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A Quick Assessment of Local Area Impacts Resulting from National Energy Shortages

MARTHA E. HENNIGAN and ALFRED J. NEVEU

ABSTRACT

A method to aid in estimating the local area impacts of national energy shortages is presented. Using data from the 1977 Nationwide Personal Transportation Study and forecasting models developed in NCHRP Report 229, the study examines the potential travel impacts of fuel shortages in six different-sized urban areas under seven different energy future scenarios. These scenarios are defined by fuel supply shortfall, by government actions taken to offset this shortfall, and by whether long-range conservation actions are taken by the public. The study found that the most effective actions for reducing fuel use were long-range conservation actions such as moving closer to work or buying a more fuel-efficient automobile. In the absence of a fuel shortage, the 1990 scenario with long-range actions showed a decline in fuel use from 1980 of 13 to 15 percent, while the 1990 scenario without these actions showed a decline in fuel use of only 2 to 4 percent. The most effective type of transportation system management (TSM) actions for reducing fuel use are those that discourage solo driving. In addition, there is a significant difference in the amount of fuel saved by work versus nonwork TSM actions in future scenarios that do not contain long-range adjustments. However, in future scenarios with long-range adjustments, the amount of fuel saved by work versus nonwork travel becomes more of an even split. Smaller-sized urban areas will be affected the most by future energy shortages because of lack of available transit and fewer opportunities for carpooling. The impact of long-range actions on fuel use is greater in these areas because of a greater proportion of automobile travel. However, this does not fully compensate for the reduced availability of alternatives to automobile use in these areas.

The two energy crises of the 1970s highlighted the need for methods to incorporate energy considerations into travel forecasting procedures. It became evident during these fuel shortages that disruptions in energy supply were an eventuality that transportation planners should consider in their estimates of future travel needs.

At the same time, it also became evident that urban areas were affected differently by supply shortfalls and that consumers chose certain transportation-related actions over others to adapt to crisis conditions (1,2). The different reactions to fuel shortages were due to a variety of factors, for example, region of the nation, population, geographic characteristics, transportation options, and season of the year.

This study had three goals. First, a procedure was developed to aid local planners in predicting the travel impacts of potential energy shortfalls in their areas. Second, the study analyzed the effectiveness of some general actions the government could take to alleviate some of the travel disruptions due to any fuel shortages. Finally, the effectiveness of several long-term actions that could be adopted by the public to reduce fuel demand was examined.

In the following sections the models used in the study are described, the various future energy scenarios are defined, and the data used in the analysis are discussed.

METHODOLOGY

The methodology used in this paper is a version of the model developed by Charles River Associates in NCHRP Report 229 (3). Although the method is identical to the NCHRP procedure for incorporating energy considerations into travel forecasts, this analysis differs from that found in NCHRP Report 229 in two ways. The definitions of the future scenarios are changed, and the analysis is performed on several urban area types using actual instead of hypothetical data. These data were derived from the 1977 Nationwide Personal Transportation Study (NPTS).

Work Trip Model

The work trip model is an incremental logit model that forecasts new mode shares based on modifying the base mode shares by changes in three independent variables: trip cost, in-vehicle travel time, and out-of-vehicle travel time. Trip cost includes gasoline-related costs as well as out-of-pocket costs such as tires and maintenance. In-vehicle travel time includes line-haul time as well as wait time in minutes. Out-of-vehicle travel time is the walk time for each mode in minutes.

In order to reduce the bias that results from aggregation, work trip makers in the data set are divided into the following six traveler classes, based on mode choice set and trip length:

1. Full choice set--long trip,
2. Full choice set--short trip,
3. Drive alone/shared ride--long trip,
4. Drive alone/shared ride--short trip,
5. Shared ride/transit--long trip, and
6. Shared ride/transit--short trip.

A long trip is any work trip that falls above the mean work trip distance for the entire data set and a short trip is any work trip that falls below the mean.

The formula for creating the new mode shares is as follows:

$$\begin{aligned} MS^N_{ij} &= MS^B_{ij} \exp(\Delta V_{ij}) / \sum_k MS^B_{kj} \exp(\Delta V_{kj}) \\ \Delta V_{ij} &= a_1(X^N_{ij1} - X^B_{ij1}) + \\ &\quad a_2(X^N_{ij2} - X^B_{ij2}) + \ldots \\ &\quad a_\ell(X^N_{ij\ell} - X^B_{ij\ell}) \end{aligned} \tag{1}$$

where

MS^N_{ij} = forecast share for the ith mode and the jth class,
MS^B_{ij} = base share for the ith mode and the jth class,
$X^N_{ij\ell}$ = value of the ℓth independent variable for the ith mode and the jth class for the forecast period,
$X^B_{ij\ell}$ = corresponding variable for the base period, and
a_ℓ = coefficient of that variable.

