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CONTENTS

IMPACT OF THE ENERGY SHORTAGE ON TRAVEL PATTERNS AND ATTITUDES

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This paper examines the effect of the energy shortage on transportation patterns and attitudes in the automobile-oriented, suburban Dutch Fork area in Columbia, South Carolina. Data from several nationwide surveys and selected transit operations are also used. The findings from the Dutch Fork area show that the energy shortage did not appreciably reduce (10 to 15 percent) the amount of automobile travel and did not substantially affect transit patterns or attitudes. Traffic volumes decreased primarily on weekends; there was less decline on weekdays. Travel was reduced by driving slower and limiting social-recreational and shopping trips. Shifts in travel behavior were moderate, although people expressed an interest in public transit. Gasoline supply more than price appears to have greatly affected travel habits, although the effect of price appears to be reflected in the buying of more small cars. In other words, people did not move away from relying on the car but rather adjusted their driving behavior to conserve gasoline. Data from national surveys also show this pattern. Possibly, local public transit will not realize appreciable comparative advantage against the automobile on the basis of price, and this further emphasizes the inability of transit to serve a substantial ridership. In addition, failures of public transit to capture and hold a greater part of the market during the energy shortage are a product of poor service quality. The one favorable result for public transit is the verbal support given to transit as a method for dealing with the energy shortage. Public transit can benefit from this support by garnering greater governmental resources, although there are still many reservations about the likelihood of converting public support and governmental investment into substantial patronage increases.

•WHEN the energy shortage began in fall 1973, there was considerable expectation that the ever-increasing reliance on automobile travel might be changed by gasoline supply problems and higher prices. To what extent these expectations were verified is the topic of this paper. The focus was on the automobile-oriented, suburban, Dutch Fork area in Columbia, South Carolina. Supplemental data from several nationwide surveys and selected transit operations are also used. Of particular interest was whether the consequences of the shortage, inadequate gasoline supply and higher gasoline prices, have or have not made drivers more amenable to using public transit.

To explore the nature and extent of the impact, several facets of transportation were examined.

1. By how much did the amount of driving decrease during the shortage?
2. By what means were the reductions made? Particularly, what switches were made to public transit and how much use was made of car pooling?

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3. How seriously did the suburban residents perceive the gasoline problem to be and how long did they expect it to last?
4. What short- and long-range transportation solutions did people prefer to counter problems of energy shortage?
5. Did they express more willingness during the shortage than in the past to use public transit?

RESEARCH APPROACH

The primary approach used to study the impact of the energy shortage was an analysis of travel attitudes and patterns in the Dutch Fork area in Columbia, South Carolina. The Dutch Fork area was chosen because it was the site of a broad-based study on suburban travel patterns and attitudes conducted before the energy shortage in late 1972 and early 1973 (2). A follow-up study was done in April 1974; this made a before and after comparison possible. April was chosen because the worst of the shortage was over, but the experience was still fresh in people's minds. Consequently, both a short- and long-term assessment could be made without significant interference from the emotional factor that might have existed during the peak of the shortage in the first 3 months of 1974.

In both the 1972-1973 study and the 1974 follow-up study, data on travel attitudes and patterns were collected from household surveys and roadside counts. Although the household surveys were based on random samples in each case, the two surveys differed in the method by which the data were collected and in sample size. The 1972-1973 survey was based on a 10 percent sample of households and was conducted by telephone. The 1974 survey was based on a 3 percent sample and was conducted by personal interview. The changes in sample size and method of data collection were made primarily to reduce the cost of data collection and to accommodate the fact that the 1974 questionnaire was much longer than the 1972-1973 questionnaire. The reduction in sample size was not considered a threat to the representativeness of the sample since the Dutch Fork area has a relatively homogeneous, middle-class population, and homogeneity permits reduction in sample size without loss of representativeness.

Supplemental data from nationwide experiences were also incorporated into the present analysis to get a more general picture of the effects of the energy shortage. The additional data come from the National Opinion Research Center (NORC) (1) national study of the impact of the energy shortage and also from the Transit Fact Book (5).

BACKGROUND

Dutch Fork, like many other middle-class suburbs, is heavily automobile oriented. Of the 318 households surveyed in 1974, only 1 household did not have a car. The majority of the households, 83 percent, had two or more cars. The existing transit service in the area is limited, inasmuch as only 20 percent of the population is within ¼-mile (0.4-km) walking distance from the local bus route.

The gasoline situation in the Dutch Fork area was not too much different from that in other parts of the country. Gasoline allocations for the Columbia area were 90 percent of the 1972 level, and the price of regular gasoline rose from about \$0.35 to \$0.55/gal (\$0.09 to \$0.14/liter between October 1973 and May 1974. However, population had grown by about 10 percent between 1972 and 1974 in the Dutch Fork area. The population growth put great pressure on the shortage.

To what extent and by what means did drivers meet this shortage? Did they exceed the needed cuts and do so by drastically switching away from traditional driving patterns or did they do only as much as needed and do this by making minor modifications on their traditional, one-person, one-vehicle patterns? The following sections examine the impact of the shortage on driving habits, modal shifts, and future possibilities of adjustments to energy problems.

IMPACT OF ENERGY SHORTAGE ON TRANSPORTATION PATTERNS AND ATTITUDES

Change in Amount of Driving

There are a number of ways to assess reduction in driving, and in this paper several methods are used. First, people were asked directly how much, if any, they reduced their driving. They, however, may overestimate the magnitude of their conservation effort. To take this possibility into consideration, additional data were also collected on traffic volumes and gasoline consumption.

In the 1974 Dutch Fork survey, the respondents were asked how much change the gasoline problem made in their personal or family driving. Surprisingly, few people, 15.8 percent, said they had made a considerable change (i.e., greater than 30 percent reduction). Most of the people either felt they made little or no change or only a moderate change (i.e., between 10 and 30 percent reduction). The average reduction is estimated to be around 15 percent (Table 1). In a national survey conducted by NORC, about 30 percent of the car-owning households did not cut down on driving during January through February 1974. Although the question in the Dutch Fork survey was not strictly comparable with the question in the national survey, both showed that most people were not reducing their driving or were reducing it very little.

To evaluate the motorists' perception of their travel reductions, traffic volume data on I-126 were examined. This route is the major highway connecting the Dutch Fork area and the Columbia CBD. Table 2 gives traffic volume data on I-126 for the weekday, the weekend (Saturday and Sunday combined), and the week by month for the period between October 1973 and April 1974. These data were provided by the South Caroline State Highway Department. (The traffic counter was located at I-126 and Greystone Boulevard.)

The average weekly ADT has consistently declined since October 1973 (Table 2). However, these reductions could have been caused by seasonal variations in traffic volumes. Unfortunately, historical monthly data on I-126 were not available. The only available data were seasonal counts at two stations in the general vicinity of the Dutch Fork area. Analyses of these counts indicated that traffic volumes in the winter and spring of 1974 were 95 percent and 101 percent of the volumes in the fall of 1973. However, data supplied by the local telephone company indicated that population in the Dutch Fork area increased by 10 percent between October 1972 and March 1974. This corresponds to a 7 percent average annual rate of increase. Thus, the declines of 10 to 13 percent on the weekday and 15 to 25 percent on the weekend given in Table 2 reflect the influence of the energy shortage to the extent of 5 to 10 percent for the weekday and 10 to 20 percent for the weekend.

Higher declines on the weekend than on the weekday were also indicated in Table 2. This decline could be explained by the ban on Sunday sales of gasoline and by the normal effect of winter on recreational travel. Motorists in the Dutch Fork area made less reductions on the most necessary trips, e.g., the weekday journey to work, and more reductions on the least necessary trips, e.g., those for shopping and social-recreational purposes. In fact, an examination of the 1974 Dutch Fork data based on purpose of trip for weekdays shows that weekday trips for nonwork purposes were all down from the 1972 results (Table 3). The results from the traffic volume changes in the Dutch Fork area correspond to the household results in the NORC survey. When asked about cutting down on driving, 71 percent of the people interviewed in January mentioned that they cut down on driving on Sundays, 56 percent mentioned Saturdays, and 54 percent mentioned weekdays.

The magnitude of the reductions receded in April when gasoline lines were shorter than in the more frugal January to March period although prices continued to rise in April (Table 2). This suggests that price, at least within current levels, has a limited effect on the amount of driving.

In general, these sets of data show that driving reductions during the shortage period, January to March, were about 10 percent, but that they receded in April. This is supported by a recent report (4) that shows that, on a nationwide basis, conservation efforts amounted to a 10 percent reduction in demand during the January to March 1974 period and a 3.4 percent reduction in April 1974. Data from the South Carolina State Highway Department indicated that 1974 total vehicle miles (kilometers) of travel in the Charleston area were about 8 percent less than those in 1973. It should be noted that the Charleston area population has been growing at a slower rate than that in the Columbia area.

Means of Reducing Driving and Gasoline Consumption

In the Dutch Fork survey, respondents were asked how they reduced gasoline consumption. Table 4 gives the percentage of respondents who said they frequently used a particular method for reducing gasoline consumption. The response receiving the most attention was drove slower. Almost 90 percent of the respondents in the Dutch Fork area said they frequently drove slower. The next method receiving a high response was reduced shopping and recreational trips. About 32 percent of the people said they frequently reduced shopping and recreational trips. Few, on the other hand, used car pooling frequently, and even fewer used public transit frequently.

Additional information on changes in travel patterns was collected by comparing the 1972 and 1974 survey results on mode used for the first trip to the CBD. The results of the comparison between the 1972 and 1974 surveys for the morning inbound trip to the CBD by mode are given below.

	Percent	
Mode	1972	1974
Drive	94.0	91.0
Passenger	6.0	8.0
Bus	—	1.0

As can be seen there is a slight departure from the 1972 pattern. This result is not startling when it is remembered that about 80 percent of the first trips to Columbia are for work purposes. (Bus service between Dutch Fork and the Columbia CBD did not exist in 1972-1973.)

In addition to the interview data on travel mode, data were also collected by field count on passengers per vehicle. Although the interviews showed that the amount of car pooling increased somewhat during the shortage, the field data on the average number of people per vehicle did not increase. In all three roadside counts taken on I-126 (July 1973, January 1974, and May 1974) the average automobile occupancy was around 1.27 at the Broad River bridge. Results from the NORC data similarly show little change in the amount of car pooling.

Analysis of the impact of the energy shortage on transit ridership was made by examining passenger data from the Dutch Fork transit route, from several city systems, and from nationwide totals. The data from the Dutch Fork route and from the selected cities are used to examine when the greatest impact was felt. The data from the nationwide totals are used to assess the overall effects for the entire year.

Figure 1 shows the weekly ridership data for the Dutch Fork transit route. Review of Figure 1 reveals that ridership was highest from February 18 to March 15, 1974. This period corresponds to the tightest gasoline situation in the Columbia area as evidenced by the long lines of cars at service stations.

These results are similar to those based on the experience in Columbia and

Table 1. Respondents' assessment of their reduction in driving.

Reduction Amount	 Percent	Respondents (percent)
Considerable	30	15.8
Moderate	10 to 30	40.6
Little	2 to 10	28.1
None	0 to 2	15.5
Total		100.0

[a] Average reduction equals 15 percent.

Table 2. Changes in average traffic volume on I-126.

Month	Year	Weekly ADT	Change[a] (percent)	Weekday ADT	Change[a] (percent)	Weekend ADT	Change[a] (percent)
October	1973	37,588	—	43,856	—	53,635	—
November	1973	36,527	-2.8	42,251	-3.6	54,643	-1.9
December	1973	33,769	-10.2	38,186	-12.9	44,555	-16.9
January	1974	32,828	-12.7	38,464	-12.3	45,415	-15.3
February	1974	34,406	-8.5	39,419	-12.4	40,201	-25.0
March	1974	34,347	-8.6	39,158	-10.7	44,130	-17.7
April	1974	36,439	-3.1	40,870	-6.8	49,784	-7.2

[a] October was used as the base month.

Table 3. First trip to Columbia by purpose.

	Percent	
Trip Purpose	1972	1974
Work	80.2	86.4
Shopping and bill paying	3.6	1.8
School	10.8	9.6
Serving passengers	1.1	1.3
Other	4.3	0.9
Total	100.0	100.0

Table 4. Frequency with which respondents said they used a particular gas-saving method.

	Used Method to Save Gas (percent)				
Method	Frequently	Sometimes	Rarely	Never	Total
Drove slower	88.6	8.8	1.9	0.7	100.0
Reduced shopping and recreational trips	31.4	45.0	12.6	11.0	100.0
Used car pooling	13.6	12.2	10.4	63.8	100.0
Used public transit	0.6	4.4	5.1	89.9	100.0

Charleston, South Carolina, and in other cities such as Washington, D. C.; Baltimore, Maryland; and Norfolk, Virginia. Table 5 gives the percentage of change in ridership for these cities. (Columbia and Charleston data were provided by the South Carolina Electric and Gas Company; data on Washington Metrobus are from the Washington Post, June 30, 1974; and data for Norfolk and Baltimore are from an Associated Press report, April 26, 1974.) Increases in ridership were evident and were the greatest in January and February when gas lines were the longest, but the increases were not substantial. In addition, the increases receded as the gas lines dwindled in March and April, even in the face of rising gasoline prices. These results suggest that, although there was an increase for the year, most of the increase was likely due to gasoline supply problems rather than price. Overall, there was a nationwide increase of 6.6 percent for all public transit systems and 11.1 percent for motor buses between 1972 and 1974 (5). Except for a small increase in 1973, which was probably also energy related, the 1974 increase in public transportation ridership was the first in 20 years.

These data on driving and modal choice provide a picture of how much and by what means the travelers managed to adjust their travel patterns during these several months when gasoline supply was in the range of 10 to 20 percent less than in 1972. Adjustment was not made in terms of dramatic shifts from usual patterns but rather in terms of those actions that could be most easily taken without deviating from reliance on the automobile. Drivers, in other words, did make changes and reductions but primarily those that would permit them to continue using their cars.

Policy Preferences and Potential Long-Term Effects

The data in the last two sections show that the energy shortage had only a limited impact on the amount of driving and modal shift. This limited effect is likely a function of the context in which the shortages occurred. First, the shortage never reached crisis stage. The supply deficits did not run much more than 10 percent although there was a considerable amount of uncertainty. Second, the shortage did not last long although prices continually mounted. Third, many people had little choice about mode selection. Switching to car pooling appears to be a greater possibility than switching to public transit since many people are not within realistic distance of public transit. The conditions, therefore, constrained the amount of change. It is possible, however, that the energy shortage will still be responsible for change, but it will be occurring over the long run. It is also possible that the energy shortage could have far greater impacts on travel habits if local transportation systems offered more choice or quality in mode selection. To explore both of these possibilities, data were collected on people's perceptions of how long the energy problem would last and on what kind of solution they would prefer if presented with varying degrees of choice.

To examine the consumer's likelihood of searching for and using alternative transportation modes in the future, we asked the respondents in the Dutch Fork study if they thought the gasoline situation would be serious in the next few years. Very few respondents, 5.7 percent, thought that the gasoline situation would be critical in the next few years, but almost 40.1 percent thought it would be bad.

Perceived Seriousness	Percent
Critical	5.7
Bad	40.1
Slight problem	34.7
No problem	10.7
Undecided	8.8
Total	100.0

In addition to inquiries about the future seriousness of gasoline problems, inquiries were also made about whether people perceived the energy problem as real or created. More than half of the Dutch Fork respondents felt that the gasoline situation was created.

Evaluation	Percent
Real	22.9
Created	57.2
Undecided	19.9
Total	100.0

Both these results suggest there will be a lack of propensity for use of or search for drastically different means of transportation. The results do, however, indicate a moderate level of concern and thus a moderate level of search in the future. One likely direction of future changes is a greater shift to use of economy-sized cars. When asked how they would adjust to $0.80/gal ($0.21/liter) for gasoline, 40 percent of the respondents in the Dutch Fork survey said they would buy an economy car.

Further evidence that the experiences with the energy shortage and expectation for future energy problems will not engender a serious search for change in current life-styles is the fact that few, only 6 percent, of the Dutch Fork respondents said they would not have moved to this suburban setting had they anticipated the gasoline shortage. This percentage does not change much when consideration is given to the respondents' perception of the authenticity of the energy shortage. In addition, the results do not change appreciably when a control is placed on the length of time the respondent has lived in the Dutch Fork area.

Although neither the observed change during the shortage period nor the anticipated measures of change indicate a drastic shift in transportation mode, it is possible that energy concerns and problems could or would have a greater impact on modal shift if there were more choice or better public transit quality. To explore this possibility, three hypothetical situations that combined problems of the energy shortage with varying availability of transportation modes were presented to respondents in the Dutch Fork study. Each situation offered the possibility of using public transportation, but under different circumstances. The first focused on what choices people would make for short-run solutions to energy problems; the second, on choices for long-run solutions; and the third, on choices if gasoline prices increased to $0.80/gal ($0.21/liter).

For short-range solutions to energy shortages, the alternative choices were expand public transit, ration gasoline, raise the price of gasoline, and encourage car pooling. Table 6 gives the short-range preferences of the respondents for alleviating the fuel shortage problems.

Corresponding results were obtained in a similar question on the NORC survey, in which respondents were asked, What three things would you like federal, state, or local government to do to cut fuel consumption? The alternatives included set a limit of 50 mph (80 km/h), ration gasoline, increase the gas tax, improve public transit, relax antipollution standards, and set a limit of 60 mph (97 km/h). As a first choice, 23 percent of the respondents preferred improve public transit and 22 percent preferred set a limit of 50 mph (80 km/h). Set a limit of 50 mph (80 km/h) and set a limit of 60 mph (97 km/h) together were preferred first by 36 percent of the respondents. Only 10 percent of the respondents preferred the other alternatives first.

On the surface, these results show support for public transit and car pooling when the choice is presented, but assessment of these outcomes must be interpreted with caution. The alternatives presented in the NORC question were all difficult choices, each requiring a considerable shift from current levels of travel convenience. This suggests that public transit does well only when other choices are undesirable. Even under this situation, it is only a plurality, not a majority, who rank public transit high.

Furthermore, we may not often find ourselves in a situation where all the choices require a shift from regular travel patterns. Finally, a preference for public transit may only mean that it should exist so the other person can use it.

When the range of choice of the consumer is broadened to include those choices that allow him or her to continue driving in a more or less unencumbered fashion, then the preference structure changes. On the issue of long-range policies, the consumer most often preferred the alternative of increased production of gasoline. According to Table 7, 39 percent of the respondents preferred this alternative first. Somewhat surprisingly, however, improvement of public transportation received slightly more than one-quarter of the first preferences. Horsepower restrictions also receive about one-quarter of the first preferences. Thus, when given a range of alternatives that includes wide-scale use of the car, the respondents chose the car but did not entirely relinquish their interest in public transit.

Additional support of the preference for continued use of the automobile is found in the response to a question about using public transit if the price of gasoline goes to \$0.80/gal (\$0.21/liter). When the alternative of buying an economy car is included with using public transit, forming a car pool, and paying the price for gasoline, few people give public transit as an alternative. Most people say they would either buy an economy car or pay the price of gasoline (Table 8).

