# TRANSPORTATION MODELING IN THE COMPARATIVE ENERGY STUDY

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This paper is one of a series describing a multidisciplinary IIASA research program on Integrated Energy System Modelling and Policy Analysis. The initial phase of this research program is focused on the energy systems of three regions: the State of Wisconsin in the U.S.A.; the German Democratic Republic; and the Rhône-Alpes Region in France. The primary purposes of the study are at least three-fold:

(1) To identify existing patterns of regional energy use and supply at appropriate levels of disaggregation.

(2) To compare alternative methodologies for regional energy forecasting, planning, and policy development.

(3) To use the above methodologies to examine alternate energy policy strategies for each of the regions, to explore their implications from various perspectives using sets of indicators related to environmental impacts, energy use efficiency, etc., and to evaluate the adequacy of the alternative methodologies as policy tools.

Out of these above three items should evolve improved methodologies for energy systems research and policy analysis. The comparative method, intersecting the different disciplines and nations which would be involved in this project, should serve as a powerful tool to the mutual benefit to the participating nations as well as to other countries facing similar energy problems. It could also serve as a prototype for similar studies on other resources such as materials, water, air, i.e. as a vehicle for development of an approach for improved resource management.

W.K. Foell

Papers in the series describing this research program are:

(1) Foell, W.K. "Integrated Energy System Modelling and Policy Analysis: A Description of an IIASA Research Program" IIASA Working Paper WP-75-33, April 1975.

(2) Dennis, R.L. and Ito, K. "An Initial Framework for Describing Regional Pollution Emissions in the IIASA Integrated Energy System Research Program" IIASA Working Paper WP-75-61, June 1975.

(3) Weingart, Jerome, "Preliminary Data Requirements for a Feasibility Study of the Solar Option in the Rhônes-Alpes Region of France" IIASA Working Paper, June 1975

(4) Hölzl, A. and Foell, W.K. "A Brief Overview of Demographic, Geographic and Energy Characteristics of the German Democratic Republic, Rhône-Alpes, and Wisconsin" IIASA Working Paper, June 1975.

(5) Bigelow, J., "Transportation Modeling in the Comparative Energy Study, IIASA Working Paper, June 1975.

# Transportation Modeling in the Comparative Energy Study

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The purpose of modeling transportation in this study is to help answer the following questions. What are the potentials in the different study regions for reducing the amount of energy used for transportation? What measures will accomplish these energy savings? What will be the ancillary benefits (e.g. reduced emissions of air pollutants, reduced road traffic accidents) and costs (e.g. increased travel times, reduced access to jobs) of the policies?

I will deal separately with freight transport and transportation of people. I will consider freight transport to be a derived quantity - that is, how much freight is shipped how far depends on how much is produced. Therefore, I will relate freight transport to other measures of economic activity.

I will divide the transportation of people into work-related, and other trips. As with freight transport, I will consider work-related person trips to be a derived quantity. Different forms of economic activity will generate jobs, and each job will require some number of daily work trips.

Other person trips will be very difficult to predict. Although they are related to other economic activity, and to the population and income of a region, they depend also upon a myriad factors that we cannot hope to predict. These are factors such as the price of gasoline, the availability of parking, the distribution, availability and price of recreational facilities, and so forth. Ones choice of a mode of travel, either for a work trip or a non-work trip, is similarly a function of an enourmous number of variables. This paper will, therefore, consider these quantities to be exogenously supplied.

## Notation

I have tried to be notationally consistent throughout this paper, even though it has resulted in a complex notation, using both subscripts and superscripts. However, each time a particular letter appears as a subscript, it will mean the same thing. Similarly, each occurrance of a letter as a superscript will mean the same thing.

Subscripts that I have used are:

k = industrial or commercial catagory

m = mode of travel (e.g. auto, bus, airplane)

s = species of pollutant (e.g. CO, $NO_x$, $SO_2$)

t = type of fuel (e.g. diesel fuel, gasoline, hydrogen, electricity)

In addition, the subscript 'c' is used to devote a class of autos, for example all small gasoline-burning autos manufactured in 1972.