The number of automobile vehicle miles of travel (VMT) is calculated by multiplying the new mode share percentage in each class by the number of trips in that class. This number is then multiplied by the trip length. The shared-ride classes are divided by the average occupancy of the vehicle to get VMT. The formula to calculate VMT is as follows:

$$VMT = \sum_{j=1}^{6} [(MS^N_{Dj} T_{Dj} TL_{Dj} + MS^N_{Sj} T_{Dj} TL_{Sj})/LF_S] \tag{2}$$

where

D = drive alone,
S = shared ride,
T = number of trips,
TL = trip length, and
LF = average vehicle occupancy.

Automobile fuel consumption is calculated by dividing VMT by the average fuel efficiency of the private vehicle fleet.

The formula for bus miles of travel is identical to the automobile VMT formula except that transit mode share is used.

$$BMT = \sum_{j=1}^{6} MS^N_{Tj} T_{Tj} TL_{Tj}/LF_T \tag{3}$$

Transit fuel consumption is calculated by dividing bus miles of travel by the average fuel efficiency of the transit vehicle.

The outputs of the model produce automobile and transit VMT and fuel consumption rates. Average daily automobile and transit trips can also be derived from the model.

Nonwork Trip Model

The model used to estimate nonwork trips and fuel use is a simultaneous linear equation model. It is also used in an incremental form. The two equations in the model predict household nonwork VMT for a 4-day period and nonwork transit trips for the same time period. These predictions must be divided by 4 to yield daily estimates and to be compatible with the work model results.

A set of 13 independent variables is used in the

TABLE 1 Nonwork Models

	Coefficient	
Variable	Automobile VMT	Transit Trips
TMMI	-7.838	-0.009959
TDOL	-0.2422	–
GDOL	-51.01	–
PPL	-14.128	0.7877
URBAN	-3.394	–
SMSA	-2.897	–
PLACE	-1.979	–
LICD	15.14	–
PKAV	-20.04	–
TTIME	0.2414	–
TAV	-41.38	1.707
HDOL	0.0007728	-0.00003188
HHSIZE	9.022	-0.3722

two equations. Each model is presented in Table 1. The variable definitions are as follows:

- TMMI: average travel time per mile for an automobile nonwork trip by a household, in minutes per mile.
- TDOL: average travel time per mile for a nonwork automobile trip by a household multiplied by the household wage per minute, in cents per mile. (Household wage per minute is household annual income in dollars divided by 120,000 min and converted to cents.)
- GDOL: average gasoline price per mile of a nonwork automobile trip for a household divided by the household wage per minute, in minutes per mile. (See note in previous entry.)
- PPL: number of household members aged 5 or older.
- URBAN: coded variable indicating population of urban area [(3), Table 7].
- SMSA: coded variable indicating population of a standard metropolitan statistical area (SMSA) [(3), Table 7].
- PLACE: coded variable indicating population of place of household residence.
- LICD: total number of licensed drivers in the household.
- PKAV: fraction of household's nonwork automobile trips for which free parking was available.
- TTIME: average travel time for a nonwork transit trip by a household.
- TAV: fraction of a household's nonwork automobile and transit trips for which transit is available within six blocks.
- HDOL: household income in dollars per year.
- HHSIZE: total number of household members.

To apply the equations, changes in each of the independent variables between the base and future years are multiplied by their respective coefficients and summed to calculate the change in the dependent variable (either 4-day household VMT or transit trips). These changes in the dependent variable are then added to the base year values to produce the future estimates. The general equations are as follows:

$$\Delta\text{VMT} = \Sigma a_i \, \Delta X_i \tag{4}$$

$$\Delta\text{transit trips} = \Sigma b_i \, \Delta Y_i \tag{5}$$

$$\text{Future VMT} = \text{base VMT} + \Delta\text{VMT} \tag{6}$$

$$\text{Future transit trips} = \text{base transit trips} + \Delta\text{transit trips} \tag{7}$$

Automobile fuel consumption is obtained by dividing VMT by average vehicle fuel efficiency. To get transit VMT, transit trips per household are multiplied by the number of households in the SMSA group and divided by 4 to get areawide ridership. Areawide ridership is then multiplied by a transit mile-per-trip factor to get bus miles of travel. Transit fuel consumption is then estimated by dividing bus miles by average transit vehicle fuel economy. A more detailed discussion of the models can be found in either NCHRP Report 229 (3) or the report by Hennigan and Neveu (4).

Definition of Urban Area Sizes

Several different area types defined by population size were investigated. Population is used to represent transit system availability as well. The larger areas will generally have larger transit systems, denser cores, and longer commuting distances. Table 2 shows the SMSA size groupings used in this study.

TABLE 2 Urban Area Sizes

Type	Population Range
Small	Under 100,000
Small to medium	100,000–249,999
Medium	250,000–499,999
Medium to large	500,000–999,999
Large	1,000,000–2,999,999
Very large	3,000,000 and over

Definition of Future Scenarios

The various energy scenarios used in this study are listed in Table 3. The base year for the analysis is 1980, which represents current travel and demographic conditions for the six city sizes.