Part of the reason for the poor showing of transit as a preferred solution to the energy problem, except when use of the car is constrained, is perhaps a function of the poor image people have of local public transit. To further answer the question of potential ridership under improved service conditions, the 1974 Dutch Fork survey repeated a question from the 1972 survey on willingness to use rapid transit. This way the same question, use of a quality transit service, was posed under two conditions: low fuel prices in 1972 and high fuel prices in 1974.

Table 9 gives a comparison of the percentage of respondents who said they would be willing to take an express bus for their trip to the CBD in the 1972 survey with the corresponding percentage in the 1974 survey. The results show that only at the cheapest fare is there a difference between the 1972 data and 1974 data. These differences are consistent for all three time comparisons and cannot be explained by differences in the sample sizes between the 1972 and 1974 surveys. However, they could be ascribed to the higher price levels and the uncertainty of the availability of gasoline caused by the energy shortage.

The increased willingness to use transit in the 1974 survey should be interpreted with care. These increases are probably inflated for earlier sections of this paper show that professed interest in using transit and car pooling is higher than actual usage. For instance, 26 percent of the respondents said they saved gasoline by car pooling (Table 4). However, counts of passengers per vehicle showed that the average vehicle occupancy did not change during the 1972-1974 period. Similarly, Table 4 indicates that 5 percent of the respondents saved gas by using the local bus. However, ridership statistics show a lower value, although the one-way fare was \$0.40. Tables 6 and 7 also indicate a preference for using the automobile when it is posed side by side with public transit. Thus, there is a danger in literal interpretation of attitudinal data, and these data must be juxtaposed with cost consideration and information on how people actually behave.

SUMMARY AND CONCLUSIONS

The purpose of this study was to assess the impact of the energy shortage on travel attitudes and patterns of residents of an automobile-oriented, middle-class suburban area. The main questions asked were, To what extent did the gasoline shortage change the amount of travel by the automobile, increase use of and interest in local public transit, and increase car pooling?

Overall, the energy shortage did not appreciably reduce the amount of automobile travel and did not exert a substantial effect on transit patterns or attitudes in the study area. National patterns seem not to differ greatly from the results in the study area.

Figure 1. Ridership by week.

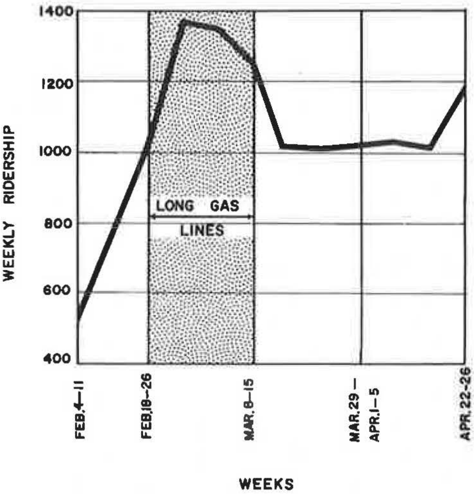

Table 5. Percentage of change in transit ridership, selected systems.

Transit System	Change (percent) From Previous Levels February 1974	Change (percent) From Previous Levels April 1974
Columbia, S.C.[a]	7.9	5.5
Charleston, S.C.[a]	17.4	7.1
Baltimore, Md.[b]	25.0	7.5
Norfolk, Va.[b]	12.3	0.2[c]
Washington, D.C.[b]	8.0	0.0

[a] Based on difference between current month and average ridership for that same month for previous 2 years, 1972-1973.

[b] Based on difference between current month and ridership for that month for previous year, 1973.

[c] For March 1974.

Table 6. Short-range preferences for alleviating gasoline problems.

Alternatives	Percentage of Respondents by Preference First	Second	Third	Fourth
Expand public transit	34.9	34.6	24.0	6.1
Encourage car pooling	29.2	36.5	23.4	10.3
Raise the price of gasoline	18.8	12.9	23.9	42.1
Ration gasoline	14.1	15.1	28.5	39.1

Table 7. Long-range preferences for alleviating gasoline problems.

Alternatives	Percentage of Respondents by Preference First	Second	Third
Expand oil production, exploration, and refineries	39.1	31.1	26.3
Improve public transit	28.6	34.9	34.0
Put a limit on horsepower	25.7	31.7	37.5

Table 8. Preferred solution if gasoline prices go to $0.80/gal ($0.21/liter).

Alternatives	Percentage of Respondents by Preference First	Second	Third	Fourth
Buy an economy car	40.5	26.7	16.4	15.4
Pay the price of gasoline	26.4	24.1	17.0	31.2
Form a car pool	18.0	29.6	29.9	21.9
Use public transit	14.5	20.3	35.4	28.6

Table 9. Percentage of respondents willing to take express bus.

	Comparisons With Automobile Travel Time					
One-Way Bus Fare (dollars)	15 Min Longer 1972	15 Min Longer 1974	Same Time 1972	Same Time 1974	Half the Time 1972	Half the Time 1974
1.50	8.6	6.7	11.7	9.6	14.4	15.7
1.00	13.6	13.8	20.9	20.6	25.8	28.9
0.75	—[a]	33.2	—[a]	43.9	—[a]	57.0
0.50	26.3	63.5	38.1	69.7	45.6	77.3

[a] Data not collected in the 1972 survey.

It is estimated that automobile travel by residents of the Dutch Fork area was reduced by 10 to 15 percent. Traffic volumes decreased primarily on weekends; there was less decline on weekdays. Travel was reduced by driving slower and limiting shopping and social-recreational trips. Moreover, only 6 percent of the respondents thought that they would have changed their place of residence had they anticipated the energy shortage. The shifts in travel behavior were, in other words, moderate. People did not move away from relying on the car but rather adjusted their driving behavior to conserve gasoline. They conserved by adjusting their driving habits, not by shifting mode. Data from national surveys also show this pattern.

In general, gasoline price did not appear to have much immediate impact on driving patterns. If price had gone up without shortages, it is likely that traffic volumes would not have decreased much. The impact of gasoline price appears to be more on the purchase of more economy-sized cars. The factor that produced the most change in both volume and mode was the shortage of gasoline supply. When the shortages were at their peak, there were decreases in traffic volumes and increases in public transit ridership.

One possible conclusion that can be drawn from these findings is that public transit will not realize appreciable comparative advantage over the automobile on the basis of price and that this is further evidence of the inability of transit to capture substantial ridership. There are several reasons for this result. First, the automobile still has too many other advantages in terms of flexibility and convenience. Second, gradual adjustments, such as greater gasoline economy from more economy-sized cars, will help reduce gasoline consumption. Third, motorists did not perceive the gasoline shortages as a serious long-range problem. It is possible, however, that the failure of public transit to capture and hold a greater part of the passenger market during the energy shortage is a product of poor service quality.

Seventy to 80 percent of the respondents in the Dutch Fork study did indicate that they would patronize a bus rapid transit system if it were attractively priced ($0.50 one-way fare) and if it were to offer the same or better time than the automobile. Comparison of attitudinal data with corresponding field data suggests that the stated high percentage of transit use is overinflated and should be cautiously interpreted.

The one positive result for public transit is the moderate support given to transit as a solution to energy problems. This support for transit was also apparent during the 1960s when the environment was a key political issue. The progress public transit legislation made during the 1960s was in part a function of the environmental movement. It is possible that local public transit can gain the same kind of federal legislative benefits during the 1970s as a result of the energy concern. The legislative benefits can in turn be a force for improving the quality of transit service, although there are reservations about whether public interest and governmental investments will be converted into substantial patronage gains for public transit.

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EVALUATION OF INTERACTION BETWEEN RURAL REGIONAL TRANSPORTATION AND ENERGY AVAILABILITY

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The energy crisis of 1973 can be considered an indicator of future problems. The impact on personal and goods mobility alone will have far-reaching consequences, not only in the urban areas but also in the rural regions. In fact, because of the less dense population distribution, rural regions are more sensitive to changes in energy form, cost, and availability. Maintaining the desirability of U.S. rural regions as a place to live is important to the welfare not only of this country but also of other countries of the world who depend on U.S. food exports for their survival. The wholesale abandonment of unproductive railroad lines imposes limitations on the economic viability of bypassed small cities. It creates constraints in the options for electric power generation and distribution system development and will have a dramatic effect on the economics of grain terminal locations and grain transportation. Even the system for providing heat to isolated farm homes and small towns will be interrelated with transportation forms of the future. Transportation system decisions have far-reaching implications on individual life-styles and the welfare of the nation, and it behooves decision makers to consider these interrelationships.

•THE energy crisis of 1973 created concern among governmental administrators and policy makers and persons involved in business and industry. In fact, many citizens for the first time became aware of how sensitive their life-style and mobility are to changes in the availability of energy. They noted that their homes were heated by natural gas or fuel oil and that the electric power generating plant used these same energy sources. A critical shortage in these forms of energy would have an immediate effect on personal comfort, especially for those in the cold winter areas of our nation. Some persons recalled that the conversion from coal to natural gas or fuel oil, for heating the home, had been a source of joy and that the conversion from coal to natural gas and fuel oil, as the fuel for the local electric generating plants, had only recently been accomplished.

Everyone recognizes the complex social and economic structure of our large metropolitan areas. The interrelationship of home location, shopping, business, recreation, and place of work in carrying out the activity of urban living has been studied and modeled extensively.

Perhaps less well known is that an equally complex social, cultural, and economic system has evolved in rural regions. And, because of the less dense population distribution, the rural region system is more sensitive to changes in the form of energy, its availability, and its costs.

Public transportation may become a more widespread substitute for the automobile if gasoline availability is restricted. In a rural region this change in personal mobility would dramatically influence the perceived desirability of that location as a place to live.

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The loss of railroad service to a small urban area imposes limitations on economic viability of that city. Certain types of industry depend on rail. In addition, if the motor carriers were to move to an uncompetitive position, the community without an alternate mode would have a reduced potential for economic development.

As the availability of natural gas and fuel oil is reduced, the applicability of alternates will be influenced by transport requirements and capabilities. Rural region dwellers are concerned about heating their homes and about the generation and distribution of electricity. Coal is an alternate, but its applicability is influenced by rail accessibility.

THE CURRENT SITUATION

Personal intraregional and interregional travel in rural regions is done almost exclusively by private automobile and intercity bus, but a generation removed traveled extensively by train. The availability of low-priced gasoline and the ubiquitous automobile led to the development of an extensive, publicly financed highway system. As each family acquired a private automobile, the potential for railroad passenger service declined. The intercity buses finally replaced the railroad in all but a few locations.

The freedom that the automobile with a high degree of flexibility gives a person makes rural regions more attractive. The attractiveness of a small city (or a farm home) is in large part due to the easy accessibility of recreation, culture, shopping, and other activities available at varying distances. However, because of the dispersed population distribution and low densities, the personal satisfaction of living in a rural region is sensitive to personal mobility. Public transportation in its present form is not an acceptable alternative to the car for a rural resident with a choice.

If the attractiveness of the automobile is diminished (e.g., because of cost, rationing, or peer pressure), the mobility aspects of alternative locations will be enhanced to a certain degree. The degree depends on flexibility, extensiveness of the system, and quality of service. It appears however that any change in personal transportation will reduce the perceived desirability of a rural region. Thus, the form of personal transportation is highly correlated with degree of location satisfaction.

The transport of goods and commodities within and between rural regions has a comparable historical record of shift from rail to highways. Rail shipments are trending to bulk commodities between long-haul markets. The privately owned and financed, highly regulated railroads are abandoning all but the profitable main lines as rapidly as possible. The abandonment of these branch lines is of concern to the cities and towns located on the route. Currently motor carriers of freight can efficiently and economically transport small shipments over short distances. But a city limited to only one mode has a reduced potential for expanding in the economic marketplace. In the long run, the reduced attractiveness to industry, with the resultant loss of economic spin-off and employment opportunities, is a factor in measuring the attractiveness of that rural region.

In small cities homes are primarily heated by natural gas and fuel oil, and in rural areas they are heated by liquified petroleum and fuel oil, all delivered by pipeline and truck. As these forms of energy are depleted, alternates will probably be based on coal, perhaps as electricity or manufactured gas. Although a pipeline-truck transportation system is currently serving this need, the future may see a need for railroad service to deliver coal to a central plant or distribution center.

Many small cities and towns have municipally owned electric power plants. These have almost exclusively converted to natural gas and fuel oil. A change in availability of this form of energy interacts with the total electric generating system and in the transportation system providing the fuel. If the city does not have access to rail service it probably is faced with interconnecting with a power grid and purchasing its entire needs. The alternatives for other than rail transportation of coal for a local operation are not feasible.

The recent pioneering activity in using solid waste as a portion of the fuel for coal-fired electric generating plants is related to the energy-transportation problem being discussed. The lack of rail service to a community probably negates its opportunity to use this technique. Ames, Iowa, will soon start substituting 20 percent solid waste for coal in its municipal power plant operation.

RAILROAD NETWORK

As in most states, Iowa had developed an extensive railroad system by the turn of the century. The distribution of this network is shown in Figure 1 [7,600 total route miles (12 200 km)]. All counties were served, and the viability of a community was based on rail service. Since World War II however there has been a concerted effort by the railroads to abandon branch and spur lines. Through a program of deferred maintenance and poor service, the railroad has the power to discourage traffic. In 1973, Iowa derailments due to track conditions cost the railroads over $3.7 million.

The mechanism for allowing railroads to abandon nonprofitable lines has been simplified. Low-traffic lines will be abandoned rapidly in the future. It has been hypothesized that rail-line abandonments may in fact become so intense that the system will virtually be reduced to main-line Interstate routes. Such a system (category 1) for Iowa is shown in Figure 2 [1,600 total route miles (2575 km)].

ELECTRIC POWER GENERATION

The generation and distribution of electric power in Iowa are a complex mix of public and private ownership and of interconnections between these individual companies and agencies. Hydropower is purchased and distributed from the government dams on the Missouri River and privately owned dams on the Mississippi. Privately owned nuclear power stations and other large fossil fuel plants are operating in Iowa. Figure 3 shows the existing electric generating plants in Iowa superimposed on the rail network of Figure 2. Notice that, under the bare-bones rail network, a large number of the smaller utilities are located off any rail access.

In addition, many of these plants are municipal electric generating plants. The cities that have elected to operate their own electric generating power plant do so primarily for control and dependability. Frequently they have chosen to reduce production through interconnection and purchase of power but still maintain the local generating plant as a standby. In most cases, the fuel for these electric generating plants is natural gas or fuel oil.

The fuel for the nonnuclear, nonhydro municipal plants is usually natural gas or fuel oil. In a few cases coal is still used. The trend in fuel sources for U.S. generating stations is given in Table 1 (3). Notice that coal and oil use has continued to increase and that the effects of a natural gas shortage can be seen in recent years.

To obtain the proper perspective of the role of each form of fuel's application to electric power generation, one must examine the current and planned uses. Internal combustion and combustion turbine (gas or oil) are more significant power fuel sources in the upper Midwest (Table 2, 3). However, examination of future electric generating plant fuel sources indicates tremendous added fossil steam (coal) generating capabilities (Table 3, 3).

As the natural gas and fuel oil supply is exhausted, two alternates will probably exist. The first involves the consolidation of electric power generation in the state into a few larger coal-using facilities, and power will be distributed to those users who do not elect to convert or rebuild their existing generating plant to use coal. The second alternative is for a local plant that uses natural gas or fuel oil to remodel or rebuild to a plant using coal. Such a decision requires direct access to a railroad line.

Figure 4 shows a map of Iowa with the main-line railroad system previously discussed. Each number on the map (53 in total) represents an existing electric generating plant that would not have access to this streamlined rail network. These generating plants would probably be abandoned, and an interconnection to a distribution system would be made. The local control would have been transferred, and the potential for

Figure 1. 1971 railroad system route structure in Iowa.

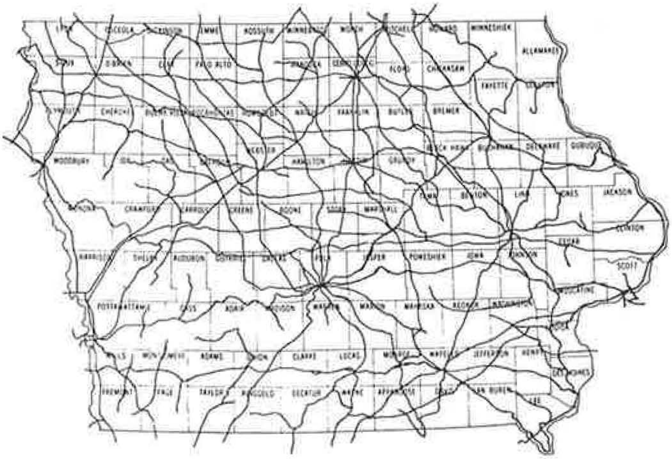


Figure 2. Category 1 system.

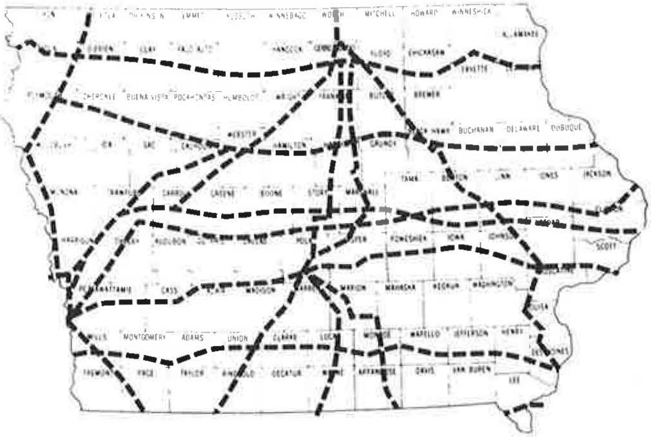


Figure 3. Category 1 railroad system and electric generating plants.

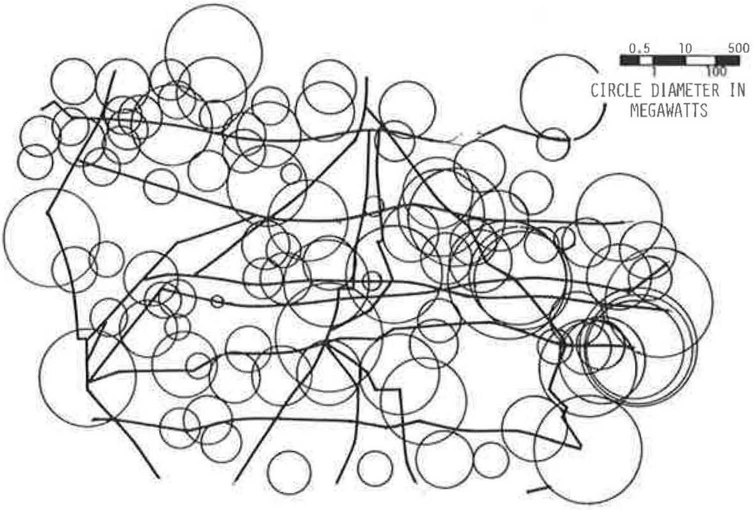


Table 1. Consumption of coal, oil, gas, and nuclear fuel in U.S. generating stations.

