unless model coefficients developed outside the study area are applied, these models do require collection of fairly extensive origin-destination survey data through intercepts or vehicle diaries. These models typically do not provide information about the commodities being moved. Trip distribution using gravity modeling methods can be problematic if factors other than distance (e.g., concentration of warehousing land uses, location of manufacturing facilities, etc., location of port facilities) influence commercial vehicle movements.

For use in GHG analyses, truck trip forecasting methods provide a means of dealing with issues such as highway investments, land use options, and growth management. They can only be used to account for vehicle- and fuel-related policies if the impacts of these policies on environmental effects such as emissions and fuel consumption have been developed outside the truck trip forecasting process. Also, because these methods are not multimodal, they cannot be used to evaluate issues of mode choice for freight movements, or of the environmental impacts of freight transportation by other modes than truck.

7.5 MATRIX ESTIMATION METHODS FOR TRUCK TRIPS

Matrix estimation methods use optimization techniques to identify the truck trip matrix which best explains observed data such as vehicle classification counts.[10] These methods take as a starting point a "seed" matrix of origins and destinations (trip table); passenger or truck tables developed from "Quick Response" techniques are often used for this purpose. A more complex variation of this method was recently used to develop commercial vehicle models for the New York Metropolitan Transportation Council (NYMTC). The NYMTC model combined partial origin-destination information obtained from intercept surveys, classification count data, and estimates of truck trip productions and attractions as functions of employment by traffic zone.

The advantage of matrix estimation methods is that they can use a variety of existing and potentially inconsistent data sources. Matrix estimation methods can also be a relatively low cost option for implementing heavy-duty truck demand models when collection of comprehensive origin-destination data is not possible. The main disadvantage of such models is a lack of forecasting capabilities. Typically, growth factor methods are used to represent future conditions rather than travel demand models, although in the NYMTC model, the distribution of future employment was used to influence future year truck movements to some extent.

In the context of GHG analyses, truck trip matrix estimation methods are most likely to be useful mainly as a means of establishing base year conditions rather than for forecasting future conditions. They do not include the means to evaluate the impacts of GHG strategies in the future. They can be combined with the other freight models discussed in this section to provide a means to obtain a better calibration of truck travel patterns to observed data.

7.6 COMMODITY FLOW METHODS

This approach to development of freight demand models takes an exogenous estimate or forecast of commodity flows within the study area, ranging from a metropolitan area to an entire state, as the basis for freight flows, potentially by all modes, and truck trip forecasting. These commodity flow estimates and forecasts are typically developed by combining available national commodity flow data by mode between counties or BEA areas with econometric models to obtain current and future flow data. If the commodity flows are not already given by mode, an estimate of the portion moving by truck is first made. The truck commodity flows are then distributed to a finer level of geographic detail on the basis of employment by industry and then converted to vehicle (truck) trip equivalents. Examples of this approach may be found in the Portland, Oregon metropolitan area[11] as well as the commodity flow/truck model developed for the state of Indiana.[12]

The benefits of an integrated commodity/truck movement approach include consistency with existing commodity flow data, ties to forecasts of economic activities as reflected by commodity flow forecasts, ties to forecasts about commodity flows through major port facilities, and knowledge about how traffic conditions may impact different industries. The primary disadvantage to this approach includes difficulties in converting commodity flows to vehicle trip equivalents and poor representation of secondary vehicle movements such as drayage and pickup-and-delivery tours within metropolitan regions. This approach works best in representing line haul movements between distinct metropolitan areas.

For the analysis of GHG strategies, commodity flow models have the primary potential advantage of representing all modes of freight flows and of reflecting the results of regional econometric models. These models also can deal with mode choice issues for freight movements, although none of the current models deal with these with the level of policy-sensitivity required to deal with traffic operations issues. For truck trips at the metropolitan or statewide levels, the results of these models can be assigned to highway networks as parts of travel demand forecasting models just as the truck trip matrix estimation methods are, providing the basis for evaluating highway investments, land use options, and growth management strategies.