Several future energy scenarios for 1990 are used, covering a wide range of possible situations. These scenarios are defined in terms of supply shortfall and duration, government actions taken to offset the shortfall, and whether long-range conservation actions are taken. Three shortfall levels are considered: 5, 15, and 20 percent. These shortages are assumed to last from 3 to 6 months, which was the approximate length of the previous two crises. A shortage of longer duration would begin to affect the household's long-term decisions, and an analysis of that type of situation is beyond the scope of this study.

The reduction in energy supply resulting from shortfall conditions is represented in both the work and nonwork models as an increase in gasoline price. This increase translates into increased trip costs. The following formula is used to calculate the new gasoline price resulting from a fuel shortage:

$$P_s = P_n \, [1 - (s/\eta)] \tag{8}$$

where

P_s = shortfall price,
P_n = nonshortfall price,
s = shortfall level (e.g., 5, 15, or 20 percent expressed as a decimal), and
η = price elasticity of gasoline (assumed to be -0.2).

The first of the 1990 future scenarios is termed the "1990 Null" scenario. This scenario represents the future travel and demographic characteristics of the various city types under a condition of no fuel supply shortage. The areas are assumed to grow, following the historic trends for each of the variables

TABLE 3 Scenario Definitions

Type	Supply Shortage (%)	Fuel Price (cents/gal)	Automobile Mpg	Government Action	Long-Range Actions[a]
Base (1980)	–	99.27	15	–	No
1990 Null	–	134.4	17.7	–	No
1990 Price	5, 15, 20	168, 235, 268.8	17.7	Price only	No
1990 TSM1	5, 15, 20	168, 235, 268.8	17.7	Nonrestrictive TSM (transit/carpool incentive)	No
1990 TSM2	5, 15, 20	168, 235, 268.8	17.7	Restrictive TSM (automobile disincentives)	No
1990 Null with LRA	–	134.4	20.2	–	Yes
1990 Price with LRA	5, 15, 20	168, 235, 268.8	20.2	Price only	Yes
1990 TSM1 with LRA	5, 15, 20	168, 235, 268.8	20.2	Nonrestrictive TSM (carpool/transit incentives)	Yes
1990 TSM2 with LRA	5, 15, 20	168, 235, 268.8	20.2	Restrictive TSM (automobile disincentives)	Yes

Note: TSM = transportation systems management, LRA = long range adjustments

[a] Long-range actions are defined as a rise in average fleet efficiency to 20.2 mpg and a shift of 5 percent of long work trips to short work trips.

used in the work and nonwork models. This is used as the baseline against which the other 1990 scenarios are measured. In this fashion, national VMT and fuel use increases can be accounted for, and a better estimate of the effectiveness of the various government and long-term actions can be derived.

Three types of government actions aimed at alleviating the fuel shortage are used. The first of these actions is really no action at all, but simply to let the price of gasoline reach the market clearing level, which is the price that causes demand to decrease by the amount of the shortage. This is called the "1990 Price" scenario and would occur under current decontrolled market conditions.

The second type of government action is a set of nonrestrictive transportation systems management (TSM) actions (1990 TSM1), which is generally a package of incentives to use more efficient means of travel. The nonrestrictive TSM actions used in this analysis are free tolls for carpools, bus priority treatment at intersections, and exclusive bus lanes. The use of these actions is reflected in the model by changes in the input variables. Because no tolls were indicated for automobile trips in the NPTS data, the free tolls for carpool action had no effect on the inputs used in this analysis.

The third type of government action is a restrictive one that comprises TSM disincentives (1990 TSM2). The restrictive TSM actions used in this analysis are a parking surcharge in the central business district (CBD) and reduced on-street parking near employment centers.

It should also be noted that the effects of one future scenario carry over to the next. In other words, the high price of gasoline in the 1990 Price scenario is also found in the nonrestrictive TSM scenario and nonrestrictive actions are found in the scenario with restrictive TSM actions. Government actions thus have a cumulative effect across the future scenarios.

The last set of future energy scenarios is identical to the first set, differing only in that it is assumed that the public has adopted some long-term conservation action to help reduce fuel demand. It is assumed in these scenarios that people react to past energy shortages, or to concern for future ones, by making major adjustments. These conservation adjustments are reflected in shorter work trips resulting from moving closer to work and higher fuel efficiencies resulting from buying a more fuel-efficient automobile.

The 1990 Null, Price, TSM1, and TSM2 future scenarios with long-range adjustments are identical to the future scenarios without long-range adjustments except that 5 percent of long work trips are shifted to short work trips and automobile fuel efficiency is increased to 20.2 mpg. The changes in nonwork travel as a result of making long-range adjustments are reflected in increased automobile fuel efficiency only.