Superscripts that I have used are:

f = freight transport

p = person transport

n = person transport for non-work related purposes

w = person transport for work related purposes

Quantities to which subscripts and superscripts may be attached are the intensive quantities:

$\phi$ = fuel use per unit transport

$\varepsilon$ = pollutant emissions per unit transport

$\mu$ = unit transport per unit industrial or commercial activity

and the extensive quantities:

F = units of fuel used

S = units of transport used

P = units of pollutant emitted

These are the quantities that appear both in the freight transport and the person transport models. Other quantities, which occur only in the person transport model, will be introduced when that model is discussed.

I use this notation as follows. A quantity is modified by its subscripts and superscripts, just as a sentence is modified by the inclusion of adjectives and adverbs. For example, I will speak of "the use of fuel of type t per unit freight transport by mode m". Here I have modified the basic quantity $\phi$, fuel use per unit transport, by a fuel type t, a mode of transport m, and I have specified freight rather than person transport. Thus the quantity is devoted by $\phi^f_{tm}$. Similarly, the amount of pollutant of species s emitted by person transport is $P^p_s$.

## Freight Transport

The freight transport model will deal with freight transport modes chosen from among those in Table I. For each mode I will list the amount of fuel used of each type t to move a ton of freight one kilometer. Let this fuel intensiveness of mode m for fuel type t be $\phi^f_{tm}$. Then, if $S^f_m$ is the number of ton-kilometers transported by mode m, we can calculate the total use of fuel of type t for freight transport as:

$$F^f_t = \sum_m \phi^f_{tm} S^f_m \tag{1}$$

The superscript f denotes "freight"; this is in contradistinction to personal transportation, denoted by the superscript p.

Table I

Possible Freight Transport Modes

Truck
Train
River Barge
Ocean Ship
Aircraft
Pipeline
Open Aqueduct

This doesn't restrict one to calculating only fuel use . For example, to calculate emissions of $NO_x$, one simply provides the amount of $NO_x$ emitted by each mode m per ton-kilometer transported. Thus let $\varepsilon_{sm}^f$ be the amount of pollutant s emitted per ton-kilometer of freight transported by mode m. Then,

$$P_s^f = \sum_m \varepsilon_{sm}^f S_m^f \tag{2}$$

an equation which one notes is of precisely the same form as equation (1).

I will deal separately with three different kinds of freight shipments. The simplest is the through-shipment, whose origin and destination both lie outside the region. I propose to make the ton-kilometers of through-freight shipped by each mode an exogenous variable, say $S_m^f(1)$ These quantities will affect regional fuel use, emissions, and employment, but they will not themselves be affected by intraregional activity.

Goods which are shipped from points within the region to destination outside, or goods shipped from outside origins to inside destinations, should be treated in more detail. I would like to relate these inter-regional ton-kilometers to the industrial and commercial activity in the region. Further, I would like to separate these ton-kilometers into those which occur within the region and those which occur outside.

Thus I define for each industrial or commercial category k, the number of inter-regional ton-kilometers generated per unit of activity on each mode m, both inside the region, $\mu^f_{mk}(2)$, and outside the region, $\mu^f_{mk}(3)$. Let the activity of category k be $a_k$, measured in some convenient units such as value added (dollar) employment, or sales. Then inter-regional ton-kilometers shipped by mode m is:

$$\begin{cases} S^f_m(2) = \sum_k \mu^f_{mk}(2)\ a_k \\ S^f_m(3) = \sum \mu^f_{mk}(3)\ a_k \end{cases} \tag{3}$$

Here, the argument 2 refers to that fraction of external shipment which occurs inside the region, and the argument 3 to the fraction occurring outside. We are of course primarily interested in transport that occurs within the region - that is, $S^f_m(2)$ is of greater interest than $S^f_m(3)$ - but we should nevertheless calculate the extra-region impacts of intra-regional activities, one of which is $S^f_m(3)$.

The third kind of freight transport is that which occurs entirely within the region. That is, both origin and destination are inside the region. These shipments should be treated in essentially the same ways as shipments of the second category.

