cost values may be more meaningful when taken in conjunction with a "moving" baseline, which means assuming that some advances in motor-vehicle fuel economy will occur simply as a result of continuing demand for more efficient transportation.

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# Forecasts of Intercity Passenger Demand and Energy Use Through 2000

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**The development of forecasts of national travel demand and energy use for automobile and common-carrier intercity travel through the year 2000 is reported. The forecasts are driven by the Passenger Oriented Intercity Network Travel Simulation (POINTS) model, a modified direct-demand model that accounts for competition among modes and destinations. Developed and used to model SMSA-to-SMSA business and nonbusiness travel, POINTS is an improvement over earlier direct-demand models because it includes an explicit representation of the relative accessibilities of cities and a utility-maximizing behavioral multimodal travel function. Within POINTS, path-building algorithms are used to determine city-pair travel times and costs by mode, including intramodal transfer times. Other input data include projections of SMSA population, public- and private-sector employment, and hotel and other retail receipts. Outputs include forecasts of SMSA-to-SMSA person trips and person miles of travel by mode. For the national forecasts, these are expanded to represent all intercity travel (trips longer than 100 miles one way) for two fuel price cases. In both cases, rising fuel prices, accompanied by substantial reductions in modal energy intensities, result in moderate growth in total intercity passenger travel. Total intercity passenger travel is predicted to grow at approximately 1 percent/year, slightly faster than population growth. Automobile travel is forecast to increase slightly more slowly than population and air travel to grow almost twice as fast as population. The net effect of moderate travel growth and substantial reduction in modal energy intensities is a reduction of approximately 50 percent in fuel consumption by the intercity passenger travel market.**

This paper describes the methods used by Argonne National Laboratory (ANL) in projecting future intercity passenger travel and associated fuel consumption through the year 2000. These projections were developed for the Office of Vehicle and Engine Research and Development of the U.S. Department of Energy (DOE) and are documented in an Argonne National Laboratory report (1).

Intercity passenger travel accounts for approximately 16 percent of domestic passenger miles of travel and 13 percent of domestic passenger-related fuel consumption. Generally regarded as highly discretionary, this travel sector is perhaps best modeled via behavioral, policy-sensitive methods. The following steps provide an overview of the methods used by ANL:

1. Detailed city pair modeling to estimate person miles of travel (PMT) from standard metropolitan statistical area (SMSA) to SMSA by trip purpose and mode,
2. Computation of growth rates from a 1977 base year for SMSA-to-SMSA PMT by mode,
3. Application of the above growth rates to 1977 estimates of intercity PMT (intercity travel is defined as all trips of 100 miles or more one way) to estimate future-year intercity PMT by mode,
4. Application of vehicle load factors to convert automobile and light-truck PMT into vehicle miles of travel (VMT), and
5. Application of VMT- or PMT-based energy intensities to convert PMT and VMT to British thermal units by mode.

MODELING SMSA-TO-SMSA PMT

SMSA-to-SMSA travel for the base year and all future years was modeled by using the Passenger Oriented Intercity Network Travel Simulation (POINTS) model. POINTS estimates passenger demand for the four major modes (automobile/light truck, air, bus, and rail) that compete for this market. Like most recent approaches to intercity travel demand modeling, POINTS is a direct demand model. It simultaneously estimates (a) the total number of trips and the geographic distribution of their origins (trip generation), (b) the joint probability distribution of trip origins and destinations (trip distribution), and (c) the mode by which the travel occurs (mode split). All of these aspects of SMSA-to-SMSA travel are modeled as a function of (and are therefore sensitive to) the amount of activity (population, employment, sales, etc.) at the origin and destination cities and the transportation level of service that connects them. Although POINTS shares these attributes with other direct-demand models, two significant improvements have been incorporated into

POINTS that distinguish it from most other models of the type. These improvements have been included in an effort to overcome certain theoretical deficiencies in the traditional direct-demand formulation (2). These improvements, which are similar to those reported by Gantzer (3), include

1. An explicit representation of origin and destination accessibility and
2. The inclusion of an internally consistent multimodal travel function based on utility-maximizing (hedonic) principles, and an explicit specification of the most probable distribution of value of time.

A direct-demand model can be written in the simplest terms as follows:

$$V_{ijm} = K P_i F_{ijm} A_j \quad (1)$$

where

- $V_{ijm}$ = volume of trips by mode m between origin i and destination j;
- K = constant of proportionality;
- $P_i$ = function of trip-producing activity at origin i;
- $F_{ijm}$ = function of travel impedances, usually time (T) and cost (C) by mode m between i and j; and
- $A_j$ = function of trip-attracting activity at destination j.

In the traditional direct-demand model, the multiplicative factors in Equation 1 are usually represented as power products:

$$V_{ijm} = K P_i^{a_1} A_j^{a_2} T_{ijm}^{a_3} C_{ijm}^{a_4} \quad (2)$$

Although this is a very simple representation of the many alternative direct-demand models that have been formulated (2), all have preserved this basic form.

One consequence of the above formulation is that the number of trips generated by each origin is directly proportional to the access of the origin to all destinations (4):

$$V_{im} = K P_i \sum_j F_{ijm} A_j = K P_i I_{im} \quad (3)$$

where $I_{im} = \sum_j F_{ijm} A_j$ is the accessibility of zone i to the activity at all zones j.