FINDINGS

The results of tests for three different shortfall levels in six different area sizes provide insight into which city types will be most affected by future shortage conditions, what impacts government policies will have on travel under such conditions, and what impacts long-range conservation adjustments will have on travel under such conditions.

A comparison of the two 1990 Null scenarios to the base year (1980) is shown in Table 4 (figures in the table are expressed as percentages). Without long-range adjustments made by the public (buying a more fuel-efficient automobile and moving closer to work), fuel use drops by 2 to 16 percent. This is primarily due to the natural increase in automobile fleet fuel efficiency. With long-range adjustments made by the public, the fuel reduction increases significantly to the 12 to 25 percent range. The major factor behind the increased fuel use reduction is the acceleration of fleet turnover implied by increasing the efficiency of the automobile fleet above the natural increase. Although this is not a government action taken in response to a short-term fuel shortage, any program that would keep the pressure on increasing fuel efficiency could limit the public hardship of a fuel supply reduction.

TABLE 4 Fuel Use Changes from 1980

	Percent by Urban Area Size					
Scenario	Small	Medium to Small	Medium	Medium to Large	Large	Very Large
1990 Null	-2.0	-2.7	-2.1	-2.6	-3.9	-15.6
1990 Null with long-range adjustments	-13.7	-14.0	-13.6	-14.1	-15.2	-24.8

The base and future total fuel usage in each SMSA group at the 15 percent shortfall level are shown in Figures 1 through 6. The results for the 5 and 20 percent shortfalls are not shown because the pattern is basically the same.

In Figures 1 through 6 the bars represent the amount of fuel used under each future scenario, including both work and nonwork travel. The 1990 Null scenario is shown to facilitate the fuel use comparison. The horizontal line across the bars represents the amount of fuel available given a 15 percent shortfall from the 1990 Null level. If the fuel use bars fall below this line, this indicates that, under these scenarios, the demand for fuel does not exceed the supply. In cases where the bars are higher than the horizontal line, the demand for fuel exceeds the supply.

Figures 1 through 6 indicate some interesting results when various city sizes are compared. In the smaller cities (Figure 1), some sort of government action is required to reduce fuel use below the shortfall supply level when no long-range conservation actions are taken by the public. Market forces

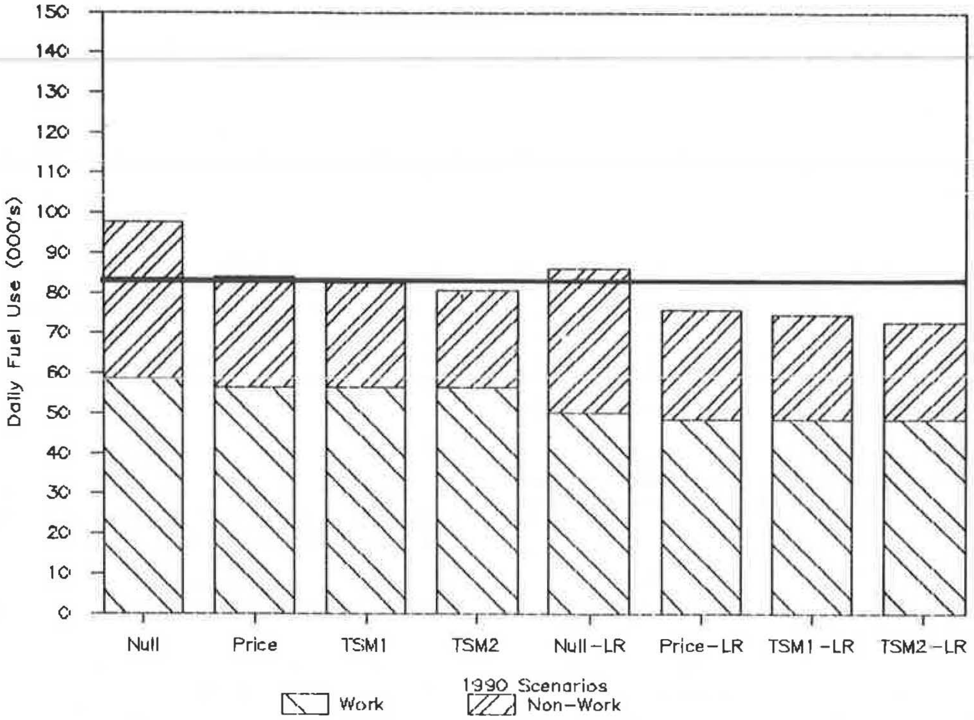

FIGURE 1 Small cities (under 100,000).