Year	Coal (tons × 10^6)	Oil (barrels × 10^6)	Gas (ft^3 × 10^9)	Coal and Equivalent Oil or Gas (tons × 10^6)	Coal Rate (lb/kW-h)
1963	211.25	93.31	2,143.51	320.27	0.856
1964	225.43	101.14	2,322.90	345.67	0.857
1965	244.79	115.20	2,321.10	369.33	0.858
1966	266.40	140.94	2,608.77	412.43	0.869
1967	274.18	161.28	2,746.35	431.77	0.870
1968	297.78	188.64	3,147.91	475.48	0.870
1969	310.64	251.03	3,487.64	524.48	0.880
1970	320.82	335.50	3,932.00	583.46	0.909
1971	327.93	396.24	3,993.00	618.28	0.918
1972	351.05	493.93	3,978.67	671.58	0.911
1973	386.55	565.51	3,754.21	723.68	0.916

Note: 1 ton = 907 kg. 1 ft^3 = 0.028 m^3. 1 lb/kW-h = 0.126 kg/MJ. 1 barrel = 0.16 m^3.

Table 2. Installed capacity of utility generating plants by type.

Item	Entire United States	West North Central States	Iowa
Hydro			
Plants	1,159	64	7
kW	61,280,602	3,134,339	131,625
Steam			
Plants	1,017	193	39
kW	339,427,661	24,833,124	3,107,967
Gas turbine			
Plants	457	51	9
kW	32,876,778	2,118,865	418,528
Internal combustion			
Plants	989	460	126
kW	4,908,050	1,879,529	449,236
Total			
Utilities	1,162	407	93
Plants	3,622	768	181
kW	438,493,091	31,965,857	4,107,356

Note: Data are as of December 31, 1973.

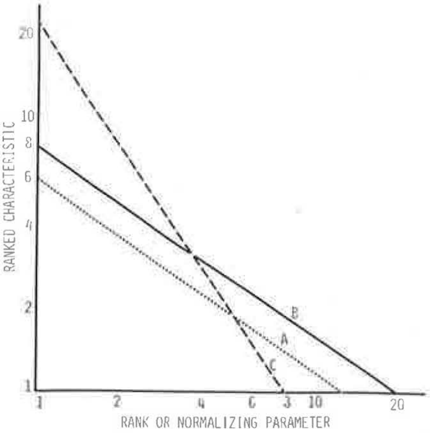
Table 3. Future electric generating capability (MW).

Type	Added in 1973	Planned				
		1974	1975	1976	1977 and Later	Total
Hydro	48	–	–	–	60	60[a]
	1,311	137	1,404	1,901	8,362	11,804[b]
Pumped storage	–	–	–	–	1,191	1,191[a]
	3,622	1,616	2,035	100	13,056	16,807[b]
Fossil steam	1,883	–	1,116	1,789	11,014	13,919[a]
	19,773	23,138	23,905	18,578	97,763	163,384[b]
Nuclear steam	455	1,803	562	200	1,730	4,295[a]
	6,367	12,097	11,314	10,323	165,519	199,253[b]
Internal combustion	27	39	10	12	45	106[a]
	62	52	29	180	265	526[b]
Combustion turbine	541	780	361	618	591	2,350[a]
	4,765	6,314	2,835	2,620	14,516	26,285[b]
Total	2,954	2,622	2,049	2,619	14,631	21,921[a]
	35,900	43,354	41,522	33,702	299,481	418,059[b]

[a] West north central region. [b] Contiguous United States.

Figure 4. Location of electric generating plants with no rail access, category 1 system only.

Figure 5. Rank-size analysis concept.



allied uses such as power from solid waste would be lost.

The ability to use solid wastes as a substitute for coal has far-reaching implications. Foremost in most persons' minds perhaps are the reduced energy needs from conventional sources as well as the reduced waste-disposal problems. Perhaps more intriguing for Iowa residents is the potential to use high-sulfur Iowa coal. When a substitute material with near zero sulfur content constitutes 20 percent of the input fuel, Iowa coal may become a practical fuel. It may be feasible to develop Iowa's vast reserves of high-sulfur coal in the future by combining combustion with solid waste.

Some of the previous ideas expressed imply that the abandonment of local electric generating plants and connection to the grid are undesirable. The economy of scale achieved in a few large generating plants, as opposed to many inefficient smaller plants, may be obvious. However, the smaller generating plants do provide a level of local control that perhaps is the reason for their continued existence today. The undesirable aspects of very high voltage transmission line services, the lack of local input into company policies and practices, and the definite hazards of being without power for a number of days following a major ice storm are reasons put forth for the continued existence of local electric generating plants.

AGRICULTURE

Iowa's economy is geared to farm production. The large-scale operations that have evolved require the transport of equipment and fertilizers to the farm and the shipment of products to all parts of the world. It is anticipated that future demands to feed undeveloped nations will intensify.

Two aspects of agricultural production are related to the energy-transportation interaction phenomenon. The first involves the production and distribution of fertilizer. In recent years, large volumes of natural gas have been converted to fertilizer at geographical distribution centers served by pipeline. The transportation to the retail outlet and to the individual farms is efficiently accomplished by motor vehicles. However, the shift from natural-gas-based fertilizers to other forms of fertilizer may involve the economics of transporting bulk commodities over long distances. Rural regions not served by rail may find the alternative terminal and distribution structure places them at an economic disadvantage.

The second aspect of the energy-transportation interaction as it relates to agriculture is the distribution of farm products. Large-scale farm operations generate great quantities of corn, grain, and soybeans for export. The collection and concentration of these commodities may be accomplished by motor vehicles, but the large terminal elevators can only be economically served by bulk-moving carriers, such as rail or barge, for the long-distance trip. A future change in energy availability will reduce the viability of the motor carrier for moving farm bulk commodities. The distribution of elevator terminals and subterminals and their access to a railroad line will be important if the United States is to remain competitive in world food production.

QUANTIFICATION OF TRANSPORTATION VARIABLE

Research recently conducted by the Engineering Research Institute at Iowa State University has attempted to quantify individual transportation modes and to aggregate them into a single regional measure. The relationship of transportation to regional growth was then analyzed through rank-size analyses techniques (1). The following adjusted transportation index formula was developed:

$$\text{ATI} = 0.68\ \text{HSI} + 0.17\ \text{TSI} + 0.06\ \text{WRMI} + 0.01\ \text{WRBO} + 0.07\ \text{ASI} + 0.01\ \text{WBBO} \qquad (1)$$

where

ATI = adjusted transportation index,
HSI = highway sufficiency index,
TSI = truck service index,
WRMI = weighted rail mileage index,
WRBO = weighted rail boarding opportunities,
ASI = airport service index, and
WBBO = weighted bus boarding opportunities.

The technique for evaluating the regional transportation system was adopted from the rank-size analysis concept of order statistics. The distribution of community sizes for a centrally placed community and its associated hinterland communities is well described by the following relationship:

$$\log S = \log A + B \log R \tag{2}$$

where

S = size of community,
A = constant,
B = constant, and
R = rank of the community, with 1 as the largest.

This relationship has also been used for defining the data limits of trip characteristics considered in urban planning. It is hypothesized that a corresponding relation appropriately describes the regional variation of transportation to provide intercity connectivity within the region.

Figure 5 shows the ATI rank-size analysis plot for a typical multicounty rural region. Line A is the least square fitted linear regression line for the current ATI ranked data. A relatively flat slope indicates the existence of region-wide accessibility between communities with the potential to encourage decentralized development. A relatively steep slope such as line C indicates lack of regional accessibility and the resultant problems in decentralized development.

The degree of regional accessibility between two lines (different regions, different time references, or different ATI system values) can be quantified through the angle relationship between the lines. The use of different time periods for ATI values is a measure of change in mobility. Line B represents ATI values for the same region as line A, but at a later date. The upward shift in the line represents an improved degree of mobility.

Figure 6 shows this evaluation technique. Each plot represents the ATI rank-size analysis for an Iowa rural region. A region-wide change in mobility between 1960 and 1970 can be noted in regions 2, 3, 15, and 16. Note also a difference in the degree of mobility for the centrally placed city between regions. A number of accessibility interpretations may be obtained from these time-series analyses.

A sensitivity analysis reflecting a change in freight mode was undertaken using this technique. Assuming that the railroads will vigorously pursue an abandonment policy, the main-line railroad system shown in Figure 2 may result. The change in the ATI rank-size analysis regression line is shown as the long-short dash line in Figure 7. With the exception of region 5 and to a lesser extent region 16, the effects of reduced railroad mileage are inconsequential in terms of region mobility and the centrally placed city rank. This indicates that a continued vigorous abandonment policy with no change in energy availability would have a minor effect on existing regional transportation.

A second alternative included the reduced railroad mileage and also a long-range energy shortage requiring a fuel allocation policy. This policy emphasized rail move-

Figure 6. Adjusted transportation index rank-size analysis.

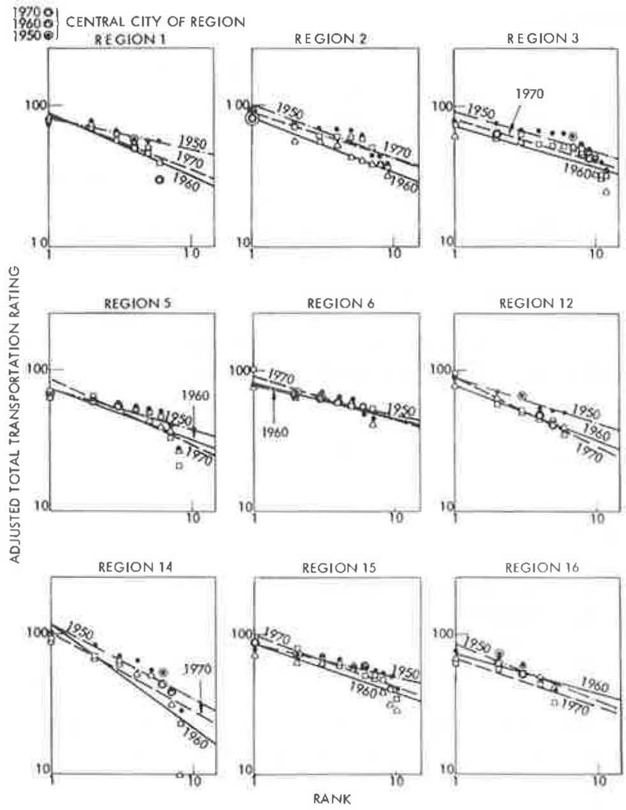
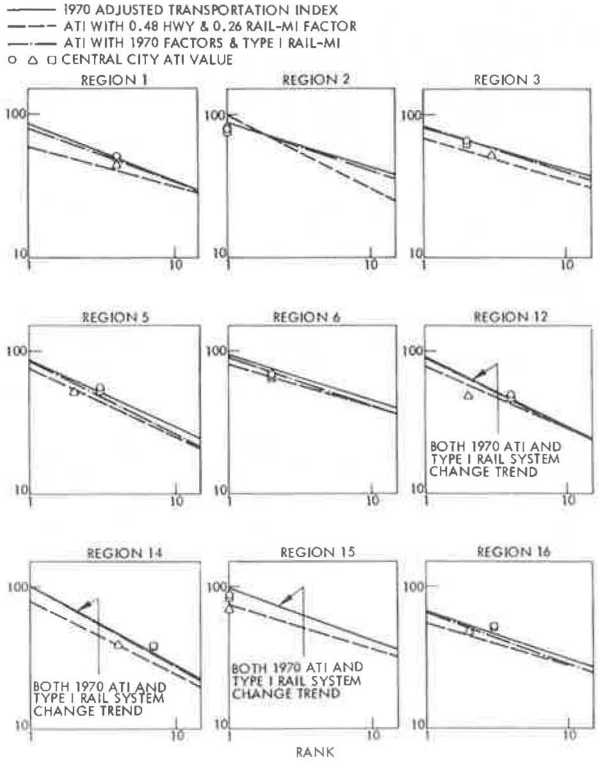


Figure 7. 1970 adjusted transportation indexes for region, centrally placed city, and reduced railroad mileage.



ments at the expense of motor vehicles and left movements of common-contract, motor truck carriers about constant. The effect of this policy is shown in Figure 7 as the short-dashed line. Comparisons are made with the 1970 ATI solid line and with the long-short dashed line. They reflect a reduced railroad system. Note the consistent regional loss of mobility in regions 3, 5, 14, and 16. Regions 1, 6, and 12 present a more complex sensitivity pattern indicating a lower level of mobility and more uniform regional distribution. The reverse is true in region 2.

These sensitivity analyses of alternative policies indicate the potential long-term impact of interacting transportation and energy policies on communities and regions.

CONCLUSIONS

The desirability of a rural region as a place to live is a function of transportation availability, form, quality, and cost. Personal access to shopping and services and to cultural and recreational opportunities as well as the economic benefits accruing from competitively priced and efficient freight shipments are variables of concern. Accessibility to the individual is important, but no more important perhaps than viability for business and industry. Job opportunities determine a region's ability to attract and retain people in a desirable socioeconomic environment; however, industry needs energy and transportation. The imminent abandonment of large segments of Iowa's rail system reduces the potential of many regions to attract and support industry. Combined with the natural gas distributor's plan to eliminate electrical generating plant users by 1976 (2) and all interruptable users by 1978 and with the fuel oil shortage, the potential for economic health and growth and the interrelated social welfare of many communities may indeed be bleak.

As the availability and cost of petroleum fuels and natural gas change the interaction with the elements of transportation, the impact on life-styles must be recognized. In fact the interaction must be anticipated and planned for to minimize adverse results. The quantification of the transportation variable and the technique of rank-size analysis have demonstrated that changes in mobility can result from changes in energy policy.

An application of the impact of interacting transportation and energy policies is in the program of railroad abandonments. This issue is of concern not only in Iowa, but nationwide. Preliminary studies resulting from the Regional Rail Reorganization Act of 1973 indicate more than 15,000 miles (24 000 km) of unproductive mileage in the Northeast and upper Midwest are candidates for abandonment.

It appears highly desirable for states, localities, or other public bodies to acquire abandoned railroad rights-of-way to preserve the continuity and interconnectability of the system. In that manner, the potential exists to reinstitute railroad service should energy policy, heavy industrial development, or agricultural shipment demands necessitate such action.

Transportation system decisions, energy source decisions for power generation based on environmental criteria, and power generation and distribution system planning options for the future are all interrelated. Therefore, decisions of the U.S. Department of Transportation, Environmental Protection Agency, and Federal Power Commission are not independent of one another. We need to recognize this situation before our future options are limited by default caused by previous decisions (or lack of decisions).

Iowa has adopted legislation that provides for the upgrading of branch railroad lines. The Iowa Railroad Assistance Plan made available $3 million for financial assistance in 1974. However, the new Iowa Department of Transportation was not to be operational until July 1975. Consequently, decisions and expenditures made under this plan are not necessarily based on statewide goals and plans yet to be articulated.

The mix of governmental control and funding and private ownership of the various transportation modes and energy suppliers creates a barrier to implementing sound management principles. Government must establish transportation and energy goals and then develop the statewide plans to implement these goals.

ACKNOWLEDGMENT

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ENERGY SAVINGS FOR WORK TRIPS: ANALYSIS OF ALTERNATIVE COMMUTING PATTERNS FOR NEW JERSEY

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This paper analyzes energy consumption for work trips in New Jersey. Prepared as an aid to the New Jersey Task Force on Energy, it develops a methodology to quantitatively compare alternative transportation policies intended to reduce energy consumption. Data were obtained on work trip distribution, transit patronage, and modal split for each of the 21 counties in New Jersey for 1970. From these data, work trip lengths and automobile and transit occupancy rates were calculated. Based on these as inputs to a model that predicted total work trip energy utilization, the total daily energy consumption was computed for work trips of New Jersey residents. Modal split, energy per vehicle mile (kilometer), and vehicle occupancy rates were then varied to test alternative strategies for reducing energy consumption. In general, the results of this analysis showed that, given current work trip patterns, greater savings in energy could be achieved by using automobiles than by increasing public transit patronage. Specific policy recommendations were then outlined for automobile and public transit planning.

•DURING the winter of 1973, America faced its first major gas shortage since World War II. At the height of the crisis, many public agencies rushed to develop plans to deal with the problem by encouraging car pooling, rationing fuel, and by implementing short-term improvements to transit systems. In some cases, services were instituted that never would prove useful or feasible. Some well-conceived plans helped ease the immediate crisis, but later, when fuel became more plentiful, old habits and patterns of travel returned.

In New Jersey, as in other states, the need was recognized for more long-range planning that could deal rationally with future crises by developing policies and bureaucratic mechanisms to coordinate and regulate energy supply and demand. Therefore, an energy policy task force was drawn together from personnel of several state agencies and local universities, under the auspices of the New Jersey State Energy Office. The task force was charged with the responsibility of preparing a report for the governor on the major problems of energy supply and demand in New Jersey. The task force was to make specific policy recommendations for the state's role in energy management. What follows is an analysis of journey-to-work energy consumption to examine potential energy savings under different transportation policies for the New Jersey Task Force on Energy.

Data were obtained on work trip distribution and modal split for each of 21 counties in New Jersey from the 1970 census. Work trip lengths and automobile occupancy rates were calculated from these data. From data obtained from the New Jersey State Department of Transportation, transit vehicle occupancy rates were calculated. Based on these as inputs to a model that predicted total work trip energy

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utilization, it was possible to compute the total daily energy consumption for work trips by New Jersey residents in 1970. Modal split, energy per vehicle mile (kilometer), and vehicle occupancy rates were then varied to test alternative strategies for reducing energy consumption. The results of this analysis were quite surprising. In general, it was found that much greater energy savings were possible by using automobiles rather than by increasing public transit patronage. This led to some specific policy recommendations that are discussed in this paper.

NATIONAL TRANSPORTATION SITUATION

Transportation accounts for about 25 percent of all energy consumed in the United States, and this percentage may be even higher if indirect consumption is included (1). Because so much transportation energy is expended in Interstate and interregional movement, it is difficult to isolate one region and quantify the total transportation energy consumption within its borders. Consequently, the following discussion of overall patterns of energy consumption must be based on the national level, since statewide statistics are unavailable. In Figure 1, the nationwide distribution of energy consumption among the various modes is shown for 1970. From this, it is clearly seen that the major consumers of transport energy are the highway users—automobiles and trucks.

The automobile alone consumes over one-half of all energy consumed by the transportation sector. The following table gives the percentage of automobile miles (kilometers) traveled.

Purpose	Percent
Earning a living	40.6
Family business, including shopping	20.0
Educational, civic, and religious	4.9
Social and recreational, including vacations	33.3
Other	1.2
Total	100.0

Trips for earning a living account for 40 percent of all vehicle miles (kilometers) traveled daily. Travel to work and back alone accounts for 32.9 percent of all vehicle miles (kilometers) daily. The first priority in reducing transportation energy consumption, therefore, is reducing the level of highway travel.