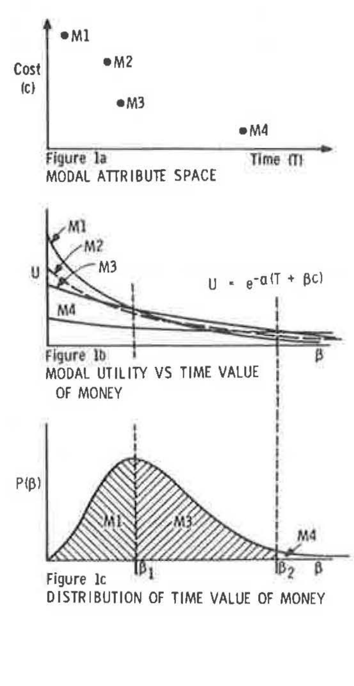
This is not a desirable trait, since the implication is that there is no competition between destinations. An increase in the attractiveness of one destination (with all others held constant) will induce a proportional gain in travel between it and all other places, while the interchanges between all other places will remain unchanged. Since it is reasonable to believe that some "new" travel will be induced and some "old" travel will be redirected, access is included in POINTS as an explicit variable with a coefficient less than zero but greater than minus one. Thus, the trip-generation implications of improved access are mitigated but not totally eliminated.

Similar problems exist with most of the functional relations of the travel impedance measures. In the simplest of formulations, Equation 2, competition between modes is completely ignored. In the commonly used logit formulation, the inclusion of new modes does not alter the relative split among previously existing modes (5). Several other formulations that avoid such logical inconsistencies rely on separate equations for trip distribution and modal split, thus sacrificing some of the theoretical attractiveness of the simultaneous nature of direct-demand models (2). One approach that avoids these inconsistencies while preserving simultaneity is Blackburn's behavioral utility-maximizing approach (6). In that approach, it is assumed that the mode selected for each trip is that which maximizes the trip's utility and that each tripmaker has a constant trade-off rate between the attributes of the modes. If only two attributes (say, time and cost) are of interest, Schneider (4) has developed a formulation based on utility-maximizing principles in which the most probable distribution of trade-off rates (value of time) across travelers is specified by the entropy-maximizing principles popularized by Wilson (7).

The development of Schneider's formulation is presented graphically in Figure 1. Assume that four alternative modes are available for a given origin-destination (O-D) pair and that they are arranged in attribute space (time and cost), as in Figure 1a. Then the disutilities of travel by each mode for travelers with varying time values of money ($\beta$) are defined according to entropy maximization as the four negative exponential curves displayed in Figure 1b. In the example, interchange mode M1 is the fastest and most expensive mode. Therefore, for travelers with the lowest time value of money (the highest value of time), $\beta = 0$ and the utility derived from traveling is highest by mode M1. The utility of travel by this mode drops rapidly as travelers who value money more highly are considered. At the opposite extreme, M4 is the slowest and cheapest mode. Since cost is a much smaller relative contribution to the total disutility of travel for M4, the curve decays at a much slower rate as $\beta$ increases in value. Consequently, travelers with very high values of $\beta$ (i.e., low values of time) will maximize the utility of their travel by choosing M4. In this example, travelers with values of $\beta$ greater than zero but less than $\beta_1$ will prefer M1, those with a time value of money between $\beta_1$ and $\beta_2$ will prefer to travel by M3, and those whose value of $\beta$ is greater than $\beta_2$ will choose M4.

According to this paradigm, in this example M2 will not be considered attractive by any traveler. It can be shown that only modes that form a convex surface when arrayed in attribute space are compet-

Figure 1. Multimodal utility maximization with distributed population for four-mode case.



itive (i.e., attractive to some portion of the population).

The aggregate modal split for the interchange is defined by the proportion of travelers in each range of $\beta$. If the population of travelers is distributed with respect to $\beta$ according to the probability density function $P(\beta)$, as shown in Figure 1c, the proportion of travelers traveling by each mode is determined by the integral of $P(\beta)$ over the range of $\beta$ that maximizes U.

A consistent aggregate measure of the relative utility of travel for the interchange that considers also the distributed value of $\alpha$ is defined by

$$F_{ij} = \int_0^{\infty} \int_0^{\beta_1} \exp[-\alpha(T_1 + \beta C_1)]\, P(\beta)\, d\beta d\alpha + \int_0^{\infty} \int_{\beta_1}^{\beta_2} \exp[-\alpha(T_3 + \beta C_3)]\, P(\beta)\, d\beta d\alpha + \int_0^{\infty} \int_{\beta_2}^{\infty} \exp[-\alpha(T_4 + \beta C_4)]\, P(\beta)\, d\beta d\alpha \quad (4)$$

The principal difficulty in applying this approach lies in determining the appropriate probability density function for $\beta$. Some researchers have postulated a log-normal distribution; others have assumed it to be empirically defined by the distribution of a surrogate variable like income (8). Schneider has deduced a "most probable" distribution of $\beta$ according to entropy-maximizing principles as (9):

$$P(\beta) = \left(\int_0^{\infty} \exp\{-\alpha[(T^{-1} + bC^{-1})/(T^{-1} + \beta C^{-1})]\}\, d\alpha\right) \div \left(\int_0^{\infty} \int_0^{\infty} \exp\{-\alpha[(T^{-1} + bC^{-1})/(T^{-1} + \beta C^{-1})]\}\, d\alpha d\beta\right) \quad (5)$$

A major advantage of incorporating this probability density function is that the integrals are solvable in closed form and do not require time-consuming numerical integration to valuate.