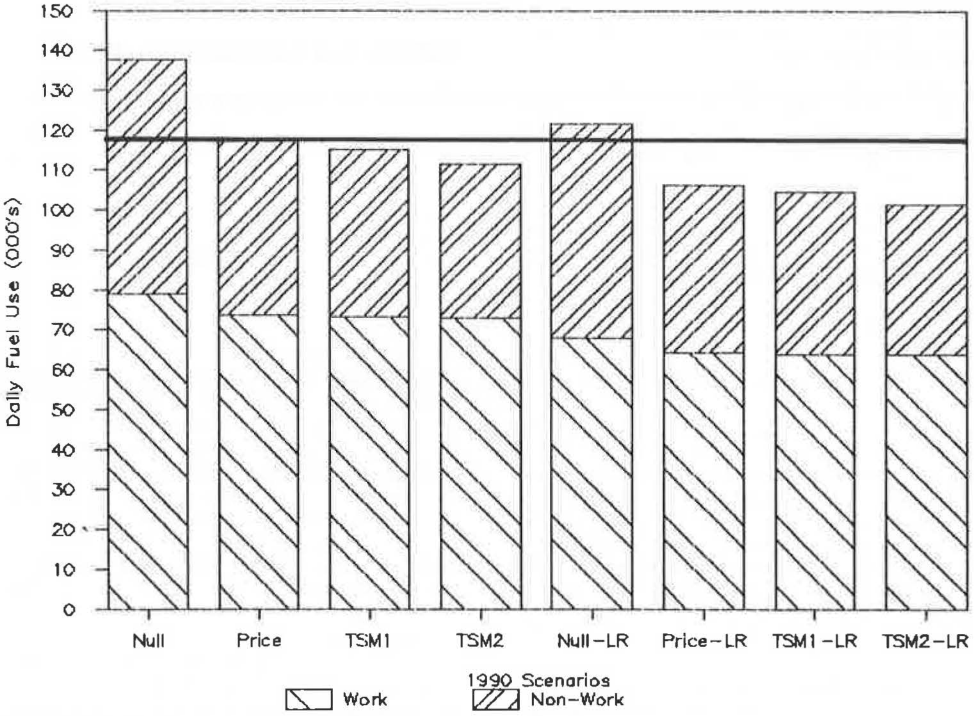

FIGURE 2 Medium to small cities (100,000 to 249,000).

are not quite effective enough. Both TSM strategies reduce fuel use below the shortfall level.

In the larger urban areas, the relative contribution of work and nonwork travel to reductions in fuel use approaches a 50-50 split. Work travel assumes a much larger burden of the fuel savings needed in the larger urban areas.

It is useful to compare the results of this analysis with what happened in the previous two energy crises in terms of shortfall level, fuel consumption, and travel impacts to determine how closely these results compare with how the public actually responded to shortfall situations. However, it should be noted that no widespread, mandatory government actions were taken during the previous two crises that can be associated with the potential shortfall

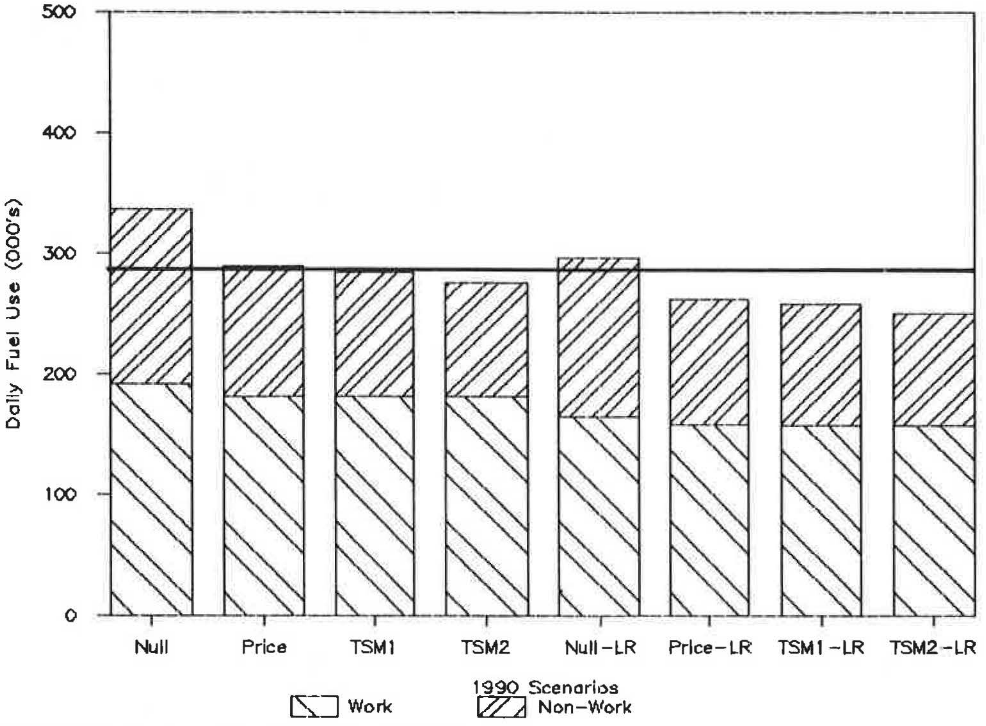

FIGURE 3 Medium cities (250,000 to 499,999).