Thus, for each industrial or commercial category 'k', we define the number of intra-regional ton-kilometers on each mode 'm' generated by activity in that category. Let this factor be $\mu^f_{mk}(4)$. Again we let $a_k$ be the activity of category k. Then intra-regional ton-kilometers shipped by mode m is:

$$S^f_m(4) = \sum_k \mu^f_{mk}(4)\ a_k \qquad (4)$$

The argument 4 refers to internal shipment.

The reader will recall that in equations (1) and (2), the factors $S^f_m$ appear. What is this factor, and how is it related to the quantities $S^f_m(i)$ calculated in equations (3) and (4)? The answer is that by using different definitions for $S^f_m$ in terms of the quantities $S^f_m(i)$, we calculate different things. Thus:

- If we wish to find fuel use and pollutant emissions due to freight shipments completely internal to the region, let $S^f_m = S^f_m(4)$ in equations (1) and (2).

- If we wish to find fuel use and pollutant emissions that occur due to all movement of freight happening in the region, let $S^f_m = S^f_m(1) + S^f_m(2) + S^f_m(4)$ in equations (1) and (2)

- If we want to calculate fuel use and pollutant emissions that occur outside the region but are related to internal activity (but not necessarily unrelated to activity outside the region), let $S^f_m = S^f_m(3)$ in equations (1) and (2).

If we wish to know total fuel use and pollutant emissions related to activity within the region, let $S_m^f = S_m^f(2) + S_m^f(3) + S_m^f(4)$ in equations (1) and (2).

Unlike inter-regional shipment, we cannot count ton-kilometers generated by an activity to include all shipments both from the category to others, and from other categories to that one. To do so would cause us to count each ton-kilometer twice. I recommend that we count as "generated by an activity" only the ton-kilometers shipped <u>from</u> that category <u>to</u> other categories. Thus we would ascribe to the cement industry the tons and ton-kilometers of cement that are shipped, steel to steel industry, and so on, rather than ascribing cement shipments to customers of the cement industry. Note, however, that both incoming and outgoing inter-regional shipments are ascribed to industrial or commercial category within the region, because - since we do not consider explicitly extra-regional industry - this will not involve double counting.

## Data Required for the Freight Transport Model

Our data needs for the freight transport model are straightforward. We need data from which to derive the fuel intensiveness $\phi_{tm}^f$ and emission factors $\epsilon_{sm}^f$ (see equations (1) and (2), and the transit usage factors by mode and industry, $\mu_{mk}^f(i)$ i =2,3, or 4 (see equations (3) and (4).

Fuel intensiveness factors should be readily available. If they are not reported directly, it is likely that total fuel used annually by a mode for freight transport will be reported, as well as annual ton-kilometers transported. The ratio is the desired fuel intensiveness.

Emission factors should also be easily obtainable. The Environmental Protection Agency (EPA) has measured emissions from a wide variety of power plants under various load conditions using many different fuels. Choosing appropriate EPA figures for the modes we consider should present few difficulties.

I anticipate that fuel intensiveness $\phi_{tm}^{f}$ and emission factors $\epsilon_{sm}^{f}$ should be similar in all study regions. These factors depend largely upon the technology used for transportation, which should not differ markedly between regions. This is not to say, of course, that the different regions use different freight transport modes in the same proportions. This is only to say that to ship one ton of freight one kilometer by a particular mode will use the same amount of fuel, and produce the same emissions, in all regions.

Transport usage factors by mode and industry - the quantities $\mu_{mk}^{f}(i)$, $i = 2, 3$ or $4$, will certainly differ from one region to another. For example, for every $1000 of value added, the Wisconsin paper-pulp industry might use 30 ton-kilometer of truck transport and 10 ton-kilometer of barge transport, while the same industry in Rhône-Alps might use 20 ton-kilometer of barge transport and 20 ton-kilometer of rail transport.

In addition, sources for this information will differ from region to region. From the DDR, for example, reference [1] gives data on the tons and ton-kilometers of different products transported by various different modes. If we can get data on tons of product per unit activity for these industries, then we can derive the figures of the ton-kilometer per unit activity in the obvious way. Whether there are data that will yield interregional factors separately for the DDR I have not yet determined.