7.7 LAND USE/FREIGHT TRANSPORTATION MODELS

Transportation researchers have long known that transportation infrastructure influences land development and vice versa yet these relationships are not typically reflected in either freight or person travel demand models. The Oregon Department of Transportation (ODOT) has developed the only known example of an integrated transportation/land use model applied at the statewide level that considers both truck and passenger vehicle movements.[13] While this model should be characterized more as a research effort than as state-of-the-practice, it is nonetheless an interesting illustration of one end of the spectrum of potential approaches to modeling statewide or regional truck movements.

The Oregon model system uses an expanded version of an Input-Output (I-O) matrix to produce monetary flows among spatially-indexed sectors such as households, businesses, and land. Flows of transportable goods, including labor and commodities, are then converted to trips. The trips are split by mode and assigned to the transportation network. Truck trips thus are modeled as an integrated part of a process that reflects demand, mode choice, and route choice for commodity movements. In the Oregon application, outputs include truck trips by three vehicle types for a system of 144 zones.

The benefits of an integrated land use/transportation approach include theoretical rigor, accounting for factors not typically considered in more conventional commodity or truck models, and consistent assumptions for passenger and freight modeling. The primary drawback of such an approach is the extensive amount of non-traditional data collection required to estimate and apply the models, including information such as historical land price data. A truck intercept survey was also used to support the development of the heavy-duty truck submodel within the overall model.

Compared with existing urban and statewide freight models, a land use/transportation model that includes commodity flows by mode, when completed, would provide a useful tool for the analysis of the widest range of GHG strategies. It would reflect vehicle price, transportation facility pricing, fuel price and efficiency, and transportation capital investment options to the extent that these are reflected in freight vehicle travel times and transport costs and prices, important inputs to this type of model. The model itself also deals with mechanisms of freight mode choice, and thus is able to address issues of truck vs. rail tradeoffs. Finally, the model estimates land use development patterns as affected by transportation supply for both passengers and freight and by growth management policies. The significant caution with respect to the Oregon model is that the modeling system has not yet been fully incorporated into a production planning environment. Freight modeling, in general, is embryonic relative to person travel modeling. Integrated Land Use/Transportation models that consider only household location and person travel are nortoriously difficult to estimate, require extensive data, and are costly to apply. Their extension to include considerations of freight movement represent a potentially noteworthy advance in the state-of-the-art of transportation air quality analysis with important implications for the analysis of GHG strategies. Such integrated modeling systems, though, are not yet being used in the United States for routine transportation planning practice.

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8. INTEGRATING MODELS AND GHG FORECASTING MODELS

8.1 MODEL TYPES

Models that predict net fuel demand by integrating vehicle, fuel and travel models or by utilizing their outputs fall into two types: simple accounting models that are typically set up as spreadsheets, or complex forecasting models that integrate the various models previously discussed into one single model, or that use simplified version of the models discussed within their framework.

Although there are numerous accounting models of fuel use in the highway transport sector, only two have seen continued development over any period of time. One, the Highway Fuel Consumption (HFC) Model has been used by the DOE Policy Office since the late-1970s but has not been in much use since the early-1990s.[1] The second, loosely called the 'Car Talk' model incorporates some input-output models (notably for travel demand) but otherwise has a structure quite similar to the HFC.[2] The HFC has five vehicle classes (cars, light trucks, light-heavy trucks) and tracks imports and domestic vehicles separately. It also tracks five fuel types: gasoline, diesel, ethanol gasoline blends, MTBE-gasoline blends, and neat alcohol fuel. In contrast, the Car Talk model (used to support a regulatory discussion), covers only light-duty vehicles but had a broader range of fuels (CNG, LPG, etc.). It also incorporated the VMT forecasting model discussing in Section 5 (as the Car Talk Model)