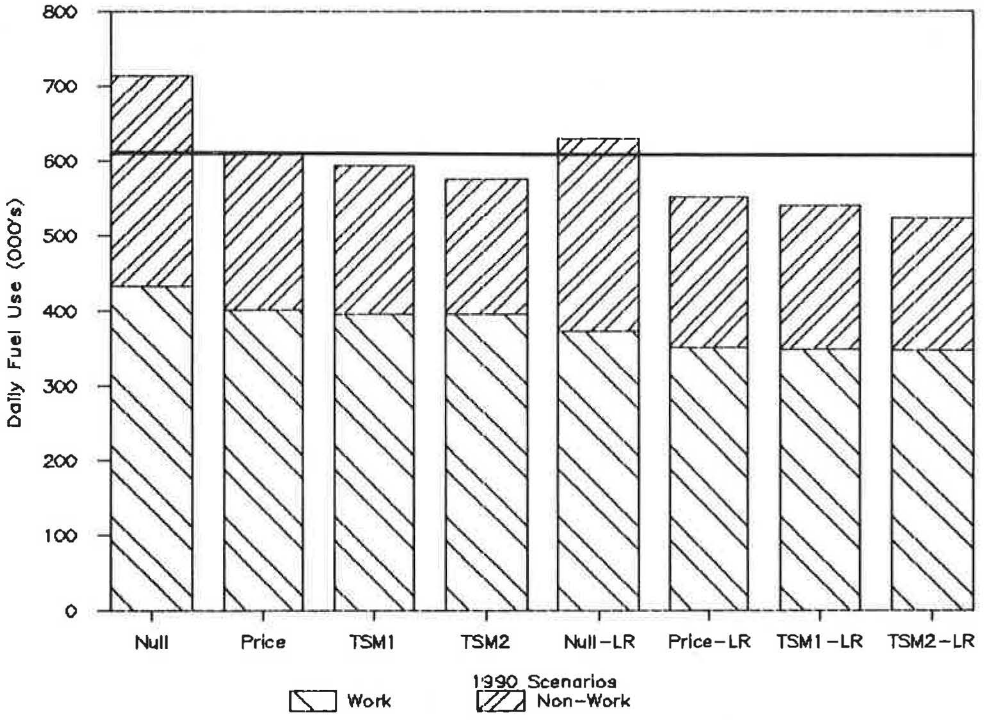

FIGURE 4 Medium to large cities (500,000 to 999,999).

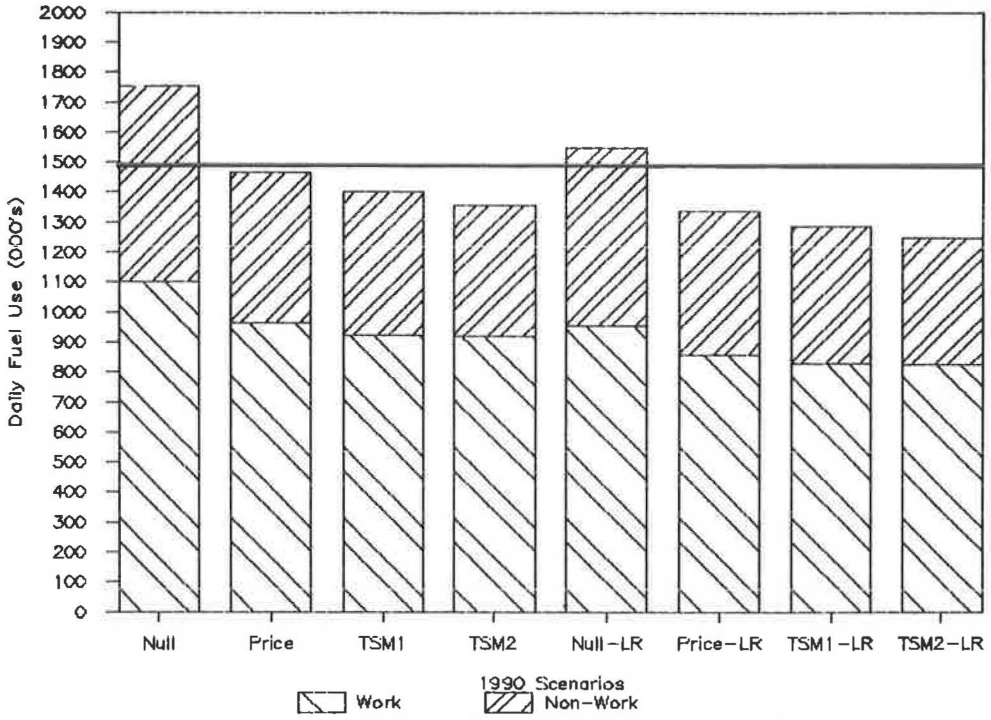

FIGURE 5 Large cities (1,000,000 to 2,999,999).

situations. There were instances of odd-even rationing and dollar limits on the sale of gasoline, but these occurred mainly in the areas with the greatest supply problems.