TRANSPORTATION IN NEW JERSEY

In 1970, vehicle registration in New Jersey reached 3.79 million vehicles, giving a ratio of 1 vehicle for every 1.9 people (7). In 1972, trucks accounted for about 9 percent of all registrations. Together, these vehicles accumulated 40 billion vehicle miles (64 billion km) of travel on 32,000 miles (51 500 km) of roads in New Jersey in 1970. Within this extensive system of roads are 440 miles (708 km) of expressways, 543 miles (874 km) of divided highways, and 1,267 miles (2040 km) of undivided state highways (7).

Fifteen of New Jersey's 21 counties are presently served by rail passenger service. Five companies operate a combined total of 467 route miles (752 km), carrying a weekday average of 166,130 commuters (7). In addition to rail transit, the state has extensive bus service, 4,700 buses operated by 274 companies. New Jersey's bus companies carry 313 million passengers each year (7). Figure 2 shows a map of the 21 counties in New Jersey.

Figure 1. Energy consumption by transport mode.

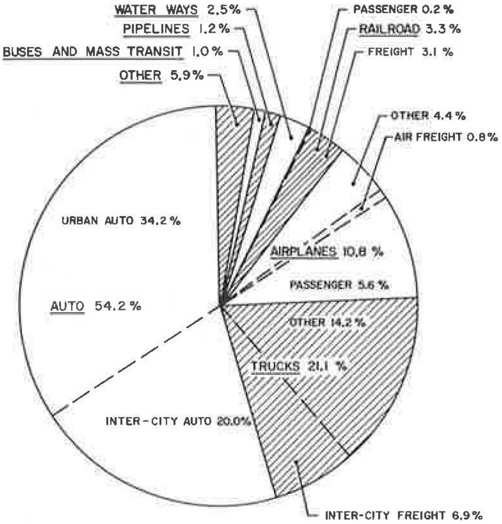


Figure 2. Counties in New Jersey.

Table 1. Distribution of mode of travel to work.

County	Automobile (percent)	Bus (percent)	Rail (percent)	Walking (percent)	Other[a] (percent)
Atlantic	74.0	8.9	0.4	10.3	6.4
Bergen	75.4	12.2	3.4	5.5	3.5
Burlington	73.4	3.2	0.8	18.3	4.3
Camden	75.7	9.7	5.0	5.2	4.4
Cape May	77.9	1.5	0.9	11.0	8.7
Cumberland	86.7	0.8	0.2	6.2	6.1
Essex	63.6	22.0	3.6	7.7	3.1
Gloucester	84.0	4.5	0.7	4.6	6.2
Hudson	48.5	28.0	7.3	13.9	2.3
Hunterdon	82.8	0.8	2.1	6.0	8.3
Mercer	79.1	5.8	1.9	8.7	4.5
Middlesex	82.9	5.5	3.4	6.4	1.8
Monmouth	77.4	5.3	5.2	7.5	4.6
Morris	83.3	2.0	5.3	5.3	4.1
Ocean	86.4	2.7	1.2	4.4	5.3
Passaic	77.9	10.6	0.9	7.8	2.8
Salem	86.3	0.5	0.1	6.0	7.1
Somerset	73.5	14.5	4.3	4.4	7.2
Sussex	85.2	1.2	0.9	5.5	7.2
Union	76.4	7.6	5.8	7.1	3.1
Warren	82.2	0.7	0.3	9.1	7.7
Avg	74.1	10.5	3.6	7.8	4.0

[a] Includes working at home.

ANALYSIS OF ENERGY CONSUMPTION

Automobile travel consumed more than one-half of all transportation energy in 1970 (Figure 1), and over 40 percent of all automobile travel was expended in earning a living (Table 1). It is clear, therefore, that about 20 percent of all transportation energy is expended in driving to work. Much of the passenger traffic carried by rail and bus is also comprised of home-to-work travelers. In fact, half of all rail passenger traffic is commuter service (8). Consequently, an examination of commuting patterns can lead to a revealing cross-sectional view of the way transportation energy is expended in New Jersey. In addition to examining energy expended in work trips alone, it is possible to extend the examination to other travel behavior as well, since the way people travel to work is strongly correlated with the travel patterns shown by their entire households. To better observe the pattern of transportation energy consumption in New Jersey and to determine the policies that will be most effective in reducing the consumption of energy, an analysis of 1970 work trips of New Jersey residents was made according to the amount of energy consumed.

Source of Work Trip Data

In the 1970 census, 15 percent of all households tabulated were asked specific questions on the mode of transportation used by each household member for the journey to work and on the address of the place of work. Tabulations of these data are available for each county in New Jersey and were used to determine the modal split for work trips (i.e., the number of people who went to work by car, bus, train) for each county (2). In addition, tabulations of numbers of workers commuting to selected cities and counties were available for each county. It was therefore possible to obtain an approximation of the average work trip length for each county.

Existing Commuting Patterns

Table 1 (2) gives the modal split for work trips in 1970 by county. For every county, the automobile carries the majority of all workers, an average of 74.1 percent for the state. All public transit, rail and bus together, carry only 14.1 percent of all workers. Of all counties, Hudson County has the largest share of transit riders, 35.3 percent, and the smallest percentage of automobile travelers, 48.5 percent. Salem County has the smallest percentage of transit riders, 0.6 percent, and Cumberland County has the largest share of automobile work trips, 86.7 percent. Burlington County has the largest percentage of walkers, 18.3 percent. This figure may reflect the contribution of three large military bases in the county, containing large numbers of resident workers.

Many New Jersey residents commute from their counties of residence to work in adjacent counties or neighboring states. In fact, according to the census, 182,000 New Jerseyites commute to New York, and 74,000 commute to Pennsylvania each day; they make up approximately 9 percent of the New Jersey labor force. A significant proportion of out-of-state residents commute into New Jersey each day, equal to about one-half of the total outbound New Jersey commuters. These calculations do not include those workers residing outside New Jersey. Table 2 gives a county-by-county tabulation of the percentage of out-of-county commuters. Only 4 counties have fewer than 25 percent commuting, and two-thirds of the counties have more than 30 percent commuting to work out of county.

The results of the wide dispersal of homes and jobs are reflected by the distance one must travel to work. In Table 3, the approximate average one-way work trip lengths for each county are given. The data in Table 3 are based on county-to-county work trip tables from New Jersey Department of Labor and Industry 1970 census data. These trip tables only contained data about work trips to the first 20 selected locations for each county, ranked by number of trips to each location. In most cases, these locations

Table 2. Percentage of residents commuting to out-of-county jobs.

County	Percent	County	Percent
Atlantic	14	Middlesex	36
Bergen	43	Monmouth	29
Burlington	37	Morris	38
Camden	40	Ocean	35
Cape May	16	Passaic	35
Cumberland	12	Salem	26
Essex	29	Somerset	48
Gloucester	47	Sussex	43
Hudson	36	Union	36
Hunterdon	40	Warren	33
Mercer	14	Avg	36

Table 3. Average work trip length (one-way).

County	Trip Length (miles)	County	Trip Length (miles)
Atlantic	10.9	Middlesex	12.0
Bergen	9.1	Monmouth	14.1
Burlington	12.8	Morris	13.1
Camden	8.3	Ocean	15.7
Cape May	14.4	Passaic	7.8
Cumberland	10.8	Salem	11.6
Essex	6.4	Somerset	13.6
Gloucester	10.7	Sussex	18.0
Hudson	6.6	Union	7.9
Hunterdon	13.7	Warren	15.5
Mercer	9.4	Avg	9.9

Note: 1 mile = 1.6 km.

Table 4. Average vehicle occupancy for work trips by automobile and public transit.

	Occupancy (persons per vehicle)			Occupancy (persons per vehicle)	
County	Automobile	Public Transit	County	Automobile	Public Transit
Atlantic	1.17	6.9	Middlesex	1.15	25.7
Bergen	1.15	17.8	Monmouth	1.15	7.4
Burlington	1.14	15.6	Morris	1.13	11.8
Camden	1.19	16.2	Ocean	1.14	6.2
Cape May	1.15	8.0	Passaic	1.17	13.4
Cumberland	1.18	4.9	Salem	1.24	10.6
Essex	1.19	25.0	Somerset	1.13	23.3
Gloucester	1.17	14.7	Sussex	1.15	3.4
Hudson	1.24	31.8	Union	1.17	19.2
Hunterdon	1.12	10.6	Warren	1.17	3.4
Mercer	1.19	20.6			

accounted for >90 percent of all work trips for the county. The work trip tables had origins disaggregated by municipality. For each county, a theoretical center of population was assigned based on the population distribution among all municipalities. All out-of-county trips were assumed to begin at this location. For trip ends, a center of employment was assumed for each destination. Distances were obtained from the Offical Map and Guide 1972 of the New Jersey State Department of Transportation. Intracounty trip lengths were calculated by using an assumed average trip time of 20 min and speeds averaging about 20 mph (32 km/h), but varying with the urban or rural nature of the county. Finally, the average trip length for each county was computed by weighting each tabulated trip length by the number of workers traveling that distance. The average trip lengths for the more rural counties are generally longer than those for more urbanized counties (Table 3). Sussex County, for example, has an average trip length nearly three times that of Essex County. Overall, the 9.9-mile (15.9-km) average work trip length in New Jersey is quite close to the national average of 9.4 miles (15.1 km) (6).

Calculation of Transportation Energy for Work Trips

The following expression was used to determine the total energy consumed by work trips (3):

$$E = \sum_{c} \left\{ W_c L_{cw} \left[\sum_{j} \alpha^{w}_{cj} \left(\epsilon_j / \lambda_{cj} \right) \right] \right\} \tag{1}$$

where

E = total work trip energy,
W_c = number of one-way work trips made in the c th county,
L_{cw} = average work trip length for the c th county,
α^{w}_{cj} = percentage of work trips by the j th mode,
ϵ_j = energy per vehicle mile (kilometer) for the j th mode, and
λ_{cj} = load factor for the j th mode in the c th county.

L_{cw} is assumed to be constant for all modes for a given county. Most likely, average trip length would vary with mode, particularly with respect to rail trips. Since automobile trips tended to dominate all other modes in the base year 1970 and trip length distributions were unavailable for each mode, a constant value assumed for L_{cw} did not appear unreasonable.

The load factor λ_{cj} for each mode by county required estimation for input into the model. For automobiles, λ was known since the 1970 journey-to-work data specified automobile driver or automobile passenger as separate modes. Automobile occupancy was calculated as the total automobile users (drivers + passengers) divided by the number of automobile drivers. For buses, however, λ was estimated from data provided by the New Jersey State Department of Transportation. Annual bus route statistics for 1973 were obtained. These contained total number of trips, total passengers carried, and total vehicle miles traveled for each route. In addition, a description of each route was obtained to determine which counties were traversed. Average vehicle occupancy was based on the total number of passengers multiplied by the assumed average trip length and divided by the total number of vehicle miles (kilometers) traveled for each route. Because of the method by which load factors were calculated, the factors provided here should be considered as approximations rather than absolute values. In this analysis, they were included primarily for use relative to other assumed load factors. Table 4 gives the load factors obtained for automobiles and buses for 1970. It should be noted that, although the census data aggregate the bus and the streetcar, all travel in this category was assumed to be by bus, since the only streetcar line presently operating in New Jersey (Newark) is generally considered to be a subway. Later, all other commuter rail travel was aggregated with bus travel. Although railroad cars hold more people per vehicle than buses, in actual operation, their occupancy ratios and energy consumption per passenger-mile (kilometer) were similar. Consequently, it was decided to consider both bus and rail as one mode, transit.

The automobile occupancy for work trips is about 1.2 persons per car (Table 4). This indicates that about 5 out of every 6 workers who drive to work travel alone. Bus occupancy fluctuates widely, from 31.8 passengers in Hudson County to 3.4 passengers in Sussex and Warren Counties.

Energy Consumption per Mode

The energy consumption parameters ϵ_j were obtained from the work of Fels (4). Although Fels included the energy cost of manufacture for both the vehicle and the guideway, only operating energy was used in these calculations. Assessment of only the energy savings achieved by presently available alternatives was desired, considering both the vehicles and the guideway as sunk energy costs. Obviously, any consideration of future alternatives or of an increase in the supply of transportation facilities to meet increases in demand would have to account for energy of manufacture for new components. The following table (4) gives the energy requirements in kilowatt-hours (joules) per vehicle mile (kilometer) for each mode under consideration (1 kW-h = 3.6 MJ):

Mode	Energy Required (kW-h)
Automobile	3.19
City bus	8.66
Rail rapid	15.50

[The 1973 automobile had an internal-combustion engine and weighed 3,600 lb (1630 kg).]

Journey-to-Work Energy

The total energy expended in work trips for 1970 is given in Table 5. In addition to total energy, per capita energy and the ratio of transit energy per passenger-mile (kilometer) to automobile energy per passenger-mile (kilometer) are given. Per capita consumption varies considerably by county. Sussex County consumes about 4½ times as much energy per capita as Hudson County. What accounts for the difference? As determined earlier, energy consumption depends heavily on modal split, average trip length, and average vehicle occupancy. All of these variables are correlated with the overall population density of the respective counties, which is shown for 1970 in Figure 3. Where densities are higher, trip lengths are shorter, more people ride public transit, and the buses and trains are fuller. Even automobile occupancy is higher. Figure 4 shows the correlation between energy consumption and population density by county for New Jersey in 1970.

ALTERNATIVE PATTERNS OF ENERGY CONSUMPTION

Based on the model of energy consumption developed here, the energy savings achievable through the adoption of different policies will now be examined. Several policies will be considered, including car pooling, increasing the efficiency of automobiles, and encouraging people to use public transit.

Table 5. Transportation energy for 1970 work trips.

County	kW-h per Capita	Total Energy (kW-h × 10^3)	Ratio of Transit to Automobile Efficiency
Atlantic	16.9	2,967.8	2.2
Bergen	16.6	14,920.0	5.7
Burlington	21.9	7,086.7	5.0
Camden	13.2	6,061.4	5.0
Cape May	20.7	1,236.3	2.6
Cumberland	19.1	2,324.0	1.5
Essex	8.9	8,343.4	7.8
Gloucester	18.1	3,126.2	4.6
Hudson	7.2	4,394.4	9.4
Hunterdon	25.6	1,783.0	3.5
Mercer	16.4	5,010.7	6.4
Middlesex	22.3	12,993.0	8.2
Monmouth	23.4	10,823.0	2.4
Morris	24.6	9,453.6	3.8
Ocean	34.9	5,149.7	2.0
Passaic	13.9	6,415.0	4.2
Salem	19.7	1,189.8	3.2
Somerset	27.1	5,371.1	7.6
Sussex	32.3	2,505.9	1.1
Union	14.4	2,825.4	6.0
Warren	27.1	2,007.9	1.0
Avg	16.8	120,988.3	5.3

Note: 1 kW-h = 3.6 MJ.

Figure 3. County population density for New Jersey.

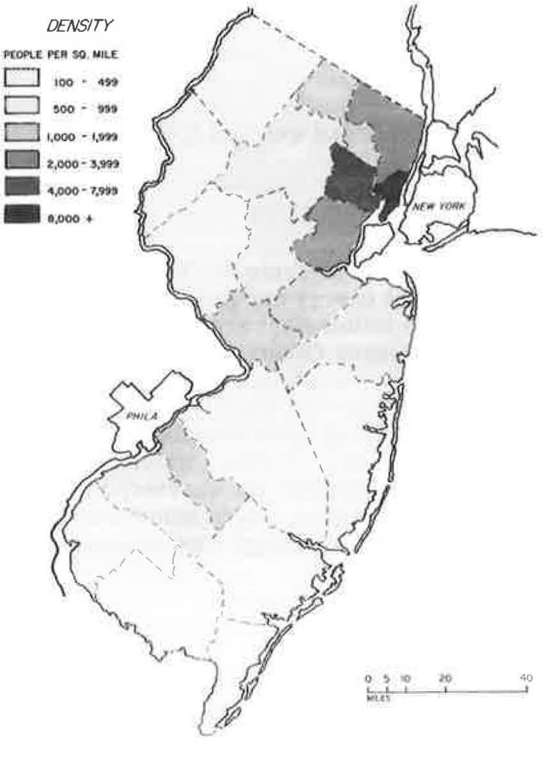
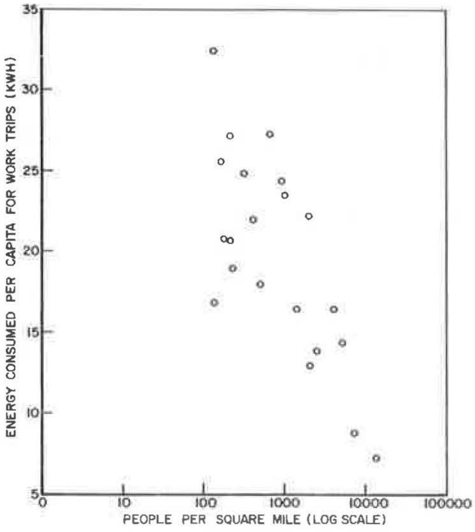


Figure 4. Per capita work trip energy consumption versus county population density for New Jersey.



Energy Savings Through Car Pooling

As stated earlier, the average automobile occupancy for work trips in New Jersey was about 1.2 passengers per car, meaning only about 1 in every 6 drivers were in a car pool in 1970. If everyone shared a ride and the average automobile occupancy rose to 2.0, according to the figures in Table 6, the state would save about 40.7 percent of the journey-to-work energy. If average occupancy rose to 3.0, over 59 percent of the 1970 energy consumed could be saved.

More Efficient Automobiles

If a 25 percent increase in automobile efficiency were achieved, which might be accomplished by reducing average car weight to 2,400 lb (1090 kg) and by increasing fuel economy to achieve 20 miles/gal (8.5 km/liter), the overall energy savings would amount to 25.3 percent, as given in Table 7 (3). If even smaller cars were driven, weighing about 1,800 lb (816 kg) and getting about 25 miles/gal (10.6 km/liter), similar to the Honda CVCC, the savings would be almost 52 percent of the energy used in 1970. Finally, if car pooling were combined with the use of small cars, an energy savings of 70.7 percent of 1970 consumption could be achieved.

Energy Savings Through Public Transit

For evaluation of energy savings to be achieved through more effective use of public transit, the energy consumed per vehicle mile (kilometer), ϵ_j, was not varied although this is certainly possible within limits. For this analysis, α_j^w, the percentage of people using public transit for work, and λ_j, the average number of passengers, were varied. Four strategies were tested:

1. Shifting 10 percent of all automobile travelers to public transit and holding the 1970 load factors constant;
2. Shifting 30 percent of all automobile travelers to public transit and increasing the load factors to 25 (this represents approximately 50 percent bus occupancy);
3. Shifting one-half of all automobile commuters to public transit and increasing the load factors to 40 (about 80 percent of bus capacity); and
4. Shifting 50 percent of all automobile commuters to public transit (the remaining 50 percent uses small cars).

It should be noted that a shift of only 10 percent of all automobile commuters to public transit would nearly double present transit ridership, and in some counties transit ridership would have to increase tenfold. The results of this analysis are given in Table 8. A 10 percent shift results in a savings of only 8.8 percent. The 30 and 50 percent shifts to transit result in 26.5 and 46.4 percent savings respectively. The biggest savings, 72.3 percent, would be achieved through a shift of 50 percent of all automobile commuters to public transit; the remaining drivers would travel to work in small cars that are 53 percent more efficient than the cars of 1970.