With the travel function defined by the above logic and an explicit representation of accessibility, two direct-demand models (one for business travel and one for nonbusiness travel) have been included in POINTS. These are described by Equations 6 and 7. The choice-of-activity variables (GVPOP and HTPOP) were adopted from earlier intercity demand modeling efforts at the New York State Department of Transportation (10).

$$V_{ijm}^{BIZ} = [K^{BIZ}(GVPOP_i * GVPOP_j)\exp(\gamma^{BIZ})\, F_{ijm}^{BIZ}] \div (I_i^{BIZ}\, I_j^{BIZ})\exp(\delta^{BIZ}) \quad (6)$$

$$V_{ijm}^{NBIZ} = [K^{NBIZ}(HTPOP_i * HTPOP_j)\exp(\gamma^{NBIZ})\, F_{ijm}^{NBIZ}] \div (I_i^{NBIZ}\, I_j^{NBIZ})\exp(\delta^{NBIZ}) \quad (7)$$

where

$V_{ijm}^{BIZ}$ = volume of business trips between origin SMSA i and destination SMSA j by mode m;
$V_{ijm}^{NBIZ}$ = volume of nonbusiness trips between origin SMSA i and destination SMSA j by mode m;
GVPOP = SMSA population weighted by percentage of government employment;
HTPOP = SMSA population weighted by percentage of total services receipts generated by the hotel sector;
$I_i^{BIZ}$ = access of SMSA i to the business travel attraction variable GVPOP [$I_i^{BIZ} = \sum_j \sum_m F_{ijm}\, GVPOP_j \exp(\gamma^{BIZ})$];
$I_i^{NBIZ}$ = access of SMSA i to the nonbusiness travel attraction variable HTPOP [$I_i^{NBIZ} = \sum_j \sum_m F_{ijm}\, HTPOP_j \exp(\gamma^{NBIZ})$]; and
$F_{ijm}$ = solution to Equation 4, where $P(\beta)$ is defined as in Equation 5:

$$F_{ij1} = \left(\{K_2[2\sqrt{a(T_1 + bC_1)}]\}/[a(T_1 + bC_1)]\right)\{1 - [1/(1 - R_1 S_{12})]\}$$

$$F_{ij2} = \left(\{K_2[2\sqrt{a(T_2 + bC_2)}]\}/[a(T_2 + bC_2)]\right) \cdot \{[1/(1 + R_2 S_{12})] - [1/(1 + U_2 S_{23})]\}$$

$$\vdots$$

$$F_{ijn} = \left(\{K_2[2\sqrt{a(T_n + bC_n)}]\}/[a(T_n + bC_n)]\right)[1/(1 + R_n S_{n-1,n})] \quad (8)$$

where

$K_2$ ( ) = modified Bessel function of the second order;
$T_m$ = travel time between SMSAs i and j by mode m;
$C_m$ = travel cost between SMSAs i and j by mode m;
$S_{m,m+1}$ = $(T_{m+1} - T_m)/(C_m - C_{m+1})$ when the modes are ranked by ascending travel time;
$R_m$ = $C_m/T_m$;
a and b = calibration constants that specify the average sensitivity of trips to the impedance measure $(T + \beta C)$ and the average value of $\beta$, respectively;
$\gamma^P$ and $\delta^P$ = calibration parameters that determine the utility curves of activity and accessibility for trip purpose P, respectively; and
$K^P$ = constant of proportionality for purpose P.

Despite the theoretical advantage of the POINTS travel demand model, at least two disadvantages are associated with it. First, the utility-maximizing logic precludes the choice of "inferior" modes. An inferior mode, in the context of the paradigm, is any mode that lies above the convex surface formed by the line segments that connect the competitive modes (e.g., M2 in Figure 1a). In reality, many such modes do attract some (though most often few) trips. Such behavior can be explained either by including additional dimensions in the attribute space or by explicitly defining a random error term to account for travelers' imprecise perceptions. Pragmatically, however, difficulties of measurement and mathematical tractability preclude such extensions.

An even more pragmatic problem associated with the POINTS demand model is its highly nonlinear form. It is difficult, if not impossible, to transform Equations 6 and 7 into linear forms. Thus, standard algorithms to estimate the model parameters based on goodness of fit to observed data cannot be used. In consequence, a heuristic process must be used for parameter estimation.

## DEVELOPMENT OF POINTS MODEL INPUT DATA

To model intercity travel, two data bases were required: One provided projection-year information to be input to the POINTS model, and the other provided base-year information necessary to calibrate the model. Both contained demographic and transportation system data. The base-year data base provided additional information on actual travel demand.