The effects of the 1973 to 1974 and 1979 crises can be seen in the following table (5, Table MFG-33; 6):

Percent Change	1974	1979
Fuel use	-8.2	-6.0
VMT	-6.0	-4.3
Fuel use	-4.0 (annual)	-3.4 (annual)

The gasoline shortfall and VMT reduction figures represent peak quarterly percentage changes from the year before. The fuel use values represent overall annual percentage changes from the previous year. These figures are compared with the work and nonwork results summed from the potential shortfall scenarios that are summarized as follows:

	Percent Shortage		
	5	15	20
Automobile fuel use	-5 to -15	-15 to -30	-20 to -40

As can be seen, the impacts of the potential shortfalls if long-range actions are not taken are similar to the impacts of the previous two fuel crises at the 5 percent level.

The difference between the results from the previous two crises and the results from the potential shortfalls becomes greater as the shortfall level increases. This is to be expected because the previous two crises did not reach nationwide shortfall levels of 15 and 20 percent. In addition, because the potential shortfalls include widespread institution of government actions to offset the shortages, one can expect a greater impact on VMT, fuel use, and transit ridership.

CONCLUSIONS

In this paper a procedure is presented to be used by local planners to predict the travel impacts of potential energy shortfalls in a given area. The most important conclusions to be drawn from this analysis deal with the following four questions:

1. Areas of what size will be most affected by future shortage conditions?
2. What government policies will be most effective in alleviating crisis conditions?
3. What impacts will long-range conservation actions have on travel under energy shortfalls?
4. What will be the roles of work and nonwork travel under future shortage conditions?

In regard to the first question, it was found that the smaller the size of the area, the greater the impact future crises will have on that area. This is because there are fewer opportunities for transit and carpooling in smaller areas. However, it was also found that because small areas have proportionally more automobile travel, there is more potential for fuel savings to result from long-term conservation actions such as moving closer to work or buying a more fuel-efficient automobile.

Another finding for smaller-sized SMSAs is that when long-range conservation actions are not taken, TSM actions targeted for work travel alone will not be successful in reducing fuel use enough to alleviate crisis conditions. However, nonwork-related TSM actions reduce fuel use enough to compensate for supply shortfalls.

Larger areas with a population of over 1 million will not be as severely affected by future energy crises. In these areas, work-related TSM actions alone are able to cause fuel use reductions that could alleviate crisis conditions. These larger areas tend to have significantly more opportunities for transit and enough commuter congestion to encourage carpooling.

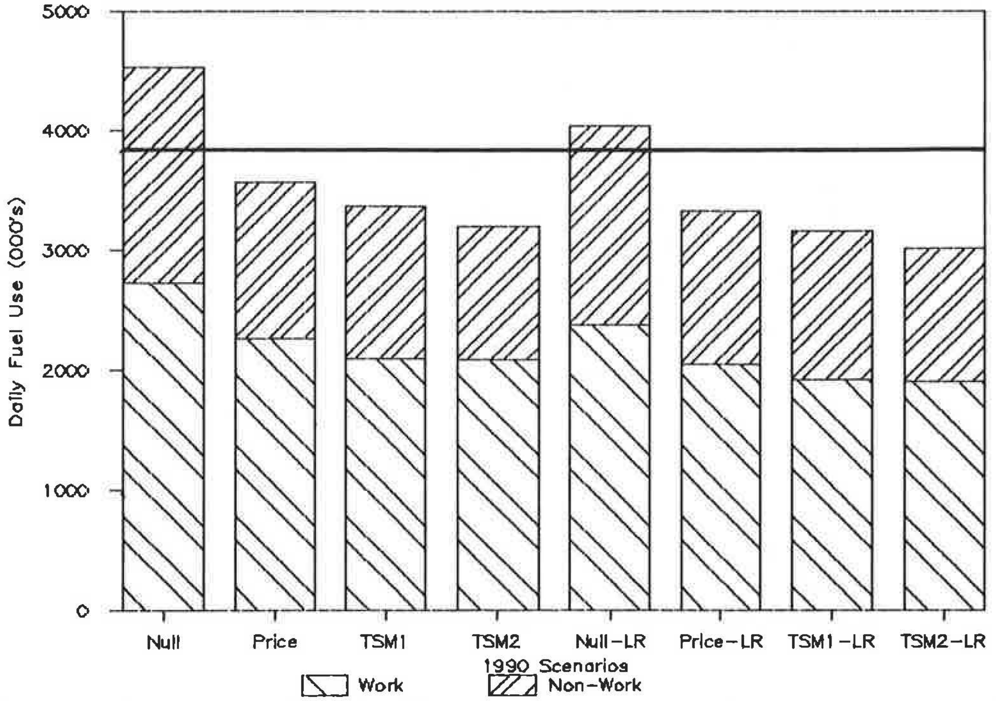

FIGURE 6 Very large cities (over 3,000,000).