While these models are useful in the context of having a ready tool to assess numerical targets (for example: fuel economy standards, or conversion of a specific percent of vehicles to CNG), they are insensitive to all the secondary and feedback effects of policies, unless these effects are calculated off-line and input into the model. For example, increased fuel economy reduces that cost driving and hence, consumers drive more. As another example, increased sales of CNG vehicles increases demand for natural gas, thereby increasing gas prices. These effects would not be recognized in any accounting model unless the VMT is increased externally, or the effect of increased CNG prices calculated externally. These models should be used only if these limitations are well understood.

8.2 INTEGRATED MODELS

There are very few integrated process models of the entire transportation system, and CALCARS[3] is perhaps the only model that is regionally based. As described in Section 4, CALCARS has a relatively sophisticated model of vehicle choice and use, but requires exogenous inputs of vehicle attributes and fuel price are availability. These exogenous inputs may be a reasonable way to address these sectors for a regional model since regional strategies may have limited or no influence on vehicle attributes or fuel prices.

A more comprehensive model developed for the DOE is the Integrated Dynamic Energy Analysis Simulation (IDEAS) Model.[4] It is a multi-sectoral energy model that includes a relatively comprehensive representation of the vehicle sector model. The Vechlce Sector model has six modules: car ownership, fuel choice, VMT, vehicle efficiency, vintaging and scrappage. The car ownership and fuel choice models are the multi-nominal logit type models and are similar to the Train and CALCARS models (with far fewer classes of vehicles). Vehicle efficiency is based on supply curves derived from more detailed approaches such as the TCSM, while the travel model is of the input-output type. Scrappage and vintaging are largely accounting functions with some sensitivity to economic conditions.

The main benefit to IDEAS is that the vehicle model is one sector of a larger energy model, and many of the economic feedback loops affecting travel and fuel prices are incorporated into the structure. The model does not have extensive desegregation of the vehicle and fuel sectors, but this results in a simpler and more easily usable model relative to the only other comprehensive integrated model available, NEMS.

The National Energy Modeling System (NEMS)[5] features the more sophisticated representation of the vehicle fleet available, and is a loosely knit group of submodules, which are executed sequentially. The model has 11 submodules, three of which deal with transportation systems that are not part of the on-highway fleet. The other submodules include the Fuel Economy Module (patterned after TCSM), an Alternative Fuel Vehicle Submodule (patterned after the ITS based logit models using stated preference survey data), a travel module using an input-output structure, and regional and stock submodules that are largely accounting models. The Transportation model is itself part of a much larger Energy Model where the supply and demand for fuels are adjusted into equilibrium.

While the NEMS is very sophisticated and reasonably complete, its size and complexity make it difficult to use, and interpreting its outputs may not be straight forward. In addition, the submodules and different sectoral models were developed by many different organizations, and their integration has required a number of model adjustments to prevent instabilities, or to make the model outputs more consistent with observed reality. For example, the stated preference models for alternative fuel vehicle choice routinely over predict AFV demand, so that the forecasts have to be scaled to the current reality by methods that are not consistent with model methodology. Hence, a thorough understanding of the built-in constraints are required before NEMS can be used as a policy analysis tool.

Since most models only predict fuel demand and travel, additional factors are required to estimate GHG emissions. If the output of interest is purely the GHG emissions from the tailpipe, the conversion model is very simple. However, the use of different fuel types has larger implications for the energy use related to production and distribution of the fuel, and the energy use related to the manufacture of the vehicle. These considerations have led to the development of “full fuel cycle” GHG emissions models described below.