For Wisconsin, these factors will come largely from an input-output matrix that is being sent to us. This will supply the units of transport used for each unit of economic activity by economic category. Whether the categories used in the Wisconsin Energy Model [2], and whether transportation use is broken down by mode, we do not yet know. These uncertain points may become real problems as they cease to be un known.

I have not yet discovered the most likely sources of the transport usage factors for Rhône Alps.

## Model of Personal Transportation

Transportation of people is conceptually much the same as freight transport. I will, however, deal separately with inter-urban and intra-urban trips. Table II shows the modes I will consider for inter-urban trips, and Table III modes for intra-urban trips. In Table II, 'Bus' refers to inter-city bus travel such as that provided by the Greyhound Company in the United States. In Table III, 'Train' refers to a mass-transit mode using an exclusive guideway, as opposed to 'Local Bus', which shares its guideway (the road) with another mode (private auto).

Table II

Modes for Inter-Urban Person Trips

Auto
Bus
Train
Aircraft
Boat

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Table III

Modes for Intra-Urban Person Trips

Auto
Local Bus
Train

As with freight transport, I let the amount of fuel of type t used by mode m per unit of transportation be the fuel intensiveness factor $\phi^{p}_{tm}$. Similarly, I let the emissions of species s by mode m per unit transportation be $\varepsilon^p_{sm}$. Then, if $S^p_m$ is the number of units of personal transportation on mode m, one calculates (analagous to equations (1) and (2) the fuel use and pollutant emissions due to person transport as:

$$F^p_t = \sum_m \phi^p_{tm} S^p_m \qquad (5)$$

$$P^p_s = \sum_m \varepsilon^p_{sm} S^p_m \qquad (6)$$

Although the unit of freight transport was ton-kilometers-i.e. an amount of freight shipped a given distance, for person transport we will use the unit vehicle-kilometers. The reason for this is that passenger vehicles will typically use the same amount of fuel and emit the same amount of pollution regardless of the number of passengers they happen to be carrying. For example, whether an auto has only a driver or a driver and four passengers, it will still use - to pick a typical figure - 12 liters of gasoline to go 100 kilometers. Thus if we can choose person-kilometers as our unit, the fuel intensiveness and emission factors would depend heavily on the vehicle occupancies, which I expect for a variety of reasons not to remain even approximately constant. On the other hand, choosing vehicle-kilometers as the unit permits the factors $\phi^p_{tm}$ and $\varepsilon^p_{sm}$ to remain constant.

Data on fuel consumption and emissions of different modes of transportation should be available from EPA.

## The Auto: A Special Case

Auto is a very special mode of travel. It accounts for very large proportions of the fuel used for personal transportation, and of the emissions due to such transportation. Also, autos come in different sizes and ages, each with different fuel intensiveness and emission factors. Indeed, autos built in the future may have enourmously different factors - for example, electric autos emit virtually no pollutants and consume (directly) no petroleum.

Thus, I will partition the inventory of autos into classes, certainly by age, and probably by size as well. Each class c will have its own fuel intensiveness factors $\phi_{tc}$ and its own emission factors $\varepsilon_{sc}$.

To compute energy use and emissions for auto, I shall partition the vehicle kilometers among autos in the different classes. The partitioning shall be according to the proportions observed today; that is, if a fifteen-year-old small auto is driven only half as far today as a new large auto, we shall assume the same two-to-one ratio holds at all times in the future. The annual kilometers driven by autos in each class will depend on the size and composition of the inventory of autos.