POLICY RECOMMENDATIONS AND PRIORITIES

The preceding analysis has provided insight into the results of several alternative transportation policies. All of these would have a significant impact on patterns of energy consumption, but they would have profound effects on life-styles as well, perhaps in ways not altogether favorable. Now, the implications of these policies will be examined in more detail.

Table 6. Effects of car pooling on energy consumption.

	Energy Saved by Increasing Automobile Occupancy (percent)	
County	2 People	3 People
Atlantic	39.2	57.6
Bergen	41.0	59.5
Burlington	42.2	61.1
Camden	39.1	58.2
Cape May	42.1	61.0
Cumberland	40.9	60.3
Essex	38.6	57.4
Gloucester	41.1	60.3
Hudson	35.2	54.5
Hunterdon	43.4	61.9
Mercer	39.9	59.4
Middlesex	41.9	60.8
Monmouth	40.3	58.4
Morris	42.3	60.8
Ocean	42.1	60.7
Passaic	40.0	58.9
Salem	38.1	58.7
Somerset	42.2	60.4
Sussex	41.7	60.4
Union	40.4	50.3
Warren	40.8	60.2
Avg	40.7	59.4

Table 7. Energy savings due to increased automobile efficiency.

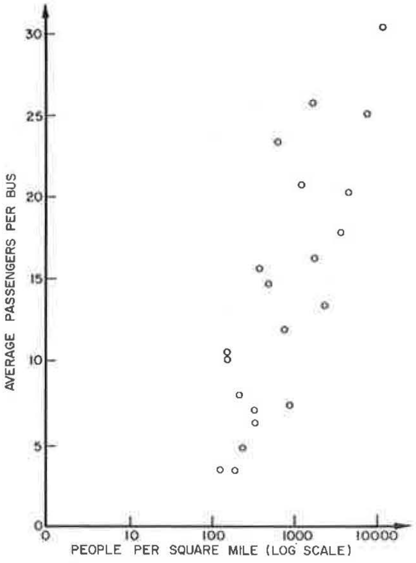
	1970 Energy Saved (percent)		
County	25 Percent More Efficient Car	53 Percent More Efficient Car	53 Percent More Efficient Car With 2 People[a]
Atlantic	23.7	50.4	68.7
Bergen	24.2	51.4	70.6
Burlington	24.8	52.7	72.4
Camden	24.1	51.3	69.6
Cape May	24.8	52.6	72.3
Cumberland	24.9	52.9	72.0
Essex	23.8	50.6	68.7
Gloucester	24.7	52.6	71.8
Hudson	23.3	49.5	65.9
Hunterdon	24.8	52.8	73.0
Mercer	24.7	52.5	71.1
Middlesex	24.7	52.6	72.2
Monmouth	23.7	50.4	69.3
Morris	24.5	52.1	71.9
Ocean	24.5	52.1	71.8
Passaic	24.2	51.5	70.2
Salem	25.0	53.2	71.0
Somerset	25.4	51.6	71.3
Sussex	24.5	52.1	71.6
Union	24.4	51.8	70.6
Warren	24.8	52.7	71.8
Avg	24.3	51.7	70.7

[a] Average.

Table 8. Potential energy savings due to public transit.

County	Energy Saved (percent)			
	10 Percent Shift to Transit, 1970 Load Factor	30 Percent Shift to Transit, 50 Percent Load Factor	50 Percent Shift to Transit, 80 Percent Load Factor	50 Percent Shift to Transit, Use of Small Cars
Atlantic	5.1	28.7	48.0	73.2
Bergen	8.0	26.3	46.4	72.1
Burlington	8.9	26.3	46.3	72.6
Camden	7.7	26.5	46.5	71.9
Cape May	6.0	26.8	46.5	72.8
Cumberland	3.5	26.6	46.3	72.8
Essex	8.3	24.8	45.6	70.9
Gloucester	7.7	26.4	46.3	72.6
Hudson	8.3	24.9	44.0	68.7
Hunterdon	7.0	26.6	46.5	72.8
Mercer	8.3	26.0	46.0	72.2
Middlesex	8.7	25.6	46.0	72.3
Monmouth	5.5	28.6	48.2	73.2
Morris	7.2	26.9	46.2	72.7
Ocean	4.9	27.4	47.0	73.0
Passaic	7.4	26.9	46.7	72.5
Salem	6.8	26.0	45.9	72.5
Somerset	8.4	25.7	46.0	71.8
Sussex	0.8	27.6	47.1	73.2
Union	8.1	26.1	46.2	72.1
Warren	0.6	26.9	46.5	72.9
Avg	8.8	26.5	46.4	72.3

Figure 5. Average public transit load factors versus county population density for New Jersey.



Car Pooling

It is clear that significant energy savings can be achieved through car pooling, especially if smaller automobiles are used. It would seem that this method of energy conservation would have the least impact of all on current life-styles. Current patterns of residence and employment are not affected, and most people could continue to drive larger cars if they preferred. The difficulties with car pooling are several. First, if car pools are to be effective, large numbers of individuals would have to voluntarily agree to car pool since there seems to be slight chance of imposing enforceable and effective car pool regulations. Second, many people do not live close to individuals with whom they share similar work destinations. Third, many people do not find car pooling acceptable because of incompatibility with other riders, lack of privacy, and schedule constraints. Fourth, the energy savings achieved through car pooling may not be extendable to other trip purposes since many other types of trips now have higher automobile occupancy rates and are not amenable to further increases.

On the whole, however, significant energy savings from car pooling could be achieved in relatively short time through incentive policies such as preferential parking, exclusive lanes, reduced tolls, and automobile insurance subsidies.

Automobile Efficiency

Of all policies examined, the most dramatic savings were achieved through increasing the energy efficiency of the automobile. Although most Americans seem to prefer larger cars, this policy seems to offer the least need for readjustment of patterns of living and traveling. Technologically, efficiency increases of the magnitudes used in this analysis are possible today, and some current car models meet the standards of the most efficient automobile tested here. It is certain that the automobile industry would be opposed to regulations requiring smaller, more efficient cars, as might some automobile safety advocates since smaller cars sustain more damage in collisions with stationary obstacles and larger cars. The energy savings, however, are great, and unlike those of car pooling could be extended uniformly to other trip purposes.

To obtain energy savings from small-car ownership, the state would necessarily require rigid automobile efficiency standards or high registration fees for large cars or both. Higher taxes on gasoline would also deter large-car ownership but probably not sufficiently to achieve great savings. Taxes paid at the time of purchase, however, have the effect of stimulating both consumer and producer to alter the sales market for automobiles in favor of smaller cars. In fact, one of the major recommendations of the task force on energy was the restructuring of the present automobile registration fee schedule to encourage the purchase of more efficient automobiles. A formula was developed in which the registration fee for an automobile would be proportional to its weight and engine displacement and inversely proportional to its age and passenger capacity.

Public Transit

Public transit, although much more efficient per vehicle mile (kilometer) than the automobile, could not provide an energy savings comparable to that achieved through more efficient automobiles and car pooling. There are several reasons for this. First, the automobile currently accounts for so large a share of work travel that even slight increases in automobile efficiency or automobile occupancy have a large impact on total energy consumption. Conversely, public transit carries so few riders on work trips that only large increases in ridership have a significant effect in reducing energy consumption. Second, transit load factors are generally quite low, compared to vehicle capacity. Full buses are much more energy efficient than those with only a few passengers. Average load factors depend on a number of characteristics of the system and the region served. Transit routes that pick up large numbers of people at one point and that transport all of them to a common destination will have high load factors. Routes that have many stops and offer frequent service will have lower load factors. Routes that offer frequent service in off-peak hours will also have lower load factors. In general, routes that serve areas of low population density will have low load factors. The relationship between population density and public transit load factors for 1970 is shown in Figure 5. There is a strong correlation between the two measures.

Because of the strong relationship of transit load factors to population density, one may conclude that the greatest energy savings from public transit could be achieved in those counties of greatest population density. Public transit would also be most energy efficient for longer trips between highly concentrated areas.

In recommending improvements to our public transit system to achieve savings in transportation energy, one must quickly point out that such improvements are costly and that provision of transit service is influenced by other factors such as the provision of service to specific social groups, the reduction in congestion and localized pollution, and the stimulation of economic activity. These factors may work to reduce energy efficiency but are often socially desirable.

Trip Length

In this analysis, strategies to reduce trip length were not treated primarily since it is not clear how to achieve this fundamental way of reducing travel. That a great deal of cross-commuting occurs between counties and states leads one to suspect that improvements in dissemination of information on local employment opportunities might help people find jobs nearer their homes. It might also be possible to encourage a more diversified range of housing opportunities in each community so that workers of all classes would have more chance to find housing in the communities in which they work. In the final analysis, the greatest savings that can be achieved require an overall state land use policy that shapes development into higher density clusters rather than continuous low-density sprawl. Higher densities mean shorter trip lengths and greater effectiveness for public transit systems.

Policies With Potential Negative Impact

Two correlated policies frequently mentioned in energy conservation strategies are restriction of urban parking and increased suburban bus service. These policies are singled out here because they may actually lead to increases rather than decreases in long-term patterns of energy consumption. The probable result of disincentives to parking in urban areas will be an increase in the already significant competitive advantage of suburban shopping and employment centers and the long-run encouragement of more dispersed trip patterns. Increased suburban bus service to low-density areas, unless it is carefully planned to ensure high vehicle occupancy, will most likely result in transit service with low load factors and inefficient utilization of energy.

CONCLUSIONS

Based on this analysis of work trip energy consumption, it is clear that New Jersey must adopt a multimodal approach to transportation planning, which stresses the most desirable aspects of each mode. First priority should be given to the implementation of policies designed to encourage the use of smaller, more economical cars. Second priority should be given to the development of public transit in the areas in which it is most effective: high-density urban areas and heavily traveled corridors. In many areas, rail should be given priority over bus, since rail can better serve longer trips and achieve higher loadings. In addition, electrification of rail systems, although it does not significantly reduce energy consumption, will allow future flexibility in choice of fuels, as petroleum resources diminish. Third priority should be given to the reduction of unnecessary travel, possibly in the area of personal use of trucks and other energy-intensive vehicles. Finally, a long-term commitment is needed to the development of coordinated statewide transportation land use planning as the ultimate mechanism for reducing the consumption of transportation energy.

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GASOLINE DEMAND BY OWNER CHARACTERISTICS

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This report is a preliminary analysis of gasoline demand in New York State by automobile-owner characteristics. It establishes a base-year (1971) average weekly gasoline demand for male and female automobile owners ages 16 to 85. This demand is based on vehicle type, percentage distribution in the automobile mix, annual mileage, and fuel economy. The report examines the impact of a 10-gal (38-liter) per-vehicle rationing policy, its effects on owner demand, and possible reductions in fuel consumption that can be expected by increasing the percentage of smaller cars in the automobile mix.

•BEFORE the average weekly gasoline demand can be established, information pertaining to vehicle type, annual vehicle mileage, vehicle type by percentage of the automobile mix by age and sex of the owner, and fuel economy has to be identified. The Vehicle Mileage Exposure Study performed by the New York State Department of Motor Vehicles (NYSDMV) for base year 1971 (1) provided the necessary data. 1971 was relatively free from the influencing market conditions being exerted on consumer demand and driving and purchasing habits because of currently depressed gasoline supplies within the public market. The exposure study provided information regarding vehicle type and annual vehicle mileage by age and sex of the registered owner. Subsequent correspondence with NYSDMV provided information for 1971, relating vehicle type by age and sex to the total number of registered vehicles in the automobile mix. Information pertaining to fuel economy in miles per gallon (kilometers per liter) for various model years and inertia weight classes was obtained from A Report on Automotive Fuel Economy (2). Classification of vehicles on the basis of inertial weight was available from weight figures in the National Automobile Dealers Used Car Guide (3).

PROCEDURE

So that the data (1, 2, 3) can be applied to the analysis of gasoline demand of vehicles, several assumptions are required:

1. The vehicle mileage is attributable to the registered owner;
2. There are no identifiable differences in an individual's physical driving habits resulting from ownership of different vehicle types;
3. Variation in driving habits exists only between age groups;
4. All computations refer to the average vehicle driven by the average owner-operator within each age group; and
5. No distinctions will be made among the various grades of gasoline, driving conditions, and urban or rural locations.

Table 1 gives the line models for the various vehicle types that are to be considered based on 1971 data. The various vehicle types given distinguish themselves by their

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actual weight rather than by their common vehicle descriptions. This is particularly important as manufacturers begin changing vehicle descriptions in their shift to smaller cars. For example, today's full-sized luxury vehicle weighs 5,500 lb (2495 kg); however, several years from now it may weigh only 3,500 lb (1588 kg), be twice as economical, and continue to be referred to as a full-sized luxury vehicle. Similarly, future intermediate vehicle types may refer to vehicles in the compact or subcompact range today. Table 2 gives the fuel economy in miles per gallon (kilometers per liter) for various model years and inertial weight categories. The fuel economy data given in Table 2 may in certain cases vary with the fuel economy obtainable under actual operating circumstances. However, in view of the consistent and uniform methodologies applied by the Environmental Protection Agency in the calculation of fuel economy for all vehicle types, these figures are equitable for comparative purposes.

In the calculation of fuel economy for each vehicle class, consideration was given to the representation of vehicles older than model year 1971 in the stratification of the automobile mix. Based on the New York State vehicle-age percentage distribution of registered vehicles by vehicle mileage (4) and the values of fuel economy for each model year before and including 1971, a corrected vehicle class fuel economy value was obtained. The difference between this corrected value and the value for model year 1971 was marginally significant. Therefore, values of fuel economy for model year 1971 are used in all calculation in this paper.

Table 3 gives the percentage distribution for males and females respectively by age of the owner for automobile ownership of the various vehicle types in the automobile mix (2). Vehicle type is also given as the percentage of the whole automobile mix, and age group ownership is given as the percentage of all cars owned.

It should be noted that there are only seven types of vehicle classification in Tables 3 and 4. This results from the combination of the subcompact and foreign vehicle categories, since their inertial weight and fuel economy, as given in Table 2, are both the same. This combined category is labeled subcompact vehicle type in these tables.

Table 4 gives the average annual vehicle mileage for the seven vehicle types, stratified by age group for both male and female owners. Since the average annual vehicle mileage data (1) by sex did not distinguish between the three types of full-sized automobiles (low, medium, luxury), the annual vehicle mileage for the Monte Carlo was selected to represent the full-sized, low-priced category, the annual vehicle mileage for the Chevrolet was selected to represent the full-sized, medium-priced category, and the annual vehicle mileage for the full-sized, luxury category was based on an extrapolation of the vehicle mileages for the other vehicle types and the average group annual vehicle mileage.

Using the data mentioned (1, 2, 3), two methods were examined for the calculation of weekly gasoline demand. The first method could be called the disaggregate approach, and the second could be called the aggregate approach. In the first method, the individual average annual mileages for each vehicle type within an age grouping are used for determining the gasoline consumption rates for male- and female-owned automobiles. This procedure is as follows:

$$\text{Miles per week } (j) = \frac{\sum_{i=1}^{7} \text{PDF ji} * \text{AAM ji}}{52} \tag{1}$$

$$\text{Gallons per week } (j) = \frac{\sum_{i=1}^{7} \frac{\text{PDF ji} * \text{AAM ji}}{\text{MPG i}}}{52} \tag{2}$$

Table 1. Line models for various automobile types.

Specialty	Sub-compacts	Compacts	Foreign	Intermediate	Full-Sized, Low-Priced	Full-Sized, Medium-Priced	Full-Sized, Luxury
AMX	Gremlin	Chevy 2	Datsun	Belvedere	Ambassador	Buick	Cadillac
Barracuda	Pinto	Corvair	Fiat	Buick Special	Chevrolet	Chrysler	Imperial
Camaro		Dart	Jaguar	Chevelle	Dodge	Mercury	Lincoln
Challenger		Falcon	MG	Classic	Ford	Oldsmobile	
Corvette		Hornet	Mercedes	Comet	Fury	Pontiac	
Cougar		Maverick	Opel	Coronet	Monte Carlo	Toronado	
Firebird		Rambler American	Peugeot	Fairlane			
Javelin		Valiant	Renault	F-85			
Mustang			Saab	Marlin			
Thunderbird			Simca	Montego			
			Toyota	Rebel			
			Triumph	Tempest			
			Volvo				
			Volkswagen				

Table 2. Automobile type, inertial weight, and average mileage per gallon (kilograms/liter).

Vehicle Type	Inertial Weight (lb)	Avg Miles per Gallon
Specialty	3,500	12.2
Foreign	2,250	21.4
Subcompact	2,250	21.4
Compact	3,000	14.8
Intermediate	3,500	12.2
Full-sized, low-priced	4,000	11.7
Full-sized, medium-priced	4,500	10.7
Full-sized, luxury	5,000	9.6

Note: 1 lb = 0.45 kg, 1 mile/gal = 0.43 km/liter.

Table 3. Percentage distribution for male and female automobile ownership by automobile type and age of owner.

Automobile Owners		Automobile Type							
Sex	Age Group	Special	Sub-compact	Compact	Inter-mediate	Full-Sized, Low-Priced	Full-Sized, Medium-Priced	Full-Sized, Luxury	All
Male	16 to 20	23.6	1.2	14.2	35.4	20.2	5.27	0.2	0.7
	21 to 30	17.8	1.0	13.3	35.2	21.0	10.3	1.5	15.0
	31 to 40	7.3	0.5	10.4	26.6	33.2	18.5	3.4	19.4
	41 to 50	6.3	0.4	9.8	23.4	34.4	21.3	4.3	24.5
	51 to 60	6.3	0.4	10.6	24.6	31.4	22.0	4.7	22.8
	61 to 85	3.6	0.2	13.4	26.3	28.4	22.3	5.9	17.6
	All	7.9	0.5	11.3	26.7	30.3	19.2	4.1	
Female	16 to 20	24.9	3.2	21.9	28.9	16.5	4.3	0.4	0.9
	21 to 30	21.2	1.6	19.1	32.3	17.1	7.6	1.2	20.6
	31 to 40	9.6	0.7	14.4	27.7	28.7	15.7	3.2	16.5
	41 to 50	9.3	0.6	14.8	27.8	27.1	16.7	3.7	23.0
	51 to 60	7.7	0.4	16.7	30.0	24.9	16.7	3.9	22.5
	61 to 85	3.8	0.2	22.0	31.3	22.5	15.8	4.5	16.6
	All	10.7	0.7	17.3	30.0	24.0	14.4	3.3	

Table 4. Average annual mileage for male and female automobile ownership by automobile type and age of owner.