The Bureau of Economic Analysis (BEA) 1980 cycle of regional economic projections provided the required population and employment data (11). The BEA projections are compiled by SMSA for three scenarios. Scenario 1 assumes that within a state each SMSA will maintain its 1969 share of the state's economic activities; scenario 2 assumes that the SMSA share will change as a result of 1969 to 1978 shifts, moderated by a set of decay factors; and scenario 3 assumes that the SMSA share will change as a result of the 1969-1978 trend and that there will be still greater moderation from decay factors (12). In each scenario, national totals remain constant. For this project, scenario 2 was selected and data were aggregated from the 266 SMSAs to 142 urban areas.

Four transportation networks (highway, air, bus, and rail) were coded. Each of the 142 urban areas was coded as an O-D node. Eleven Canadian cities were also coded as nodes to allow for alternative travel routes available through Canada. Several nodes were coded for the rail network to represent nonurban route intersections. Travel times, distances, tolls, and fares were obtained for each network. Four network files were created. Frequencies for the air network were included on each link record; frequencies of rail routes were coded as a separate file to be input directly to the path builder. Rail route numbers were coded on each link to permit the path builder to identify transfer between routes.

A minimum-impedance path-building algorithm that can estimate layover times at transfer points for the air and rail networks was used. The highway and bus networks were assumed to have no layover times. For long trips on highway and bus networks, additional time and cost penalties were input exogenously to the POINTS model.

Layover times were computed by using the frequency of service on connecting links. It was assumed that frequencies cover a 12-h period, which represents a typical travel interval. Airline and rail services normally cover such a period. This period may be longer for very heavily traveled routes and considerably shorter for small urban areas. Layover times are dependent on interarrival times on one link and interdeparture times on possible connecting links. These interarrival-interdeparture times in turn are dependent on frequencies. Two methods are used in computing layover times, one based on uniform probabilities and the other based on random service. For each transfer point, layover times were computed by using both random and uniform probability methods. An average of the two values was taken for miniminum-impedance path building.

The minimum-impedance paths were traced and urban-area-to-urban-area matrices were developed for time, distance, toll, and fare. Within the POINTS model, highway costs were computed as a function of distance. For highway and bus modes, time and cost penalties for overnight stays were added.

The observed calibration trip tables were constructed from detailed information on each trip, including origin, destination, purpose, and mode, as obtained from the 1977 National Travel Survey (NTS) (13), in which O-D information is provided in the form of state or county codes for all intercity trips and SMSA codes for trips involving certain selected urban areas. Origin information is provided for 30 SMSAs, and destination information is provided for 52 SMSAs, including the above-noted 30 origin SMSAs. After consolidating all the nearby SMSAs, the 30 origin SMSAs were reduced to 26 urban areas for the POINTS model. Though an additional 22 destination SMSAs were available on the file, their usefulness for calibration purposes was limited since the POINTS model deals with both productions and attractions. Data on attractions alone were not sufficient.

The NTS file was searched for trips between the 26 urban areas. These trips were disaggregated by purpose and mode. Two purposes, business and nonbusiness, were assigned. Four mode categories (highway, air, bus, and rail) were developed from the modes on the data file. Eight trip matrices, one for each purpose-mode combination, were developed. Base-year population and employment data were obtained from the BEA regional economic projections file for the selected 26 urban areas. The 1980 modal network files were assumed to represent the 1977 transportation system with respect to travel times and distances. Travel costs were deflated back to 1977 values.

## CALIBRATION OF INTERCITY PASSENGER MODEL

The calibration of the POINTS travel demand model attempts to replicate multimodal intercity travel between 26 U.S. cities. The 26 cities were chosen because they are the only cities coded explicitly for both trip origin and destination in the 1977 NTS. However, because the POINTS model considers destination competition (through the access term), the modeling of travel between the 26 city pairs was performed in the context of all U.S. SMSAs. The POINTS calibration process is shown in Figure 2.

Data on intercity travel times and costs by mode and trip end were input for 142 consolidated SMSAs. Trip-end data included one-way access-egress times and costs by mode, population, government employment, total employment, hotel receipts, and total retail receipts. The four calibration coefficients (a, b, $\gamma$, and $\delta$) were systematically varied in successive applications of the POINTS model. After each model run, the trip interchanges (by mode) between the 26 city pairs were extracted from the trip tables produced by POINTS for the 142 SMSAs. The synthetic 26-city trip tables were compared with the observed 26-city trip tables constructed from the NTS data. Coefficients of determination ($R^2$), trip length distributions by mode, and modal-split estimates by distance of travel were compared. The process continued until the "best" fit was obtained. The word "best" is used here quite loosely to mean the best under the circumstances as opposed to a truly global optimum fit. Because the calibration process was one of trial and error, it is entirely possible that a better fit could have been obtained (though it is not likely to have been much better). The final calibration coefficients and the $R^2$ between observed and synthetic trip inter-

Figure 2. POINTS calibration process.