This is expressed mathematically as follows. Let $N_c(y)$ be the number of autos in the inventory which are in class c in year y. Let $S_c(o)$ be the kilometers driven per autos in class c in some reference year - for example, 1970. Finally, let $S^p_{auto}(y)$ be the total kilometers driven by autos in year y. Then it can be calculated that the kilometers driven per auto in class c in year y must be:

$$S_c(y) = S_c(o) \frac{S^p_{auto}(y)}{\sum_c N_c(y) \cdot S_c(o)} \tag{7}$$

Then the fuel intensiveness and emission factors applicable to the average auto-kilometer are:

$$\phi^p_{t,auto} = \frac{\sum_c N_c(y) \cdot S_c(y) \phi_{tc}}{\sum_c N_c(y) \cdot S_c(y)} \tag{8}$$

and

$$\varepsilon^p_{s,auto} = \frac{\sum_c N_c(y) \cdot S_c(y) \varepsilon_{sc}}{\sum_c N_c(y) \cdot S_c(y)} \tag{9}$$

Then these factors - which the reader should note depend upon the year y - may be substituted into equations (5) and (6) to yield fuel use and and pollutants emitted due to personal transportation.

It may be desireable to acquire the MOVEC model, described in reference [3], from the Rand Corporation. A great deal of the work for the auto mode has already been done in constructing that model.

### Dynamic Aspects of the Auto Inventory

The auto inventory, described by the quantities $N_c(y)$, will change from year to year by the loss of the old autos and the addition of new ones. In reference [4], the yearly additions are specified exogenously. No connection is made in that model between the number of kilometers the newer autos are to drive and the number of autos to be added to the inventory. Yet it is clear that a connection exists. If autos are, on the whole, being driven less, they will be bought less too.

Also in reference [4], the rate at which autos leave the inventory depends on their age. It is known, however, that auto survival is much more closely related to total distance driven rather than time since manufacture. This observation suggests that autos should be dropped from the inventory according to a survival distance distribution rather than a survival time distribution.

This model differs from those of [3] and [4] in both of these ways, thus accomplishing two interesting and important things. First, it ensures that some consistency exists between the variables of auto ownership and auto use. Second, it permits one to calculate the demand for new cars, an important impact of transportation upon industry.

I will first describe my proposal for calculating the rate at which old autos leave the inventory. There are widely available (in the United States, at least), functions giving the average number of kilometers driven per year by autos of each age, and the proportion of autos of each age that one can expect to survive another year. Let $d_i$ be the average distance driven in the ith year of an auto's life and 'p' be the probability that autos beginning their $i^{th}$ year will survive to the end of that year of their life.

Given these quantities, one can easily compute a function q (d) which describes the probability that a new auto will still be in the inventory once it has been driven a total distance 'd'. Let me define:

$$D_l = \sum_{i=1}^{l} d_i$$

and:

$$Q_l = \prod_{i=1}^{l} p_i$$

for each point l = 1,2,---. It will be easy to obtain points of $q(D_l)$ by interpolation. In words, $D_l$ is the average distance an auto will have been driven in its first l years, and $Q_l$ is the probability that it has survived through these l years. Strictly speaking, these figures apply only when autos are driven according to the time-vs-distance schedule $d_1, d_2$,--, etc. But I will assume that q (D) describes the survival possibility for an auto as a function of distance, regardless of how long (or short) a time is taken to drive that distance.

Each year, as pointed out before, we will have a total distance driven by autos, $S^{p}_{auto}$ (y). Using equation (7), this will be divided up among autos in the inventory, we shall keep track of the number of kilometers driven by the average auto in that class, $M_c$ (This quantity is initialized to zero when the autos of the class first enter the inventory:the entry process is described below. Each time a year passes, $M_c$ is augmented by the average kilometers $S_c(y)$ driven by autos in that class-i.e.,

(10) $$M_c(y+1) = M_c(y)+S_c(y).$$

Then the number of autos in that class is updated by the equation:

(11) $$N_c(y+1)=N_c(y)\ \frac{q(M_c(y+1)}{q(M_c(y))}$$

There remains the question of how rapidly new autos should be added to the inventory. I propose that they should be added during a year at a rate proportional to total auto kilometers driven in that year- that is, at a rate proportional to $S^{p}_{auto}(y)$. This rule is simple, and will, I believe, reproduce to day's inventory given to-day's history.

In addition, it says that once a steady-state relation is reached between total distance driven per year by autos and total autos in the inventory, the average distance driven per auto, and the average lifespan of an auto, will be approximately as they are today. This is arguable on the grounds that people will not buy autos in order to drive them markedly less than they do today, nor will they drive them very much more. To do so would be an extravagence in the first instance, and would elevate the act of driving to a goal in itself, rather than a means of getting from one place to another, in the second instance.