Automobile Owners		Automobile Type							
Sex	Age Group	Special	Sub-compact	Compact	Inter-mediate	Full-Sized, Low-Priced	Full-Sized, Medium-Priced	Full-Sized, Luxury	All
Male	16 to 20	14,436	14,145	13,300	12,114	11,035	13,759	15,235	13,432
	21 to 30	12,735	13,355	12,753	12,425	14,362	12,503	10,123	12,608
	31 to 40	11,463	11,764	10,953	11.145	12,932	11,674	10,485	11,488
	41 to 50	11,362	12,179	10,982	11,122	13,116	11,805	10,921	11,641
	51 to 60	10,613	11,376	10,130	10,409	10,975	11,165	11,800	10,924
	61 to 85	9,989	9,535	7,452	7,981	10,159	9.250	7,087	8,779
	All	11,725	12,091	10,232	10,718	12,544	11,263	9,575	11,164
Female	16 to 20	12,302	13,473	11,832	12,199	14,164	11,769	11,061	12,400
	21 to 30	11,223	11,742	10,857	11,024	12,397	11,705	10,124	11,296
	31 to 40	9,961	10,385	9,293	9,960	12,151	11,238	10,554	10,506
	41 to 50	11,031	11,333	9,773	9,826	13,016	11,165	8,644	10,684
	51 to 60	10,060	10,322	8,376	8,692	10,637	9,892	7,821	9,400
	61 to 85	8,105	7,309	5,781	6,242	7,506	7,732	5,317	6,856
	All	10,795	10,948	8,715	9,284	11,113	10,370	8,376	9,943

Note: 1 mile = 1.6 km.

$$\text{Miles/gallon } (j) = \sum_{i=1}^{7} \frac{\text{PDF } ji * \text{AAM } ji * \text{MPG}i}{\sum_{j=1}^{7} \text{PDF } ji * \text{AAM } ji} \qquad (3)$$

where

i = vehicle type,
j = age group,
PDF ji, PDF ji = percentage distribution of the seven vehicle types in the automobile mix (Table 3),
AAM ji, AAM ji = individual average annual mileage for each vehicle type within an age grouping (Table 4), and
MPG i = average fuel economy in miles per gallon (kilometers per liter) for each vehicle type (Table 2).

In the case of the second method, the average mileage for all vehicle types within an age group is used for determining the gasoline consumption rates for male- and female-owned cars. This procedure is almost identical to the previous procedure, except that the individual average annual mileage for each vehicle type within an age grouping (AAM ji) is replaced with the average age group mileage AAGM j (last column, Table 3).

For the purpose of this paper, the first method is used exclusively. However, during this analysis, it was necessary to determine the accuracy of the second method in the event that a stratified automobile mix would not be available for the analysis of fuel consumption in years after 1971. The use of the average annual vehicle mileage for all vehicles in the automobile mix proved to be representative of the mileage of the automobile mix when the individual vehicle types were taken into consideration. This indicated that, for the purpose of calculating fuel consumption and economy, the average annual vehicle mileage when weighted by the number of vehicles in each class is a reasonable approximation of the mileage for all vehicles in the automobile mix.

The calculation of miles per gallon (kilometers per liter) for each age class, as represented by equation 3, is much more sensitive to changes in the automobile mix than is an equation for miles per gallon (kilometers per liter) based on equation 1 divided by equation 2. As a result, it is possible to obtain the value of gasoline consumption in gallons (liters) per week in two ways: (a) by calculating it from equation 2 and (b) by dividing equation 1 by equation 3 (for this paper, mileage is the given). The difference between the two values of gasoline consumption is due to the differences in equations 2 and 3. Equation 3 is weighted to best reflect the economy of scale, that is, the economy due to the percentage of the market occupied by a particular vehicular type. Equation 2 is based on the relative empirically determined fuel economy of each vehicle type in miles per gallon (kilometers per liter) and the relative proportional annual mileage. Both of these fuel consumption values are given in Table 5.

DEMAND CHARACTERISTICS

The results of the calculations based on equations 1, 2, and 3 are given in Table 5, which contains the average weekly mileage, fuel consumption rates, and the relative miles per gallon (kilometers per liter) in fuel economy for each age group.

Table 5 clearly indicates that gasoline demand in terms of the average number of gallons (liters) consumed by the automobile on a weekly basis decreases as age of the owner increases. This is because, annually, fewer miles are driven. Gasoline consumption in general is lowest for cars driven by females and by the 51 to 60 and 61 to 85 age groups. This second observation is understandable since most people stop driving automobiles during these years. There is one exception, however, and it is in the 16 to 20 male age group when the calculation is done with equation 2. In this instance, cars driven by males have a lower gasoline consumption rate than those driven by females. This may, in part, be due to the higher insurance risk grouping for young male drivers, which tends to discourage vehicle registrations at such a young age. Since the data used in calculating Table 3 are based on the number of registrants by vehicle type, age, and sex, it is quite possible that cars driven by males may actually have a high consumption rate but that their cars are registered in their parents' or guardians' names.

For the cars driven by the 21 to 50-year-olds, gasoline demand is high and relatively constant in terms of the number of gallons (liters) consumed each week. Furthermore, there is a definite upward trend in car ownership from the compact to the full-sized car. This trend in increasing car size with increasing age also continues into the 61 to 85 age group (Table 3). This trend more or less parallels family growth (and increasing affluence) in the middle years when the need for a larger car in which to drive the family around becomes a predominant factor in vehicle selection. This, coupled with the possible retention of an older or the addition of a smaller, more economical car, might explain the relatively constant consumption rate for ages 21 to 50.

Gasoline demand is generally lower for women than for men, and, similarly, fuel economy is generally higher for cars driven by women than for cars driven by men. This is partially explainable by the data in Table 3. It is apparent that women tend to purchase and own a greater percentage of the more economical, compact, and subcompact automobiles than men. The trend also follows for young people in general. Similarly, the trend to move up to a bigger and heavier vehicle type is not as pronounced for women as it is for men. This again concentrates ownership of more economical vehicles among women.

IMPACT OF RATIONING POLICY ON GASOLINE DEMAND

The nature of the gasoline demand discussed so far has been examined only in terms of identifiable trends, relating age, sex, and vehicle preference based on registration to gasoline consumption on a weekly basis. Because of the imminence of nationwide gasoline rationing, various rationing schemes had been proposed. In view of this, it was necessary to examine the existing data on gasoline demand to determine whether gasoline rationing would possibly impact one automobile-owner age group more severely than another.

The gasoline requirements of 1971 (Table 5) indicate that for cars owned by males aged 16 to 50 demand is at a reasonably constant average of 19 gal (72.2 liters) per week (no distinction is made among the various grades of gasoline available). However, this demand significantly decreases from 19 gal (72.2 liters) per week for male owners aged 51 to 60 to a low of 14 gal (53.2 liters) per week for male owners aged 60 and above. Similarly, gasoline demand for female owners is approximately 2 to 3 gal (7.6 to 11.4 liters) per week less than that for male owners at all ages. Obviously, any gasoline rationing plan advocating allotments on the order of 10 gal (38 liters) per week (such as those proposed during the midst of the fuel crisis) would severely restrict automobile use and availability to most owners in their principal earning years, ages 21 to 50. It would not, however, really impose any severe hardship on those 60 and older (assuming of course that the registered owner is the only driver of the vehicle).

Monthly average daily vehicular travel counts (recorded at continuous counting stations throughout New York State) were compared with those of the previous year to measure the margin of excess driving that had been eliminated as a result of voluntary conservation on the part of the public. During February 1974, when the impact of the gasoline shortage was at its worst, the value for the average daily vehicular travel in New York State indicated a 14.2 percent decline from the previous year. This decline, when applied to a gasoline demand of 19 gal (72.2 liters) per week, represents a reduction in demand of 2.7 gal (10.2 liters) of gasoline per week for the average owner. Even with this reduction, demand is still much above a proposed rationing level of 10 gal (38 liters) per week.

Table 5. Miles (kilometers) per week, gallons (liters) per week, and miles per gallon (kilometers/liter) for males and females by age of owner.

Automobile Owners		Miles per Week	Gallons per Week[a]	Gallons per Week[b]	Miles per Gallon
Sex	Age Group				
Male	16 to 20	206.26	13.88	19.75	14.86
	21 to 30	249.55	20.23	20.47	12.33
	31 to 40	227.35	19.01	19.20	11.96
	41 to 50	229.83	19.36	19.57	11.87
	51 to 60	207.73	17.52	17.72	11.86
	61 to 85	169.88	14.30	14.46	11.88
Female	16 to 20	239.38	18.61	18.97	12.86
	21 to 30	217.69	17.29	17.54	12.59
	31 to 40	206.07	17.03	17.24	12.10
	41 to 50	210.13	17.35	17.66	12.11
	51 to 60	180.80	14.88	15.02	12.15
	61 to 85	95.32	7.81	10.59	12.21

Note: 1 mile = 1.6 km. 1 gal = 3.8 liters. 1 mile/gal = 0.43 km/liter.

[a] Calculated with equation 2. [b] Calculated with equation 3.

Table 6. Observed distribution of New York State automobiles by weight class.

Item	Sub-compact	Compact	Intermediate	Standard, Full-Sized
Current 1971[a]	0.0060	0.1438	0.3748	0.4765
DMV 1980 forecast	0.15	0.20	0.30	0.35
Ad hoc committee 1980 estimate				
Low	0.30	0.20	0.25	0.25
High	0.35	0.25	0.25	0.15
Empirical vehicle fuel economy (Table 2)	21.4	14.8	12.2	10.67

[a] Calculated from Table 3 by a weighted percentage distribution based on the combined male and female distributions and, when necessary, consolidated into the above categories on the basis of fuel economy.

Table 7. 1980 market changes in consumption and economy.

Item	Fuel Economy (miles/gal)	Gallons per Week
Current 1971	11.84	18.15
DMV 1980 forecast	13.64	16.58
Ad hoc committee 1980 estimate		
Low	15.29	15.33
High	16.07	14.47

Note: 1 mile/gal = 0.43 km/liter. 1 gal = 3.8 liters.

In addition to an examination of the measure of excess driving that in part makes up gasoline demand, the overall shift to smaller cars and its subsequent effect on this demand had to be estimated. As such, the data for 1971, on which the analysis in this paper has been based, provide the necessary starting point to observe the changing trend in consumer preference for smaller or just plain economical automobiles. An analysis of vehicle registration at this time indicates that the percentage of subcompact cars within the entire automobile mix is relatively small, since the impact of the subcompact car (or the most economical car) is not yet significant enough to be reflected in relative gasoline consumption. Therefore, if we assume that the shift toward more economical cars has been accelerated because of the psychological impact of the severity of a reduced gasoline supply, then we must recognize that this shift will also impact the used-car market and the 13-year automobile life cycle to the extent that the larger, less economical automobiles will be forced out of the market at an earlier date. This would then raise the relative fuel economy of the automobile market as a whole, since people would become more selective in their used-car purchases.

To estimate what the probable change in gasoline demand could be, the Ad Hoc Committee on Energy Efficiency in Transportation estimates for the 1980 automobile distribution were used (Table 6) (5). These distributions were analyzed to determine the probable reduction in gasoline demand resulting from increases in the percentage of economical vehicles making up the market distribution (Table 7). The results indicate, that if the number of economical vehicles registered in 1980 were to significantly increase to represent 30 percent of the total automobile mix, then the corresponding effect on gasoline consumption would be equivalent to a 20 percent reduction in the current (1971) weekly gasoline demand. However, this observation is based on two assumptions:

1. The annual mileages for each of the following vehicle categories remain consistent with those previously observed (1 mile = 1.6 km):

Automobile Type	Mileage
Specialty	10,991
Foreign	11,602
Subcompact	13,004
Compact	9,912
Intermediate	10,781
Full-sized, low-priced	11,591
Full-sized, medium-priced	11,306
Full-sized, luxury	11,354

2. The economy for all the vehicle types remains the same as that observed in 1971. (Based on the procedures discussed in this paper and the average annual mileages above, a similar analysis can be done for the four vehicle categories. These mileage values are used for Table 7 since stratification of the automobile mix by age and sex is not required. When necessary, the categories above were combined into the four categories of Table 6 on the basis of fuel economy, and a corresponding average mileage and average fuel economy were then used. The net predicted market changes in consumption and economy are given in Table 7.)

As such, the predicted change in consumption depends on whether energy conservation as observed during the crisis (1973-1974) will continue or will yield to the wasteful driving habits previously in existence when gasoline supplies return to normal. In addition, automobile efficiency has continually declined as automobile emission controls have increased.

Therefore, if a 14.2 percent reduction in vehicle travel due to conservation efforts were to be experienced in 1980, in addition to the estimated change in vehicle distribution, a reduction of 34.2 percent in the 1971 gasoline demand would result. This reduction would make the weekly gasoline demand for male owners aged 21 to 50 about 12 gal (45.6 liters) per week or just slightly above the 10 gal (38 liters) given as a proposed rationing level.

CONCLUSIONS

The analysis of gasoline demand in New York State and the relative impact of a nationwide gasoline rationing policy on that demand serve to emphasize the seriousness of an energy shortage in the private transportation sector. As such, the following observations can be made relating owner characteristics based on present gasoline demand and the effects of rationing and changes in the automobile mix on that demand.

1. Gasoline demand decreases as owner age increases and as annual mileage decreases.
2. Gasoline demand is lower for women than for men because women have a greater preference for smaller, more economical compact and intermediate vehicles. Similarly fuel economy is higher for cars driven by women than for those driven by men.
3. The trend to purchase larger, heavier, and consequently more expensive vehicles and a relatively constant rate of gasoline demand are most pronounced in the 21 to 50 age group. This trend parallels the period of increasing family size and financial security when the need for a large car or second car exists.
4. Subcompact and foreign cars are clearly more economical than the other vehicles. They travel in excess of the average annual mileage for the entire automobile mix. However, they are present in too small a proportion of the total automobile mix (in 1971) to have a significant impact on the reduction of the gasoline market demand and fuel economy at this time.
5. Based on estimates of future automobile mixes, an increase in the proportions of more economical automobiles to 30 percent of the automobile mix (with the economies of all other vehicle types remaining the same) would yield a 20 percent reduction in market gasoline demand.
6. Based on current (1971) estimates for gasoline demand, a 10-gal (38-liter) per-week, per-vehicle rationing scheme would most severely impact owners in the 21 to 50 age group. Assuming no reductions in vehicular travel through public conservation efforts, demand would exceed the allotted supply by a ratio of 2 to 1. Given the maximum reduction in vehicular travel, as observed during February 1974, demand would still exceed the allotted supply by a somewhat lower ratio of 1.5 to 1. If the present vehicle distribution were to be equivalent to that expected for 1980, where the percentage of subcompact cars represents 30 percent of the market distribution, then the ratio of demand to supply would be just slightly greater than 1 to 1.

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GASOLINE USE BY AUTOMOBILES

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This paper describes research on the demand for gasoline by automobile drivers. It discusses the relationship between the ownership of and the use and fuel consumption of automobiles. In view of the difficulty in relating behavioral hypotheses about individuals and households to aggregate data, the intricacies of the new- and used-automobile markets are presented. Aggregate gasoline demand models are reviewed and, where available, short-run price elasticities of gasoline are given. Variables, functional forms, and levels of aggregation are indicated. A method of integrating time-series and cross-sectional automobile data and a hypothesis about the prices of services of different sorts of automobiles are discussed. Two other models that simultaneously treat the demand for automobiles and gasoline are reviewed: They are based on (a) the different size classes of new automobiles and aggregate automobile travel as the jointly dependent variables and (b) the new- and used-car markets and aggregate automobile travel as the interrelated entities. These models used only annual data at the national level. Our empirical analysis consists of a single equation model for which the dependent variable is per capita gasoline consumption. The predetermined set includes a lagged dependent variable, demand for new automobiles, deflated gasoline price, and gasoline consumption per automobile at the annual and national levels. Some alternate forms of the hypotheses are given, and the results of estimation are presented and compared. The most reasonable specification produces a short-run gasoline price elasticity estimate of -0.23, a result midway among those of other investigators who have based estimated elasticities on similar data sets.

•ONLY recently has there been interest in modeling gasoline consumption as a consumer product. Most attempts to model gasoline consumption have ignored or have lightly treated possible adjustments in ownership, purchase, and use of automobiles. Similarly, past attempts to model automobile ownership or purchases over time (or over cross sections) have mostly ignored the influence of gasoline price or gasoline consumption as determinants.

This paper surveys some of the recent work on gasoline demand and draws on the literature on automobile demand to suggest the beginning of an integrated theory. Then a gasoline demand equation is formulated and estimated with annual national time-series data for the United States. The results are subjected to formal statistical tests and somewhat more subjective tests of economics and common sense. The preferred specification is used to forecast for 3 years past the estimation period.

Balestra and Nerlove (2) point out the following in their original study of the demand for natural gas:

> While it is true that natural gas is not a durable commodity, i.e., a commodity that is enjoyed repeatedly over a length of time or that may be stored for future use, yet it is also true that the consumption of gas, at least at the household level, is closely related to the stock of gas appliances in existence, and that to a large extent it is governed by such stocks.

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In this sense, gasoline and automobiles are analogous to natural gas and gas appliances. Models that posit that either gasoline consumption or automobile use (similar entities in the aggregate) is determined by gasoline prices or other costs of automobile use are intuitively more palatable than those that ignore the gasoline and other cost of using automobiles.

Having ownership of or access to a gas appliance or an automobile is a necessary prerequisite for its use. The link between fuel consumption (the flow) and the ownership or availability of the durable (the stock) is use. As overall use is changed, fuel consumption changes for a fixed stock of durables. In the shortest time frame for which measurement of fuel consumption is meaningful, little change may be observed in the stock of durables. In such a short term, the effect of a change in the price of fuel is translated primarily into changes in the use of the existing stock of durables. Moreover, since ownership costs are incurred in the purchase of a durable, it is difficult for the consumer to revise choices once the choice is made: Buying, selling, and moving costs, which together make up the transactions or transfer costs of conversion, are too great. Because plans involving the use of durables, such as gas appliances for home heating and automobiles for commuting or business purposes, are relatively inflexible in the short term, a very low short-run price elasticity for these fuels is expected.

But as the time period considered gets longer, the available options expand. Not only can people change their uses of durables, they can exchange the durables for others. In the case of used gas appliances, the market is not interesting. In the case of automobiles there is an active market; it is rather well organized for cars from 1 to about 6 years of age. (The markets for cars less than 1 or more than about 6 years old are small and do not provide much useful information.) The structure of equilibrium prices for used cars provides much data on absolute and relative prices among makes, models, vintages, and among cars with different optional equipment. These data can be supplemented with information on physical attributes and performance characteristics. Such data sets have been used by economists to construct hedonic price indexes from which hypotheses on quality change, on depreciation, and on value differences among cars of different models or vintages can be tested (7, 14).