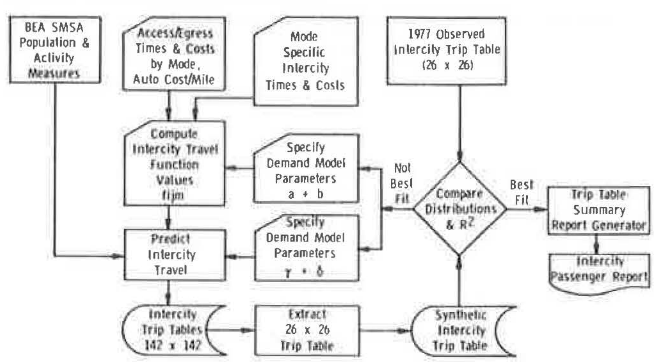


Table 1. Fuel prices for low and medium price cases.

| Case | Type of Fuel Price | Amount ($) 1980 | 1985 | 1990 | 2000 | Avg Annual Change (%) |
|---|---|---|---|---|---|---|
| Low price | Crude oil price per barrel | 27.9 | 43.6 | 52.8 | 75.8 | 5.1 |
| | Fuel price per gallon | | | | | |
| | Gasoline | 1.23 | 1.61 | 1.85 | 2.45 | 3.5 |
| | Diesel | 1.03 | 1.50 | 1.75 | 2.39 | 4.3 |
| | Jet | 0.97 | 1.32 | 1.58 | 2.23 | 4.3 |
| Medium price | Crude oil price per barrel | 27.9 | 37.9 | 46.3 | 64.3 | 4.3 |
| | Fuel price per gallon | | | | | |
| | Gasoline | 1.23 | 1.42 | 1.68 | 2.24 | 3.0 |
| | Diesel | 1.03 | 1.31 | 1.58 | 2.18 | 3.8 |
| | Jet | 0.97 | 1.14 | 1.41 | 2.08 | 3.8 |

Note: Prices in 1980 dollars.

changes are given below [b in minutes per cent (1977 dollars)]:

| Coefficient | Business | Nonbusiness | All |
|---|---|---|---|
| a | 0.000 28 | 0.000 018 | |
| b | 0.017 | 0.05 | |
| $\gamma$ | 1.30 | 1.35 | |
| $\delta$ | 0.35 | 0.40 | |
| $R^2$ | | | |
| All modes | 0.756 | 0.923 | 0.910 |
| Automobile | 0.761 | 0.966 | 0.960 |
| Air | 0.604 | 0.595 | 0.645 |
| Bus | 0.0 | 0.056 | 0.278 |
| Rail | 0.979 | 0.133 | 0.833 |

PREDICTING SMSA-TO-SMSA TRAVEL

The calibrated POINTS model was used to predict SMSA-to-SMSA PMT of travel by automobile, air, bus, and rail for three forecast years (1985, 1990, and 2000). Forecasts were made for two fuel price cases: low (moderate economic growth) and medium (constrained economic growth), as given in Table 1. BEA projections of SMSA population and employment for each of the forecast years were input to the model. Inter-SMSA travel times, access-egress times and costs, and percentage of hotel receipts remained unchanged in all forecasts. Automobile operating cost per mile and common carrier fares were modified to account for the effects of changing fuel prices and vehicle fuel efficiencies. These cost factors are given in Table 2.

Initial POINTS forecasts indicated rather large increases in bus PMT. The model predicted an increase in the bus share of PMT from approximately 2 percent to almost 9 percent in the medium fuel price case. This was considered to be unreasonable, and the POINTS estimate was adjusted. The adjustment process made the simple assumption that the combined share of surface common carriers (bus and rail) would remain constant over time. The excess PMT was reapportioned between the automobile and air modes in proportion to their originally modeled shares.

Table 2. Modal cost factors.

| Year | BIZ, Automobile | NBIZ Automobile | Air | Bus | Rail |
|---|---|---|---|---|---|
| 1977 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1985 | | | | | |
| Low | 1.12 | 1.25 | 0.98 | 1.06 | 1.11 |
| Medium | 1.21 | 1.35 | 1.03 | 1.08 | 1.12 |
| 1990 | | | | | |
| Low | 1.18 | 1.30 | 1.05 | 1.08 | 1.21 |
| Medium | 1.25 | 1.37 | 1.09 | 1.09 | 1.24 |
| 2000 | | | | | |
| Low | 1.35 | 1.47 | 1.09 | 1.12 | 1.45 |
| Medium | 1.42 | 1.54 | 1.13 | 1.14 | 1.51 |

Predicting Intercity Travel

Comparison of the 1977 POINTS estimate of SMSA-to-SMSA PMT (206.242 billion PMT) with the NTS reported intercity PMT (381.860 billion) demonstrated the necessity to account for non-SMSA-to-SMSA travel. Total intercity PMT was estimated by computing percentage changes in SMSA PMT (by mode) between the base-year estimate and each POINTS forecast. These "growth factors" were applied to base-year modal PMTs. The resulting intercity PMTs are given in Table 3. The population forecast is given below:

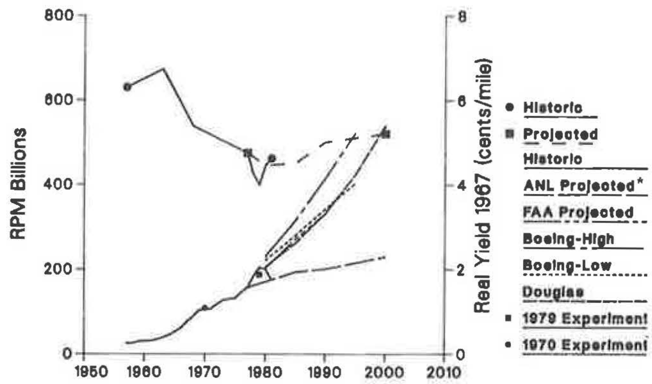
| Year | Level | Population (000 000s) | Growth (%) |
|---|---|---|---|
| 1977 | | 217 | |
| 1985 | Low | 232.5 | 7.1 |
| 1990 | Medium | 243.5 | 12.2 |
| 2000 | Medium | 260.4 | 20.0 |

According to the adjusted POINTS estimates in Table 3, total intercity PMT grows at roughly the same rate as population. From 1977 to 1985, PMT grows at a rate slightly lower than population (6.1 versus 7.1 percent); from 1985 to 1990 and from 1990

Table 3. Forecast intercity PMT.

| Mode | 1977 (000 000s) | 1985 Amount (000 000s) Low | 1985 Medium | 1985 Growth (%) | 1990 Amount (000 000s) Low | 1990 Medium | 1990 Growth (%) | 2000 Amount (000 000s) Low | 2000 Medium | 2000 Growth (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Automobile | 237 056 | 240 263 | 232 988 | 0 | 261 591 | 256 715 | 8.8 | 278 470 | 274 056 | 16.4 |
| Air | 129 587 | 152 884 | 141 981 | 17.3 | 158 450 | 157 246 | 31.9 | 181 813 | 180 477 | 39.7 |
| Bus | 9 147 | 10 424 | 9 885 | 8.2 | 11 317 | 11 068 | 21.4 | 13 222 | 13 091 | 43.2 |
| Rail | 3 977 | 3 953 | 4 601 | 5.6 | 3 607 | 3 764 | -7.0 | 2 910 | 2 862 | -27.0 |
| Other | 2 093 | 2 327 | 2 292 | 0 | 2 457 | 2 426 | 0 | 2 741 | 2 713 | 0 |
| Total | 381 860 | 409 851 | 401 747 | 6.1 | 437 422 | 431 221 | 13.7 | 479 156 | 473 199 | 24.3 |

Figure 3. Forecasts of airline revenue passenger miles and yield.




to 2000, PMT grows at a slightly faster rate than population (13.7 versus 12.2 percent and 24.3 versus 20.0 percent, respectively). However, when the data are reviewed by mode, significant differences become apparent: Automobile travel grows significantly slower than population whereas air travel grows significantly faster.

When the POINTS forecast of commercial aviation revenue passenger miles (RPMs) is compared with historical trends and other forecasts (14-17), such as those illustrated in Figure 3, a fundamental difference becomes evident. All other major forecasts show RPMs growing at an accelerated rate through the year 2000, a rate comparable to observed growth between 1960 and the late 1970s. RPMs also increase under the POINTS forecast, but they do so at a much decelerated rate. Moreover, most forecasts imply a 150 percent increase in RPMs per capita between 1980 and 2000. By contrast, the POINTS forecast estimates an increase of only 14 percent.

A view of the historical trend in yield (revenue per revenue passenger mile) helps to explain some of these differences. Yield, measured in constant 1967 dollars, is a reasonably good index of the change in the real cost of air travel to the air traveler. In the early 1960s, following the introduction and diffusion of turbofan jet technology, yield dropped dramatically. Beginning in the late 1960s, the rate of decline slowed somewhat until 1978, when a combination of events, including deregulation, resulted in strong competition and a sharp reduction in yield. This latter trend continued through 1979 despite higher operating costs brought on by a rapid increase in jet fuel prices. A widespread discount campaign by major airlines fostered the 1979 decline in yield. Although yield was down, RPMs reached record levels, partly as a result of discount fares and coupons and partly as a result of travelers shifting from automobile to air travel because of the unavailability of gasoline. In 1980, and again in the first quarter of 1981, yield registered its first significant real dollar gains since the early 1960s. This increase is consistent with the future cost factors presented in Table 2. The POINTS input assumed that real yield would increase at a rate consistent with rising fuel costs while accounting for improved aircraft energy efficiencies. This reversal in the yield trend helps account for the shape of the POINTS forecast curve.

Although the POINTS model was calibrated with cross-sectional data at only one point in time (1977), the POINTS forecast implies that the future demand for aviation travel will respond like a typical technology substitution curve, taking its familiar S-shape. The high RPMs recorded for 1978, 1979, and 1980 (in relation to the POINTS forecast) represent an artificial technological "improvement" (intense marketing and price competition) that could not be sustained in the long run because of low associated profit. Therefore, from the point of view of the POINTS forecasts, these data points are aberrant. Nevertheless, a simple experiment was devised to test the ability of POINTS to simulate some of the unusual conditions that resulted in these demands. In an effort to replicate the peak demand of 1979, a 15 percent reduction in the real cost of air travel (from 1977 values) and a 50 percent increase in out-of-pocket automobile costs were input to the model. The automobile cost increase is based solely on the rate of growth in retail gasoline price. It does not include the opportunity costs associated with waiting in gasoline lines or the intangible "cost" of uncertain fuel availability. The result was a 17.7 percent increase in air RPMs (over 1977 levels) as compared with the 23.8 percent observed increase. This shortfall can be attributed to the 1979 fuel shortage, which was not simulated in the test run. Nonetheless, the POINTS estimate is in the range of the other forecasts of 1979 demand shown in Figure 3. This indicates that POINTS is capable of responding reasonably well to a range of input specifications.