As for other modes, the EPA will have collected data on fuel consumption and emission factors for auto. At least in the case of emissions, this has been done by model of automobile, and year of manufacture. Data on distance driven per year, and survival probabilities, for autos of different ages, has been collected (for the United States situation) in reference [ 3 ].

## Estimating Vehicle Kilometers

To this point I have described only how to calculate fuel use and emissions due to the transportation of people, starting from vehicle-kilometers for each mode. Now I wish to describe how to estimate vehicle kilometers.

I have found it useful to distinguish "demand" type modes from "scheduled" modes. A "demand" mode, such as auto (the only such mode I have considered), operates only when people wish to travel. By contrast, a "scheduled" mode, such as local bus, runs on predetermined routes at regularly scheduled times, whether passengers are riding in the vehicles, or whether the vehicles are empty.

In reference [5] it is pointed out that for scheduled modes, the number of vehicle-kilometers is independent of the number of passengers or passenger-kilometers carried. Thus, I choose to calculate vehicle-kilometers from the description of service provided by mode m- i.e. total kilometers of route-way, $R_m$, average headway (time between vehicles) $H_m$, and average velocity $V_m$. Also, let $L_m$ be the length of the service day (e.g. 18 hrs.). The result is,

(12)
$$S^p_m = \frac{60 R_m \; L_m}{H_m}$$

a result which can be checked with reference [5].

If one wishes to provide better service during part of the day (a peak period) than during the rest, one specifies two separate headways, and service times $L_m$ corresponding with each. The vehicle kilometers resulting from the two service periods are then added to yield $S^p_m$. If one wishes to relate these quantities to a better measure of transportation service, provided, one may relate the length of routeway, $R_m$, to the area being served. How far, on the average, must people walk to the nearest route? Reference [6] deals with a simple model of this kind.

Of course, to assert that vehicle-kilometers of scheduled modes is independent of passengers or passenger-kilometers is to bend the truth. If too many passengers try to ride such a mode, the operator of the mode will place additional vehicles in service, thus decreasing the headway. And if no-one rides the mode, the operator will surely cease to provide the service. Thus, to maintain a balance between the service offered by a mode of travel and the use made of it, we will wish to estimate person trips and person-kilometers carried on each mode.

For auto-the only "demand" type mode - I propose to calculate vehicle-kilometers from a combination of person-trips, an average trip length, and an average auto occupancy. It will be convenient to deal separately with trips for work-related purposes and trips for non-work purposes. Thus I will need person trips by auto, trip lengths, and occupancies for each purpose separately. Let $T^w_{auto}$, $\lambda^w_{auto}$, and $W^n_{auto}$ be these quantities for work trips, and $T^n_{auto}$, $\lambda^n_{auto}$, and $W^n_{auto}$ be the same quantities for non-work trips. Then auto-kilometers can be calculated as:

$$(13) \qquad S^p_{auto} = \frac{T^w_{auto} \cdot \lambda^w_{auto}}{W^w_{auto}} + \frac{T^n_{auto} \cdot \lambda^n_{auto}}{W^n_{auto}}$$

We shall deal separately with auto as an inter-urban mode and an intra-urban mode. Thus will shall specify separate numbers of trips, average trip lengths, and occupancies for the two categories of trips. This further implies that we shall have two equations (13), one each for inter-urban and intra-urban auto-kilometers. However, when auto-kilometers $S^{p}_{auto}$ appears in equations (5), (6) and (7), it will be the sum of inter-urban and intra-urban auto-kilometers.

For modes other than auto-that is, for the scheduled modes- I will estimate person trips for the two purposes, $T^{w}_{m}$ and $T^{n}_{m}$ , and the average trip lengths, $\lambda^{w}_{m}$ and $\lambda^{n}_{m}$. Then, rather than estimating an occupancy and then calculating vehicle-kilometers as in equation (13), I will calculate an occupancy using vehicle kilometers from equation (12). That is,

$$(14) \qquad W_{m} = \frac{T^{w}_{m} \cdot \lambda^{w}_{m} + T^{n}_{m} \cdot \lambda^{n}_{m}}{S^{p}_{m}}$$

If this occupancy is low, we should consider increasing the headway $H_m$ for that mode; if it is high, we should consider reducing $H_m$. In either case, $W_m$ serves as a measure of the balance between the service offered by mode m and the use made of that mode.