In regard to the second question, the government policies that are most effective in alleviating crisis conditions are the nonrestrictive and restrictive TSM policies. Restrictive policies have the most effect on reducing fuel consumption. However, they may overcompensate for the lack of supply and may not be necessary. The nonrestrictive TSM actions are effective in reducing fuel demand and present a less painful way to conserve, thus making them more attractive to consumers.

The third group of conclusions to be drawn from this paper concerns what impacts long-range conservation adjustments will have on travel under shortfall conditions. Long-range conservation adjustments such as buying a more fuel-efficient automobile or moving closer to work reduce fuel use significantly in and of themselves. In addition, once these adjustments are combined with TSM actions in a crisis situation, they provide the greatest fuel-savings capability of all the scenarios examined in this paper. It should also be noted that long-range conservation actions, by virtue of causing a more rapid rate of fleet turnover, may help prevent future crises by reducing the demand for fuel.

The final conclusion to be drawn from this paper concerns the roles of work and nonwork travel under shortfall conditions. The greatest reductions in fuel use under the future scenarios used in this analysis were realized by TSM actions targeted at nonwork travel in future scenarios with and without long-range actions. However, in cities with a population of over 1 million, the fuel savings due to work and nonwork travel actions becomes more evenly distributed.

In addition, there may be more of a shift in the future to work-related conservation actions in smaller areas if the trend of the availability of more fuel-efficient automobiles continues. This is because substantial savings in fuel used in work travel can be realized by using a fuel-efficient automobile, and once such an action has been taken, the TSM actions that have been most effective in reducing nonwork fuel use may become less important.

The model presented here is not without its problems, primarily on the transit side where transit system size should be considered and where a shortfall level variable should be included for nonwork trips. On the other hand, one must consider that transit is not the mode of choice in a crisis situation. Studies have shown that most consumers responded to the previous crises by taking automobile-related actions (2,7).

Therefore, the automobile side of the model is perhaps more important because it provides a reasonable method for calculating VMT and the effect of supply shortages on fuel use. It also produces results that are in the range of those found in previous crises. By far the most important aspect of this analysis is that it presents a procedure for local planners to estimate the effects of a given shortfall level on their particular areas. The fact that the model is data-intensive and that these data may be available only in national averages or default values is a drawback. However, the results of this study provide some insights that should prove useful to local planners facing future energy shortages.

When long-range actions are taken by the public, the situation brightens somewhat. In this case, government actions will not be required to reduce fuel demand below the shortfall level. Price increases due to the supply shortfall provide the impetus to reduce fuel demand below the shortfall level.

Looking at the very large cities (Figure 6), a different pattern of fuel savings emerges. In these cities, market forces are more than sufficient to reduce fuel demand. In fact, significant fuel savings result when fuel prices rise to the shortage-induced level.

Long-range conservation actions can play an important role in the larger cities. The impact of the fuel shortfall is alleviated somewhat if these long-range conservation actions are taken by the driving public. Although these are not government actions, special care should be taken to ensure that other

TABLE 5 Fuel Savings by Work and Nonwork Travel During a 15 Percent Fuel Shortage

	Urban Area Size					
Scenario	Small	Medium to Small	Medium	Medium to Large	Large	Very Large
Work						
Price	16	25	21	31	47	48
Nonrestrictive TSM	14	25	20	31	50	54
Restrictive TSM	12	22	17	27	45	48
Null/long-range	73	68	68	71	72	71
Price/long-range	45	46	45	51	58	56
Nonrestrictive TSM/ long-range	43	45	43	49	58	59
Restrictive TSM/ long-range	40	41	39	45	54	54
Nonwork						
Price	84	75	79	69	53	52
Nonrestrictive TSM	86	75	80	69	50	46
Restrictive TSM	88	78	83	73	55	52
Null/long-range	27	32	32	29	28	29
Price only/long-range	55	54	55	50	42	44
Nonrestrictive TSM/ long-range	57	55	57	51	42	41
Restrictive TSM/ long-range	60	59	61	55	46	46

Note: Values in the table are expressed as percentages.

government policies do not adversely affect these consumer responses.

The relative contribution of work and nonwork travel to overall fuel savings also varies by city size. Table 5 lists the percentage of fuel savings attributable to work and nonwork travel for each city size for all scenarios with a 15 percent fuel shortfall. (Again, the other shortfall levels yield similar results.) In the smaller cities, work travel provides a small portion of total fuel savings. In fact, by examining the earlier figure, it can be seen that work travel actually changes very little under the various energy future scenarios for the small urban areas. Long-range conservation adjustments affect work travel fuel demand significantly, but government actions taken after these long-range strategies are adopted do not affect work travel to a great degree.

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