8.3 FULL FUEL CYCLE GHG MODELS

There are a number of researchers who have included the upstream effects of fuel combustion to estimate GHG emission, but most of the studies address only one or tow specific fuels. The most commonly used model that considers most, if not all of the alternative fuels for transportation is one by Delucchi.[6] More recently Argonne National Laboratory has developed a new model called GREET[7] that is similar in structure to the Delucchi model. Both models are spreadsheet models that have only an accounting structure. They calculate GHG emission on a per mile of travel basis for the vehicle only, and for the entire fuel cycle. The fuel efficiency of the vehicle itself is an input parameter to the calculation. The two models’ capabilities are described below.

In 1991, Delucchi competed a study to estimate fuel-cycle emissions of GHGs for various transportation fuels and for electricity generation. The GHGs considered in the study included CO_2, CH_4, CO, N_2O, NO_x, and nonmethane organic gases (NMOGs). In addition to studying the emissions and energy use of the fuel-cycle stages (ranging from primary energy recovery to on vehicle fuel combustion), Delucchi examined the emissions and energy use involved in the manufacture of motor vehicles, maintenance of transportation systems, manufacture of material used in major energy facilities, and changes in land use cased by the production of biofuels. The model included the following fuel cycles: petroleum to gasoline, petroleum to diesel, petroleum to liquefied petroleum gas (LPG), natural gas (NG) to LPG, coal to methanol, wood to methanol, corn to ethanol, wood to ethanol, nuclear energy to hydrogen, solar energy to hydrogen, and electric generation form various fuels.

To calculate GHG emission for a specific fuel-cycle target, the model estimates the total amount of energy consumed at that stage. It allocates the total amount of energy to different fuels (e.g., residual oil, NG, electricity, coal), then estimates combustion-derived emission of GHGs except CO_2) by using emission factors. It then calculates CO_2 emissions by using a carbon balance approach: the carbon contained in CO, CH_4, and NMOG emissions is subtracted from all available carbon in a combusted fuel, and the remaining carbon is assumed to be oxidized to CO_2. Besides combustion-causing emission, the model includes GHG emissions from fuel losses such as leakage and evaporation. The model combines emissions of all GHGs together with their global warming potentials (GWPs) and presents the results of fuel-cycle, vehicle life-cycle GHG emission in CO_2-equivalent emissions per mile of travel.

In 1997, Delucchi[8] issued a report documenting revisions made to his 1991 study. With newly available data, many of parametric assumptions are updated and new methodologies to account for energy use and emissions associated with fuel-cycle states are used.

Comparison of the GREET model and the Delucchi model reveals that in many cases, the GREET model take its parametric assumptions from model user, while the Delucchi model calculates parametric values hat are determined by certain assumptions. For example, the value used by GREET to calculate relative differences in vehicle fuel economy between AFVs and gasoline vehicles is determined outside of GREET by comparing testing data from actual testsof AFVs and conventional vehicles. The Delucchi model calculates a theoretical relative change in fuel economy for AFVs by taking into account potential differences in engine efficiency, vehicle weight, and so on. However, the overall structure of both models are quite similar.

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9. SUMMARY OF POTENTIAL TO ADDRESS GHG STRATEGIES

The wide range of models available in the U.S. allow substantial capability to model the effects of many GHG control strategies on emissions from the on-highway transportation system. However, no one model is capable of analysis of all types of measures, especially measures that could result in significant macroeconomic dislocations which feedback to the transportation system. In addition, there is no model that integrates national level models of vehicles, fuels and refuel infrastructure with regional or local models of road capacity, transit, traffic operations and urban land use planning. Even if the effects of regional/local strategies on GHG emissions are relatively small on a national scale, there is no integrated representation of these effects in any existing model of GHG emissions.

There is considerable sophistication on the models of <u>vehicle</u> and <u>fuel</u> <u>supply</u>, and the state-of-the-art coincides with the state-of-the-practice. The models can all be termed "process" models by virtue of having detailed representation of technology, and can effectively analyze most GHG strategies aimed at vehicle or fuel supply.