A further test of the validity of POINTS as a predictive model involved backcasting to 1970. SMSA population and employment were universally factored back to 1970 levels. The real cost of travel was adjusted for each mode, and automobile travel times were reduced to represent the 70-mph versus 55-mph speed limit. The POINTS backcasted air RPM was 112 billion miles versus the 109 billion miles reported by the Transportation Association of America (18). Applying the POINTS per capita automobile PMT backcast to 1972 population resulted in 267 billion miles versus the 277.5 billion miles reported by the 1972 NTS. Thus, POINTS replicated fairly well both the past higher automobile PMT (-3.7 percent error) and the lower air RPM (+2.76 percent error).

## INTERCITY ENERGY INTENSITIES

Estimates of intercity passenger-mode energy intensities are given by year in Table 4.

The major assumptions underlying these estimates are discussed by mode below:

1. The bus energy intensity estimates are based on information provided by the American Bus Association. Improvements in fleet average miles per gallon of 5 percent by 1985 and 10 percent by 1990 are assumed. No improvements are assumed beyond 1990. These estimates are based on technological efficiency changes, primarily downweighting and a shift to turbocharged V-6 engines by major bus operators.
2. Intercity rail energy intensity has been dropping slightly over time, at an average rate of -1.4 percent/year from 1975 to 1978 (19). As the National Rail Passenger Corporation (Amtrak) attempts to improve the efficiency of its operations and to increase load factors, this trend should continue. Therefore, an average annual change of -1.0 percent has been assumed through 1990. Beyond 1990, energy intensity is assumed to remain constant.
3. Intercity automobile energy intensities were derived from projected vehicle stocks. Highway miles per gallon (MPG) was calculated for each vehicle type by using the following equations:

$$\text{Combined MPG} = 1.18 \text{ city MPG} \quad (9)$$

$$\text{Highway MPG} = (\text{combined MPG} - 0.55 \text{ city MPG})/0.45 \quad (10)$$

The result was then degraded to an on-the-road fuel

Table 4. Intercity energy intensities by mode: 1977-2000.

| Mode | Measure | 1977 | 1980 | 1985 | 1990 | 2000 |
|---|---|---|---|---|---|---|
| Bus | Passenger miles per gallon | 141.5 | 144.0 | 151.2 | 158.4 | 158.4 |
| | Vehicle miles per gallon | 6.1 | 5.9 | 6.2 | 6.5 | 6.5 |
| | Btu per passenger mile | 980 | 963 | 917 | 876 | 876 |
| | Change from base (%) | - | Base | 5.0 | 10.0 | 10.0 |
| Rail | Btu per passenger mile | 3410 | 3308 | 3137 | 2967 | 2967 |
| | Change from base (%) | - | Base | 5.0 | 10.0 | 10.0 |
| Automobile | Passenger miles per gallon | 34.5 | 41.3 | 52.9 | 64.0 | 82.4 |
| | Vehicle miles per gallon | 15.2 | 18.2 | 23.3 | 28.2 | 36.3 |
| | Btu per vehicle mile | 8239.9 | 6996.5 | 5275.5 | 4462.6 | 3495.1 |
| | Change from base (%) | - | - | 24.5 | 36.0 | 50.0 |
| Air | Passenger miles per gallon | 19.9 | 26.4 | 31.0 | 37.0 | 48.8 |
| | Btu per passenger mile | 8224 | 5114 | 4352 | 3653 | 2764 |
| | Change from base (%) | - | Base | 17.5 | 40.0 | 85.0 |

economy estimate by using historical trends and limited survey data (20,21). The degradation accounts for driving conditions, vehicle maintenance, climate, etc., and corresponds to the difference between the on-road fuel economy of new vehicles under relatively favorable conditions and the on-road fuel economy of the entire fleet across a range of conditions. The degradations were as follows: in 1980, 12 percent for all vehicles; in 1985-2000, 20 percent for gasoline vehicles, 10 percent for diesel vehicles, and 0 percent for electric vehicles. Finally, a weighted average was computed from the estimates of automobile, van, and light-truck highway miles per gallon. The results show a rapid and significant improvement from 1977 to 2000.

4. Improvements in future air efficiencies are expected to come as a result of both airline operational changes and new aircraft technologies. Aircraft technologies should undergo rapid changes throughout the 1980s and 1990s as the advances developed in the Aircraft Energy Efficiency (ACEE) program of the National Aeronautics and Space Administration (NASA) reach technological readiness (22). The ACEE program began in 1976 and was originally scheduled for completion in 1985. The goal of the program was to achieve a 50 percent improvement in aircraft fuel efficiency through the acceleration of certain key technologies. Six specific projects were chosen for research and development: (a) engine component improvement; (b) energy-efficient engine; (c) advanced turboprop; (d) energy-efficient transport; (e) laminar flow control; and (f) composite primary aircraft structures.