The decision to purchase a durable differs somewhat from that for the typical nondurable commodity. The usual analysis of a nondurable deals with the purchase and consumption (or the using up) of the commodity in question. But a durable, by definition, lasts for a long period; only its services are consumed during the demand period. The purchase is more of an investment, but investment in a durable, such as a house or a car, is not a business investment, pure and simple. The person may use the durable good for business purposes or for personal satisfaction. For a given level of quality or usefulness, the person may wish to minimize expenditure on such services. In this sense, consumer decisions on durables may be analogous to business investment decisions where the owner of the business chooses to invest capital to maximize profits. Wykoff (19) uses a variant of investment theory in the study of demand for automobiles. A major distinction of Wykoff's analysis is that the relevant price to be considered is the user cost of capital services, which is defined, relative to some time period, as the price of an asset at the end of the year less its price at the beginning plus the opportunity (interest) cost of the value of the capital (money) tied up for a year in the asset. [The recent popularity of this concept in investment theory is due to the work of Jorgenson and others (8, 10, 11, 12).] Wykoff's study goes part way in incorporating the user cost concept into automobile demand analysis. However, his equations include neither the price nor the demand for gasoline, nor do they reflect a personal decision on minimizing or optimizing expenditure for automobile purchase.

Study of cross-section information would be desirable for the formulation of a model based on comprehension of automobile purchase and gasoline consumption behavior. People in different geographic areas and of different physical and socioeconomic levels probably have different needs for automobile services. Farrell (5) has used data on automobile ownership by vintage of car to estimate automobile ownership by household income class. He did not use automobile prices, automobile maintenance costs, or gasoline prices in the cross-section analysis; he used income data to estimate automobile vintage for different income classes of urban families. Then, in a later stage, he inserted his cross-sectional results into a time-series model that estimated a price index for each vintage. Time-series data on income and on prices and numbers of cars owned by vintage were used.

Based on procedures analogous to those used by Farrell (5), it would be possible to explore hypotheses about automobile purchases, ownership, and use for a cross section. However, in the present context, the questions of most interest are those centered on gasoline consumption and automobile size or fuel economy class. No one has addressed these below the state level of aggregation, and cross-sectional or panel data for households are sparse in regard to automobile ownership by make, model, vintage, and in regard to automobile use and gasoline consumption.

Most of the recent studies of gasoline demand use time-series data. A few of these have followed the lead of Balestra and Nerlove (2), who pooled cross-sectional and time-series data at the state level. There have been many more time-series and cross-sectional studies of automobile purchase or ownership. Only two of these have been at all concerned with gasoline price or consumption.

The gasoline consumption models surveyed in the next section and my model suffer from a common flaw: None considers a level of aggregation below the state level. State data do not display much less homogeneous behavior than national data. I have not attempted to extend the work to the quarterly time period or state level because it is not immediately obvious how to disaggregate some of the variables and, more important, because it is also not clear what would be gained from a behavioral standpoint. There would be some statistical gain from an increased sample size, but moving from annual and national to quarterly and state data appears to be going from one crude aggregate model to another crude aggregate model.

GASOLINE DEMAND STUDIES

Recently, because of gasoline shortages, there have been two sorts of studies focusing on gasoline and automobile demand. One is concerned with only the gasoline price elasticity or the forecasting of gasoline consumption; the other centers on the automobile market and concentrates either on vehicle efficiency or on the model mix. (Model has usually referred to five standard market classes based mostly on size and price and a catch-all category, i.e., subcompact, compact, intermediate, standard, luxury, and specialty; however, a new classification is reportedly in the making.)

Gasoline demand has been studied by the Federal Energy Office (16). This model is specified as both monthly and quarterly equations of gasoline demand as a function of gasoline price, personal income, a weather variable (15-year average of national monthly degree days), demand for gasoline in July 1973, and dummy variables for February, March, September, and December. These equations were estimated and used in forecasting. No elasticity analysis is presented in the source report.

Houthakker, Verlager, and Sheehan (9) used a model similar to that of Balestra and Nerlove (2) in the study of natural gas demand. The equation, which was estimated from pooled cross-sectional (state) and time-series (quarterly and annual) data, contains real price, real disposable income per capita, and lagged gasoline consumption. Real, as it applies to real price, means deflated by dividing by the consumer price index (CPI). A slightly more sophisticated way to deflate is to subtract the gasoline component and recalculate an adjusted CPI. For the period examined, the difference between the two was miniscule; therefore, the recalculated CPI was not used. Lagged gasoline consumption is the result of a simple assumption about the relationship between gasoline consumption and automobile ownership, namely that they are proportional and that the constant of proportionality is invariant over time. The short-run price elasticity of demand for gasoline derived from a logarithmic specification of the model is -0.075.

Two models are currently being estimated (18), one of which will be described below. The other, which estimates only a single equation, is for gasoline consumption per capita. Independent variables include real gasoline price, real disposable income per capita, vehicle stock per capita, average vehicle efficiency, and urbanization level.

The observational unit is the state for a given year so that the time-series and cross-sectional data are pooled. Notice that vehicle efficiency and stock are considered exogenous; interestingly, they are treated as endogenous in the other Rand Corporation modeling. The range of short-run price elasticities [annual as opposed to the estimate of Houthakker, Verlager, and Sheehan (9), which was quarterly] for the single equation model was -0.10 to -0.18.

The Federal Highway Administration has estimated a model in which the dependent variable was per capita gasoline consumption (6). The independent variables were real gasoline price and real per capita disposable income. The data were annual time series for several European countries, Canada, and the United States. The price elasticity estimate for the United States equation was 0.364, a counterintuitive sign, but the (null) hypothesis that the coefficient was not significantly different from zero was not rejected. A revised equation using lagged gasoline consumption and a linear specification yielded a short-run price elasticity for the United States of -0.041, which was again not significantly different from zero by the t-test criterion used.

The Transportation Systems Center of the U.S. Department of Transportation has used the FHWA data in estimating some new equations (3). In the first formulation, gasoline consumption was assumed to be a linear function of vehicle efficiency, real income, real gasoline price, lagged gasoline consumption, and the real price of automobiles. Since vehicle efficiency and the price of automobiles enter the equation, it could be considered as a reduced form equation of a more comprehensive structural form involving automobile ownership adjustments; however, the rationale for including them is not made explicit in the paper. The short-run price elasticity was estimated as -0.06, but with a low or marginal t-value. The European data collected by Fields, Nolan, and Miller (6) were also pooled without the American observations, and a linear model of gasoline consumption as a function of price, real income, and lagged consumption was estimated from this data base. The short-run price elasticity was estimated as -0.12 with a marginal t-value.

Two other efforts deserve special mention. Both of these focus on the automobile market rather than directly on the gasoline market. Both use national data to understand the relationships between the demand for new automobiles and gasoline. The first effort considers new and used automobiles; the second looks at the size classes of new automobiles. Both employ an automobile use variable, miles (kilometers) traveled. Gasoline consumption is calculated from information on fuel economy in miles per gallon (kilometers per liter) and automobile miles (kilometers) traveled.

The Rand Corporation developed the single-equation, gasoline consumption model discussed previously and a five-equation (recursive) model. The dependent variables in this recursive model are, in order of introduction, used-car price, new-car demand per household, used-car ownership per household, vehicle efficiency in miles per gallon (kilometers per liter), and vehicle miles (kilometers) traveled per household, which is then translated into gasoline demand per household. The variables used in the five equations are as follows:

1. Real new-car price, real gasoline price, real permanent income, lagged automobile stock per household, and a strike dummy;
2. Real used-car price, real new-car price, income divided by lagged income, and a strike dummy;
3. Real new- and used-car prices, real gasoline price, real income, and a strike dummy;
4. Real gasoline price and a regulatory dummy for whether the year was before 1968 or not; and
5. Real gasoline price, new plus used automobiles, and a regulatory dummy.

The data are annual time series for the nation. The estimate of direct price elasticity for vehicle miles (kilometers) traveled (VMT) was -0.37. The overall gasoline price elasticity was estimated to be -0.83 for the first year and -0.92 for the long run. This elasticity includes effects of price on miles per gallon (kilometers per liter) and automobile ownership as well as automobile miles (kilometers) traveled.

Chase Econometric Associates (4) have also developed a model for gasoline consumption. The model is a seven-equation system designed to forecast new-automobile sales (disaggregated into the six size and price classes previously mentioned) and gasoline consumption. The dependent variables are total new-car registrations, new-car sales in the five separate market classes (excluding the specialty class), and total VMT. Gasoline consumption is then calculated, after some assumptions about sales-weighted fuel economy are made for the classes of automobiles. The variables used in the seven equations are as follows:

1. Real disposable income, unemployment rate, a strike dummy, stock of passenger cars on a new-car equivalent basis, index of credit rationing, gasoline real price index, a dummy for investment tax credit, and a price index for new cars;
2. Unemployment rate and a gasoline price index;
3. Unemployment rate, sales-weighted fuel economy for compact cars relative to all cars, real gasoline price index, and a trend dummy;
4. Sales-weighted fuel economy for intermediate cars relative to that for subcompact cars, a trend dummy, a real gasoline price index, and sales-weighted intermediate car price relative to standard price;
5. Sales-weighted standard car price relative to that for all cars, real gasoline price index, unemployment rate, and a trend dummy;
6. Unemployment rate and sales-weighted luxury car price relative to that for all cars; and
7. Automobile ownership, real gasoline price index, wage and salary component of real personal income, average price of new cars, and change in the consumer price index for all goods and services.

The second through sixth equations represent a system of equations for forecasting market shares of the different size and price classes. The variables used imply that a considerable amount of trial and error led to the final equations. The variable VMT is, therefore, the one through which gasoline price elasticity is felt. The gasoline price elasticity of VMT was calculated to be -0.5, and the gasoline price elasticity of new-car purchases was calculated to be -0.8. There is no obvious way to summarize the effects of gasoline price on market shares or on fuel economy per vehicle, since they are buried in the interrelationships of the model.

DEFINITIONS AND SOURCES

The following definitions and sources are used in this paper:

G_t = passenger-car gasoline consumption, per capita, in gallons (liters), in year t; derived by dividing total passenger-car gasoline consumption by total resident population.
Gasoline consumption: Federal Highway Administration (17). Includes taxis, motorcycles, and van vehicles (when they are for private use) as passenger cars. Prior to 1960, figures for Alaska and Hawaii were excluded.
Resident population: U.S. Bureau of the Census (15, Table 2). Excludes U.S. Armed Forces abroad and includes foreign nationals residing in the United States. Figures include Alaska and Hawaii.
G_t^* = new-car gasoline demand, per capita, in gallons (liters) in year t.
A_t = total passenger cars registered, per capita, in automobiles, in year t; derived by dividing total passenger-car registrations by total resident population.
Passenger-car registrations: U.S. Bureau of the Census (15), Federal Highway Administration (17). Figures include taxis and publicly owned vehicles and are compiled for the calendar year. Prior to 1960, figures for Alaska and Hawaii were excluded.
A_t^* = new-passenger-car registrations, per capita, in automobiles, in year t;

derived by dividing new-car registration by total resident population.
Marketing Services Inc. (13).

λ_t = average gasoline consumption per automobile, in gallons (liters), in year t; derived by dividing total passenger-car gasoline consumption by total passenger cars registered.

P_{gt} = price of gasoline, deflated, in year t; derived by dividing price of gasoline by CPI for all items, in cents.
Price of gasoline: American Petroleum Institute (1). Prices are for regular-grade gasoline per gallon (liter) and include local, state, and federal taxes.
CPI: American Petroleum Institute (1).

r_t = retirement rate of automobiles in year t; derived by dividing the number of automobiles scrapped in year t by cars in use on January 1 of year t.
Marketing Services, Inc. (13). From 1965 on, figures were adjusted by subtracting out those trucks that had been issued passenger-car license plates.

V = automobile miles (kilometers) traveled for the year.

C = gasoline consumption per mile (kilometer) traveled.

a, b = constants.

GASOLINE USE MODEL

In the work discussed, we have used variants of the model specified by Balestra and Nerlove (2) for natural gas. There are differences in our resulting equations since the assumptions about average consumption per automobile and about new-automobile demand have been generalized from their model (2). Our generalizations are partly due to the fact that it is easier to measure automobile purchases and ownership, gasoline use per vehicle, and automobile depreciation than it is to measure the corresponding variables for natural gas appliances.

The most general specification we used indicates new gasoline demand per capita as a function of real gasoline price, new automobile sales per capita, and gasoline consumption per registered automobile. [New gasoline demand is that in addition to gasoline demand carried over from previous periods. In contrast, demand for a new durable can be thought of as new demand and replacement demand for that part of the capital stock that has been retired or otherwise lost through depreciation. Jorgenson and Siebert (11) give a discussion in a capital goods context. Balestra and Nerlove (2) applied this concept to natural gas, reasoning that new demand was a net addition to demand deriving from the existing stock of gas appliances.]

$$G_t^* = f(P_{gt}, A_t^*, \lambda_t) \tag{1}$$

Equation 1 embodies the main behavioral assumptions of the model. It treats new-automobile purchases, use of the automobile stock, and gasoline price as predetermined for the period. Gasoline price is predetermined when there are no supply restrictions; this condition held for the estimation period, but not for the more recent periods of shortages (9). New-automobile demand surely depends on many other variables; as we suggested previously, it is a rather complicated phenomenon in its own right. At the level of aggregation for which the data are available, we decided that, since we could not apply an approach analogous to that of Farrell (5), we could not deal with the interactions between the new- and used-car markets and used cars. [The two general directions in which one could proceed are discussed elsewhere (4, 18). Both these efforts appear to be in the tradition of macroeconomic fishing expeditions where supply and demand factors are considered together to find variable combinations that have good fit. Such procedures have two important defects: (a) Data for the independent variables may be quite difficult to exogenously forecast in their own right, and (b) more reasonable behavioral demand relationships may be obscured by mixing of supply and demand determinants.] The only other such entity that we use in this model is the retirement rate for the entire U.S. automobile fleet, which we introduce later. The gasoline consumption per vehicle embodies two distinct entities. One of these is average gasoline consumption per mile (kilometer), which rests primarily on technological features of automobiles, given a driver's habits and the amount and composition of automobile use. The other is average automobile miles (kilometers) traveled per automobile, which depends primarily on the travel preferences of the automobile users. The first of these entities could be affected by changes in the vehicle or by changes in the way vehicles are driven. The second could be affected by changes in automobile travel demand. These variables were combined into the predetermined variable used because of the aggregate nature of the available data.

Additionally, we specify a pair of identities, one between automobiles and gasoline and the other between automobile ownership and new-automobile purchases:

$$G_t \equiv \lambda_t A_t \tag{2}$$

$$A_t \equiv (1 - r_t)A_{t-1} + A_t^* \tag{3}$$

Without loss of generality we can assume that

$$G_t^* = \lambda_t A_t^* \tag{4}$$

since our subsequent analysis will not depend on what value we use to link G_t^* and A_t^*. If we insert the definition from equation 2 in the definition from equation 3 and use equation 4, we obtain

$$\frac{G_t}{\lambda_t} = (1 - r_t)\frac{G_{t-1}}{\lambda_{t-1}} + \frac{G_t^*}{\lambda_t} \tag{5}$$

$$G_t = (1 - r_t)\frac{\lambda_t}{\lambda_{t-1}} G_{t-1} + G_t^* \tag{6}$$

Under the additional simplifying assumptions, f in equation 1 is linear and

$$a_4 = (1 - r_t)\frac{\lambda_t}{\lambda_{t-1}} \tag{7}$$

We then obtain the equation for estimation (model 1),

$$G_t = a_o + a_1 P_{gt} + a_2 A_t^* + a_3 \lambda_t + a_4 G_{t-1} \tag{8}$$

The assumption of the linearity of f in equation 1 is simply an assumption of a likely and readily estimable specification. Note that any other assumption on the form of f does not change the relationship between the dependent and lagged dependent variables; it remains linear since a linear relationship follows from the identities in equations 2 and 3. The assumption in equation 7 is more difficult to justify since some data are available on retirement rates and on the ratio of this year's gasoline consumption per automobile to that for last year. One reason for disregarding these assumptions is the quality of the data on retirements; the number of vehicles retired relative to the total is not necessarily a good representation of the depreciation of the stock.

Depreciation is a value rather than a physical concept. As Wykoff (19) has said, counting cars and adding them up are not necessarily the best way to form a capital aggregate for automobiles. His approach would be to normalize on one sort of car such as new Fords in the identity (3). Further, the ratio of gasoline use per automobile this year to that of last is a fuzzy concept at best. λ_t enjoys the role in this model of a scaling factor between gasoline consumption and automobile stock. The meaning of the ratio is unclear for any given year; over the long term it can be thought of as an average annual secular trend in gasoline use per automobile. Finally, the equation to be estimated has five estimable parameters; the parameter a_4 cannot be disentangled to obtain separate estimates of the change in fuel consumption per automobile and the retirement rate. This is consistent with intuition. Suppose fuel economy technology changes radically. λ_t/λ_{t-1} would change during the conversion, but there might be an offsetting change in r_t for the same period.

An alternative way to proceed would be to use the available data on λ_t and r_t directly. The resulting estimating equation has as its dependent variable the calculated value of new gasoline consumption. We attempted this and obtained results that were not easy to interpret. This, at the very least, suggests that the individual annual data on retirements are not an adequate representation of depreciation.

The results of ordinary least squares estimation are given in Table 1. Since the data were annual at the national level for the years 1951-1969, we settled for a single equation and did not attempt to estimate a simultaneous equation model with new-automobile sales or gasoline use per automobile. As mentioned already, an argument could easily be made in favor of a more elaborate model. The insurmountable difficulty is to specify a realistic model of automobile ownership, purchase, retirement, and use with annual national time-series data or with state data.

Table 1 indicates that the fitted equation has signs, t-values, and elasticities that are well within range of both a priori expectations and results of other investigators. The estimate of the elasticity of per capita gasoline demand with respect to its own price, -0.23, which is significantly different from zero at between confidence levels 0.02 and 0.01, based on the two-tailed t-test, lies midway among those of other investigators. The estimate of the coefficient of per capita lagged gasoline consumption, 0.70, is somewhat below expectations, since its calculated value from data on λ and r generally is above 0.9 (Table 2) and indicates that we are not sure of the meaning of a_4. As mentioned, counting automobiles and adding them up may provide an overestimate of the automobile stock. In such a case, retirements understate depreciation.

A variant on the model just presented can be obtained by deleting the variable for gasoline consumption per automobile from equation 1. This gives

$$G_t^* = f(P_{gt}, A_t^*) \tag{9}$$

If we combine equation 9 with equations 2, 3, 4, 5, 6, and 7 and with the assumption of the linearity of f, we get, instead of equation 8,

$$G_t = b_o + b_1 P_{gt} + b_2 A_t^* + b_3 G_{t-1} \tag{10}$$

where, in this case (model 2),

Table 1. Per capita gasoline consumption for model 1.

Predetermined Variable	Estimate of Coefficient	Calculated t-Value[a]	Calculated Mean	Estimate of Elasticity	Calculated Standard Error of Elasticity
Constant	-111.68	-2.99	1.000	—	—
P_g	-1.79	-2.99	29.532	-0.225	-0.075
A^*	818.69	7.04	0.038	0.134	0.019
λ	0.32	5.15	664.64	0.894	0.176
G_{-1}	0.70	12.73	226.88	0.674	0.053

Note: R^2 (uncorrected) = 0.998, R^2 (corrected) = 0.998, standard error of regression = 1.838, Durbin-Watson statistic = 1.732, f(4,13) = 1717.212, calculated mean of dependent variable = 234.67, and number of observations = 18. The Durbin-Watson statistic is useless under most formulations containing a lagged dependent variable.