Vehicle choice models and sales models are a weak link in the modeling chain. Most of the state-of-the-practice models are of the input-output type, but these models have limited capability to analyze strategies that are aimed at affecting consumer choice. Microsimulation based vehicle choice models have been developed for California, but there are few national level models that are well developed. Such models are the state-of-the-art in that this approach allows (at least in theory) capability of modeling the effects of consumer choices as affected by strategies such as fees and rebates, or increased transit availability.

Models of alternative fuel vehicle choice and alternative fuel infrastructure expansion are quite advanced in terms of sophistication, but most rely on data from stated preference surveys or on theoretical economic models. This is largely due to the fact that there is no significant presence of alternative fuels in the U.S. market today. Only one model has been developed to date that addresses the issue of a transition from the current situation to a market where alternative fuels and vehicles are a significant presence. This model is capable of analysis most types of GHG control strategies in the context of increased penetration of alternative fuels.

Travel demand forecasting models applied mainly at the metropolitan and regional levels are primarily of the input-output type when it comes to assessing the impacts of many GHG strategies (e.g., vehicle ownership patterns). More sophisticated models have been developed to include the effects of roadway infrastructure capital improvements on travel and fuel consumption. Traffic simulation models provide the greatest resolution of these effects but are typically applied on very small scales (e.g., highway corridors). However, such models are not integrated into any national level GHG model. Regional models are capable of estimating the effects of roadway improvements and additions, mass transit, land-use changes and growth management policies, but such effects are not included in any GHG model being used nationally.

To summarize, there exist two modeling domains that are applicable to estimating the impacts of GHG strategies. Models in the first domain ("vehicle and fuel") include the Vehicle Attribute and Sales Forecasting models covered in Chapter 3 and the Fuel Supply and Infrastructure models covered in Chapter 4. These were developed to assess broad policy options related to vehicle fuel economy, national consumption of fuels, and national environmental issues. Models in the second domain ("transportation") include the National Transportation Performance Models discussed in Chapter 5; Metropolitan Transportation Models discussed in Chapter 6; and Freight Models discussed in Chapter 7. These were developed primarily to assess the impacts of transportation investments (e.g., highway and transit system construction) and policies (e.g., high-occupancy vehicles). Models in the first domain are strong on estimating consumer responses to likely GHG strategies but weak on estimating the effect of highway and travel conditions (congestion). If it is assumed that future highway and travel conditions will be essentially the same as today, this is not a major shortcoming. However, recent evidence suggests that congestion is worsening nationally[1], so this assumption may not be tenable.

On the other hand, models in the second domain are strong in determining the effects of highway and travel conditions (e.g., changes in VMT) but weak in estimating market penetration of vehicle and fuel technologies, particularly with regard to public policy initiatives. Fuel consumption procedures in these models can be extremely detailed, but are usually based on a limited number of "standard" vehicles and fuels (gasoline and diesel).

Based on these observations, there appears to be some value in integrating models or linking model results in some way. However, integrated representation of all facets of transportation in one model is quite limited. Only the NEMS model incorporates many of the state-of-the-art models discussed for vehicle and fuel supply and demand. The NEMS is of daunting complexity, and is difficult to use in a policy context that it is not explicitly configured to simulate. The IDEAS model is an alternative an integrated tool, but may lack sufficient detail within the Transportation Sector to address all types of strategies considered. For many GHG strategies, analysis will be required though the use of multiple non-integrated models, with user intervention required in using the results of one model as inputs to the next. For example, detailed VMT forecasts from transportation models can be used as input to fuel consumption models. VMT may further be characterized as congested and un-congested, recognizing the large differences in fuel consumption under these conditions. Likewise, adjustment factors for the introduction of vehicle and fuel technologies can be introduced into transportation models.

The major positive finding is that there is a multitude of topic specific GHG models that can assess specific aspects of transportation GHG control strategies in the U.S. with high levels of sophistication. Their integration is not complete, but analyses of integrated strategies is possible with user intervention.

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