When the anticipated effects of operational and technological improvements are combined, total fuel efficiency can be expected to improve as follows:

| Period | Improvement Over Base (%) |
|---|---|
| 1980-1985 | 17.5 |
| 1985-1990 | 22.5 |
| 1990-1995 | 30 |
| 1995-2000 | 15 |
| Total | 85 |

The increase from 1990 to 1995 is due to the expected influx of NASA ACEE project improvements. The rate drops from 1995 to 2000 as the operational and technological improvements considered in the baseline scenario achieve full market penetration.

The PMT values in Table 3 multiplied by the corresponding energy intensities from Table 4 result in estimates of base-year (1977) and future energy use. An automobile occupancy factor of 1.9 person miles/vehicle mile was assumed for converting Btu per VMT to Btu per PMT. The final estimates of fuel consumed in intercity passenger transportation are shown in Table 5. Despite significant increases in PMT, projected increases in vehicle fuel efficiencies reduce fuel consumption by almost 50 percent.

Table 5. Forecast fuel use for intercity travel.

| Year | Fuel ($10^{15}$ Btu) Automobile[a] | Air | Bus | Rail | Total |
|---|---|---|---|---|---|
| 1977 | 1.028 | 0.8786 | 0.0090 | 0.0136 | 1.9292 |
| 1985 | | | | | |
| Low | 0.6671 | 0.6654 | 0.0096 | 0.0124 | 1.2538 |
| Medium | 0.6470 | 0.6614 | 0.0091 | 0.0144 | 1.3319 |
| 1990 | | | | | |
| Low | 0.6144 | 0.5788 | 0.0099 | 0.0107 | 1.1940 |
| Medium | 0.6029 | 0.5744 | 0.0098 | 0.0117 | 1.1988 |
| 2000 | | | | | |
| Low | 0.5123 | 0.5025 | 0.0159 | 0.0086 | 1.0393 |
| Medium | 0.5042 | 0.4988 | 0.0158 | 0.0085 | 1.0246 |

[a]An automobile occupancy rate of 1.9 person miles/vehicle was assumed across all forecast years.

## CONCLUSIONS

For two cases of relatively high fuel prices (3-4 percent/year rate of increase), with steady but relatively less dramatic improvements in modal energy intensities, the price of intercity passenger travel will increase. Despite these price increases, structural changes in the population (size and distribution) may be expected to result in an increase in per capita intercity travel; total intercity passenger miles of travel will increase slightly faster than population. With the average value of time for intercity travel held constant over time (business at $35/h and nonbusiness at $12/h, in 1977 dollars) and slower price increases for air travel versus automobile travel, air travel grows at a rate almost twice that of population while automobile travel increases at a rate slightly less than population. The net effect of moderate travel growth and substantial reductions in modal energy intensities is a reduction of approximately 50 percent in fuel consumption by the intercity passenger travel market.

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# Trends in Energy Use and Fuel Efficiency in the U.S. Commercial Airline Industry

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**The relative contributions of four components of fuel-efficiency gain to total efficiency improvement in the U.S. commercial airline industry since the 1973 oil embargo are identified, and a determination is made as to whether the efficiency improvements after 1973 represent a change in behavior from past trends. Civil Aeronautics Board data are used. Total efficiency increases since 1973 are divided into four components of efficiency gain/load factor, mix, seating capacity, and technical and operating efficiency. The contribution of each component to the improvement of fuel efficiency is measured by estimating how much fuel would have been needed to deliver actual services in a particular year had the component under study been held at its 1973 level while the other components varied. The rise in load factors accounts for one-third of the efficiency gain from 1973 to 1980. The increase is due in part to deregulation of the industry. Seating capacity made the second largest contribution, followed by mix and technical and operating efficiency. To compare pre- and post-embargo trends, a trend of yearly seat miles per gallon for the pre-embargo period was derived and extrapolated into the post-1973 period. Actual seat miles per gallon does not rise above the historic trend until 1979. Industry behavior did not change its historic patterns until 1979. Apparently, that was the first time that fuel costs became a significant financial burden to the airlines. The industry response to the fuel price rise was hampered by the time lag involved in introducing new-model aircraft into the fleet.**

The U.S. government is reducing its role in encouraging energy conservation to lessen America's dependence on imported oil. Since the government is relying more on the private sector to reduce U.S. dependence on foreign oil, it is important to know how effective the private sector has been in reducing fuel use. It will also be helpful to know what government programs have accomplished. The U.S. Department of Energy (DOE) is currently undertaking such an assessment of how much energy has been conserved by different parts of the private sector. As part of that analysis, this paper examines the record of the U.S. commercial airline industry in improving fuel efficiency from 1973 to 1980. The analysis should be of interest, certainly for what it reveals about the airline industry and how it responds to rising fuel prices but also because the time frame of the study includes both a period of government economic regulation (before October 24, 1978) and a period of deregulation (after October 24, 1978).

The basic record of the commercial airline industry since the 1973 Arab oil embargo is one of providing much more service than in the past with very little increase in fuel use. In 1973, the industry delivered 162 billion passenger miles; by 1980, that figure had increased 57 percent, to 254 billion passenger miles. Yet fuel use by the industry in 1979 was only 315 million gal, or 3 percent greater than its 1973 level of 9.565 billion gal.