## Person Trips, Trip Lengths, and Auto Occupancies

Intra-urban work-related trips are proportional to the number of jobs available, each job generating a little less than two trips per work-day. (The trip to work and the return trip home are considered a two different trips. From these trips we subtract a proportion for those who are sick, and those who walk or bicycle to work). The number of jobs supplied by an industry should be proportional to its level of activity. Thus, if we can estimate the number of jobs per unit activity for each industry, we can estimate intra-urban work trips.

Inter-urban work-related trips (let us call them business trips) are probably also proportional to industrial activity, with different proportionality constants for different industries. However, this point should be checked if possible. If it is true, it provides a simple way to estimate these trips.

We should not attempt to construct a formal model to split these trips among the available modes. Instead, this split should be made a part of the scenario. In the same way, average trip lengths by mode and the auto occupancy $W^w_{auto}$ should be part of the scenario. How to include these factors systematically in the construction of scenarios should be a matter for early discussion.

Thus our procedure will be as follows:

Let $\mu^w_k(1)$ be the number of the daily work trips (calculated as jobs times 1.9) generated per unit activity in industrial category k. Let $\mu^w_k(2)$ be the number of daily business trips per unit activity in category k. Then total intra-urban work trips is:

$$(15) \qquad \overline{T}^w(1) = \sum_k \mu^w_k(1) \cdot a_k$$

Similarly, total inter-urban work trips is:

$$(16) \qquad \overline{\overline{T}}^w(2) = \sum_k \mu^w_k(2) \cdot a_k$$

As part of the process of building the scenario, we will specify how these trips shall be appointed among modes. We shall also specify trip lengths and, for auto, an occupancy rate. (Trip lengths for long, inter-urban trips will probably be constant. Trip lengths for intra-urban trips will depend on the urban form specified in the scenario.)

I expect that we shall also specify non-work trips by mode as part of the scenario, as well as trip lengths. The non-work auto occupancy, $w^n_{auto}$ we will probably hold constant among all scenarios.

Data needs for this step are modest. We must know jobs per unit activity for each industrial and commercial category. We must know other business travel, again by category. And we must know numbers of trips, average trip lengths, and modal splits for both work and non-work trips for some reference year.

## The Inputs of the Model

To drive the models, we must input the quantities listed below. Thus these are the quantities we expect will be specified either as part of the scenario, or as outputs from other models-models which do not require quantities calculated in the transportation models for their operation. Inputs for the freight transport model are the activities $a_k$ for each industrial and commercial category. In addition to these activities, the person transport model will need:

- Emission factors $\epsilon_{sc}$ and fuel consumption factors $\phi_{tc}$ for new autos joining the inventory each year.
- Proportions of new autos in each class that join the inventory each year. (The total number of new autos is determined in the model. But the proportion which are small, or electric, or hydrogen driver must be specified outside the model.)
- Kilometers of routway, $R_m$, length of the service period $L_m$, and headways $H_m$ of each scheduled mode. If there are two or more service periods with different headways, these and the

period lengths must be given separately for each period.

- Average auto trip lengths $\lambda_{auto}$ and auto occupancies $w_{auto}$ for inter-urban work trips, inter-urban non-work trips, intra-urban work trips, and intra-urban non-work trips.

- Average trip lengths $\lambda_m$ for modes other than auto, both for work and non-work and for inter-urban and intra-urban trips.

- Fractions of inter-urban work trips that are made by each mode. (the total number is estimated from the activities $a_K$. Given these fractions, the numbers of trips by each mode can be calculated,)

- Fractions of intra-urban work trips made by each mode (see previous item).

- Numbers of inter- and intra-urban non-work trips made by each mode, $T_m^n$ .

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