[a] All are significant at the 0.02 confidence level; however those for the constant and P_g are barely significant.

Table 2. Data used in models.

Year	G	A^*	Λ	P_g	λ	r	$\left(\frac{\lambda}{\lambda_{-1}}\right)(1-r)$
1951	169.864	0.0328636	0.283766	30.0000	598.604	0.0880	—[a]
1952	178.830	0.0265857	0.280051	29.7946	638.562	0.0660	0.996346
1953	186.245	0.0360943	0.291824	30.7833	638.211	0.0890	0.910500
1954	190.951	0.0341878	0.299568	31.0256	637.423	0.0780	0.920861
1955	203.198	0.0434282	0.321623	31.1576	631.789	0.0980	0.894028
1956	210.149	0.0354253	0.322427	31.6051	651.771	0.0920	0.936718
1957	213.773	0.0347791	0.325000	31.5918	657.764	0.0870	0.921394
1958	217.810	0.0266095	0.325329	30.1688	669.508	0.0590	0.957801
1959	225.287	0.0339764	0.334083	30.0394	674.343	0.0840	0.922616
1960	228.717	0.0365389	0.342778	30.1940	667.245	0.0800	0.910315
1961	229.689	0.0319945	0.346448	29.5202	662.981	0.0790	0.915115
1962	235.581	0.0373412	0.355759	29.0702	662.194	0.0810	0.917908
1963	240.037	0.0400902	0.366048	28.5098	655.754	0.0890	0.902140
1964	248.901	0.0422030	0.376243	28.0759	661.544	0.0920	0.916017
1965	259.814	0.0481344	0.389147	28.3439	667.649	0.0960	0.912343
1966	272.551	0.0460532	0.399284	28.3643	682.599	0.1040	0.916063
1967	279.028	0.0423139	0.407089	28.5125	685.423	0.0910	0.912760
1968	293.495	0.0471615	0.419258	27.8135	700.036	0.0980	0.921230
1969	310.079	0.0469067	0.431480	27.0008	718.642	0.0860	0.938293

[a] Not applicable.

Table 3. Per capita gasoline consumption for models 2 and 3.

Independent Variable	Estimate of Coefficient	Calculated t-Value[a]	Calculated Mean	Estimate of Elasticity	Calculated Standard Error of Elasticity
Constant	42.90	1.15	1.000	—	—
P_g	-1.38	-1.38	29.532	-0.173	-0.126
A^*	483.52	2.98	0.038	0.097	0.026
G_{-1}	0.94	21.08	226.88	0.912	0.043

Note: R^2 (uncorrected) = 0.994, R^2 (corrected) = 0.993, standard error of regression = 3.0876, Durbin-Watson statistic = 1.083, f(3,14) = 808.271, calculated mean of dependent variable = 234.67, and number of observations = 18. The Durbin-Watson statistic is useless under most formulations containing a lagged dependent variable.

[a] The t-value is significant at the 0.30 level for the constant, at the 0.20 level for P_g, and at the 0.02 level for A^*. The t-value for G_{-1} is highly significant.

Table 4. Forecast results for model 1.

Year	G_t Actual	G_t Forecast	G_t Forecast/ G_t Actual	P_g	A_t^*	λ_t	G_{t-1}
1970	322.787	327.771	101.54	26.3784	0.041158	737.241	310.079
1971	337.119	346.762	102.86	25.8369	0.047677	749.081	322.787
1972	351.206	363.886	103.61	24.7975	0.05037	758.540	337.119

$$b_3 = (1 - r_t) \frac{\lambda_t}{\lambda_{t-1}} \tag{11}$$

Before empirical results are presented, it is useful to consider another model. Instead of equation 7, suppose that

$$\lambda_t = \lambda \text{ and } r_t = r \text{ (all t)} \tag{12}$$

By combining equation 12 with equations 1, 2, 3, 4, and by assuming the linearity of f, we obtain an equation of the form of equation 9. However, in this case (model 3)

$$b_3 = 1 - r \tag{13}$$

The form but not the interpretation is the same as that in model 2.

The results of estimation for equation 10 are given in Table 3. Again, signs and elasticities are reasonable. In this case, the t-value for real gasoline price is low, significant only at the 0.20 confidence level. The coefficient of lagged gasoline consumption, 0.94, is somewhat higher than one might expect under model 3 and, in fact, is quite consistent with what we would expect from model 2. This can be seen directly by the reader, since the values for (λ/λ_{-1}) $(1 - r)$ are given in Table 2. Recall, however, that they are individually somewhat suspicious and that the r_t and r are not true depreciation rates.

FORECASTING AND POLICY

So that the model may be applied to policy questions, it may be useful to separate gasoline consumption per automobile into its two component parts: gasoline consumption per mile (kilometer) traveled, say C, and automobile miles (kilometers) traveled for the year, say V. These variables are quite dissimilar in terms of the kinds of actions necessary to change them. C is a technological variable; it is the inverse of fuel economy for a given automobile. V is a traveler choice or economic variable. C would be most likely changed by changing the automobile itself, and V would be changed by providing changes in incentives to automobile travelers. As an equation, this is expressed as

$$\lambda_t = V_t C_t \tag{14}$$

A number of policy questions could be addressed by the model. These include the influence of government policy on A^* or on P_g as well as possible actions regarding C or V. In a later paper, some of these will be developed in detail and inserted into model 1. In this paper, remarks are restricted to the estimate of the price elasticity of demand for gasoline.

We tried a logarithmic form for the G^* part of the model. We also reestimated for both forms with 1970, then with 1970 to 1971, and then with 1970 to 1972 data included. Finally, we calculated elasticities for other situations. All these experiments provided results that were consistent with the results for model 1 reported above for the linear formulation based on the estimation period of 1951 to 1969.

A result of particular interest for policy is calculation of elasticities for points other than the point of means. Recall that the linear equation had a gasoline price elasticity of -0.225. The 1972 point elasticity was -0.126 or about 56 percent as great in magnitude. If the 1972 price were doubled, this elasticity would be -0.252. The semilog functional form had an elasticity at the point of means of -0.275, but the 1972 point elasticity was -0.184, or about 67 percent as great in size.

Based on our work and the work of others, we conclude that the short-run price elasticity of demand for gasoline is of the order of magnitude of -0.10 to -0.30 on an annual basis in the sort of market there has been over the past 20 or so years. Note that the extreme shift in the supply of gasoline in late 1973 and early 1974 renders the data on price and quantity for that situation incomparable with earlier and later periods. Most of the change in gasoline consumption for the last quarter of 1973 and the first quarter of 1974 was likely caused by waiting lines at and closing of gasoline stations rather than price increases.

The final quantitative exercise will be to use the model in forecasting the years since 1969 (1970 to 1972) for which data on the variables in question are available. Data are incomplete for 1972.

Table 4 gives the results of using model 1 for forecasting. The forecasts are quite close to and are uniformly larger than the actual results. Furthermore, there is a trend for the forecast error to increase as time goes on. There are two possible explanations for this systematic trend. One is that the specification error of leaving out certain important secular variables causes a misrepresentation of the way in which tastes are changing over time. The other is that the safety and air quality restrictions on the supply side, which began to influence automotive manufacture quite importantly during the forecast period, caused increased automotive costs that in turn had a dampening effect on gasoline demand. These effects were not built into the model except as they might indirectly influence the predetermined variables used.

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TOTALITY INDEXES FOR EVALUATING ENVIRONMENTAL IMPACTS OF HIGHWAY ALTERNATIVES

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The passage of the National Environmental Policy Act of 1969, general tightening of pollution laws, and increasing public concern for environmental quality make it mandatory that environmental impact studies be done for proposed construction of facilities such as major highways, airports, dams, and atomic power plants. So that the long-range impact of specific or alternative developments can be appraised, principles of environmental and systems sciences are being applied to the scaling and weighting of the factors. Increasingly, government is turning to academic centers for help and research on environmental impact studies. This paper is a brief account of how, by use of a simple linear vector analysis as an objective quantification of environmental impact, an organized interdisciplinary group at the University of Georgia responded to a specific request from the Georgia Department of Transportation. The paper also discusses how this was followed by a sequence of events that have profoundly influenced and improved the entire transportation process in the Southeast.

•IN the spring of 1971, the Georgia Department of Transportation requested that the Institute of Ecology at the University of Georgia make a summary evaluation of all reports already prepared on alternative routes for the uncompleted section of I-75 north of Atlanta. Previously, the original route proposed by the Georgia Department of Transportation (route F, Figure 1) had not been approved by the Federal Highway Administration because of objections by environmentalists who pointed out that the route might degrade a prime greenbelt and recreational area of great importance to the future of metropolitan Atlanta.

Accordingly, the Georgia Department of Transportation surveyed several alternate routes, both to the east and west (routes T, G, P, and O, Figure 1), and prepared reports on engineering feasibility and costs and benefits for all the routes. State, federal, and citizens' organizations and two private consulting firms were requested to submit reports. The reports submitted included the special interests of the Georgia Department of Transportation; U.S. Army Corps of Engineers; Georgia Department of Mines; U.S. Bureau of Mines; Georgia Department of Public Health; U.S. Geological Survey; U.S. Environmental Protection Agency; National Recreation and Parks Association; Georgia Recreation Commission; Bureau of Outdoor Recreation, U.S. Department of the Interior; Natural Areas Council of the State of Georgia; Georgia Department of State Parks; the Georgia Game and Fish Commission; and the U.S. Fish and Wildlife Service. Bolt Beranek and Newman, Inc., submitted an acoustical impact study. We at the University of Georgia agreed to evaluate the data from these reports, not only

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*Mr. Zieman and Mr. Shugart were with the University of Georgia when this research was performed.

Figure 1. Five proposed alternatives for I-75 north of Atlanta.

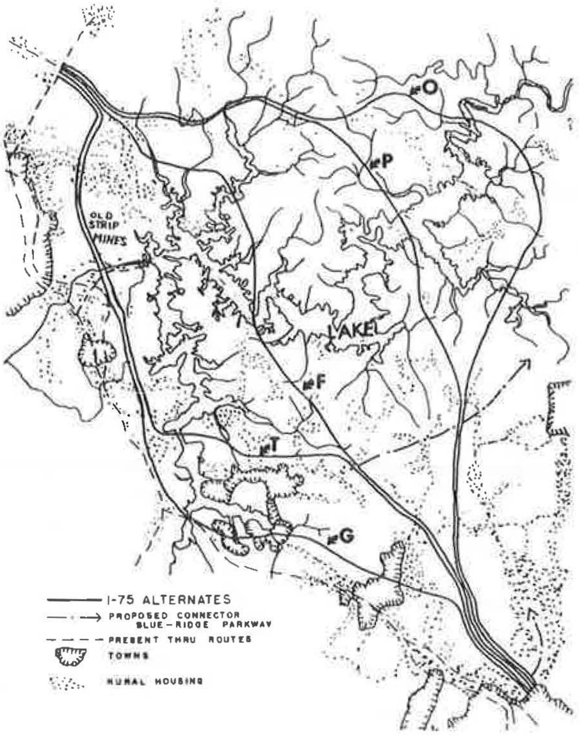
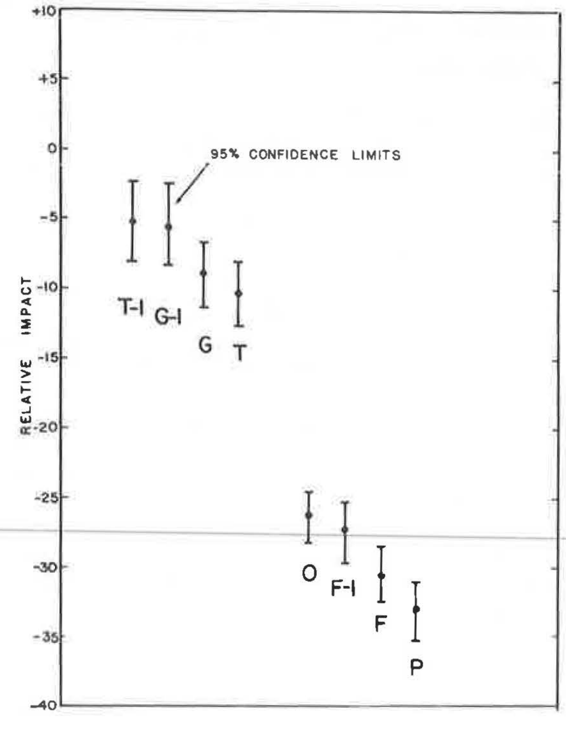


Figure 2. Mean and 95 percent confidence interval for total impact index of eight routes proposed for uncompleted section of I-75 north of Atlanta.



because we thought we might help resolve a classical confrontation between engineers and environmentalists, but, more important, because we thought we could develop a systems-ecology procedure that might have wide application to other situations where protection of the future quality of the environment is paramount and where decision making is to be based on selecting the best among alternative sites or procedures. Accordingly, our objective was to make a summary evaluation of each proposed route in terms of a single impact index, compounded by quantifying, weighting, and scaling all component values for which data or expert opinions were available. In carrying out the evaluation, we functioned as an ad hoc interdisciplinary panel with a 50-50 balance between those accustomed to dealing with environmental matters and those skilled in the application of economic and human considerations.

METHODS

When the project was first considered, several ways to accomplish the objective were examined. One possibility was what might be called the McHarg method (1), which involves preparing transparent map overlays of the area under consideration with a gradient of classes of density varying with land use or other considerations, such as human population density and slope of the land. When many overlays are superimposed on the basic map, a route of least harm or least resistance may show up as the lightest zone area. Such a graphic method may often provide a means for selecting a single alternate route or location but is rarely sensitive enough to decide among alternatives already selected and studied on the basis of engineering feasibility. The use of matrices for problems of this sort has been suggested by Leopold, Clarke, Hanshaw, and Balsley (2), and matrices have been applied in an actual situation in Wisconsin (3). Considering that we did not gather the data and that we would be dealing with information and value judgments from a wide variety of sources, a relatively straightforward linear vector analysis appeared to be the best approach for the problem at hand.

The method decided on was essentially a linear combination of observable or consensus attributes (e.g., the amount of urban land disturbed, the relative safety of a route, the cost of a route) multiplied by a weighting factor giving the relative importance of the particular attribute. For each alternative route, an impact index I was evaluated from these weighted attributes. A mean impact index $\bar{I}_k$ and a standard deviation σ_k were determined by iteration of the impact index I for respective routes k. The parameters (mean $\bar{I}_k$ and standard deviation σ_k) were then used to infer impact differences among various routes. The definition of the index I is as follows:

$$I_{kj} = \sum_i (e_{kji} + \tfrac{1}{2}) N_i S_i X_{ki} \qquad \begin{aligned} (i &= 1, \ldots, 56 \text{ attributes} \\ j &= 1, \ldots, 20 \text{ iterations} \\ k &= 1, \ldots, 8 \text{ routes}) \end{aligned} \tag{1}$$

where I_{kj} is the j th iteration of the impact index I for the k th route; X_{ki} is the response of the i th observable or consensus attribute for the k th route;

$$S_i = 1/\mathrm{Max}\,[X_{ki};\ k = 1, \ldots, 8] \tag{2}$$

is a scaling factor on the i th observable attribute; and $0 \leq S_i X_{ki} \leq 1$ will be true for every attribute on every route.

$N_i = W_i/\Sigma W_i$ is a scaling factor on the i th observable attribute such that $\sum_i N_i = 1$ (this scale factor is derived from the unscaled importance weights W_i assigned to the i th observable attributes).

e_{kji} is a random number drawn from a uniform distribution for the ith attribute on the jth iteration of the index I of the kth route. This random number will vary between 0 and 1. The scaled random number $(e_{kji} + \frac{1}{2})$ will then permit the attributes to vary by 50 percent.

The 56 observable or consensus attributes that make up the final data set are loosely categorized into four groups:

1. Group E, economic and highway engineering considerations;
2. Group L, environmental and land use considerations;
3. Group R, recreation considerations; and
4. Group S, social and human considerations.

A complete list of the 56 observable attributes, their weights as assigned by the panel, and the source of the data are given in the appendixes of the final report (4). The procedure for scaling and weighting attributes is described below.

To convert the many different observable responses expressed in different units [such as costs measured in dollars, safety measured in human lives saved, watershed erosion measured in tons (kilograms) of soil disturbed] into comparable units, we set the route with the maximum value for the attribute at unity and scaled the remaining routes relative to this standard. The 0 to 1 scale was chosen simply for ease of calculation and comprehension; any other ranges could be arbitrarily set (i.e., 0 to 10, 0 to 100). A scaling factor, as previously cited, then has the form of equation 2. For example, for acres (hectometers^2) of urban area disturbed for the different routes (attribute 9), some route responses are G = 212, T = 175, F = 68. Of these responses, line G at 212 is the maximum value.

Therefore,

$$S_{\text{attribute 9}} = \frac{1}{212} \tag{3}$$

Next the ith attribute on the kth route is multiplied by the ith scaling factor so that

$$G = \frac{212}{212} = 1 \tag{4}$$

$$T = \frac{175}{212} = 0.825 \tag{5}$$

and

$$F = \frac{68}{212} = 0.321 \tag{6}$$

This process makes the ith attribute for each route a dimensionless number that can be used to indicate the relative merit of each route.

Since attributes in an analysis of this sort are not of equal importance in terms of the overall impact, some systematic method of weighting their response must be devised. Again, an arbitrary range was selected, this time 1 to 10, and both present and long-term weights were used, although the latter were emphasized since the major controversy (hence the major problem the study was set up to resolve) involved questions of future impact on large greenbelt recreational tracts and small towns north of Atlanta.

It was decided that the importance of long-range effects should be 10 times greater than that of present effects. Because of storage limitations on the computer these were combined into one importance weight. For example, for attribute 1 [acres (hectometers^2) of pineland removed] the future effect was -10. The importance weight actually entered was

$$\text{importance weight of attribute } 1 = 1\,(-3) + 10\,(-10) = -103 \tag{7}$$

The minus signs in equation 7 indicate that removal of the existing pine forests is an undesirable or detrimental effect. The increased negative impact for the future is based on the fact that the future commercial development that inevitably follows major highway construction will remove more forest than was removed in the right-of-way construction of the highway. In another example, urban acreage removed (attribute 9), the value entered was

$$\text{importance weight of attribute } 9 = 1\,(-6) + 10\,(+10) = +94 \tag{8}$$

Change in sign for future effect in equation 8 was based on the projection that, although displacement of homes and businesses in the right-of-way would be a detrimental factor at first, the long-range impact would be favorable to an underdeveloped urban area since the highway would bring increased economic benefits to the community as a whole.

The importance weights of the attributes were normalized to keep results within reasonable and understandable bounds. This procedure involved simply dividing each weight by the total sum of all weights, as shown by the previous notation, $\Sigma W_{1\rightarrow 56}$. In this way a central point of tendency of the weights is established rather than a variety of weights from 0 to infinity. In no way are the relative positions or spreads of the final index values for the routes modified; only their absolute positions on a scale are changed.

A computer program to calculate indexes for each route and to iterate the index of the route, given the variability of each of the values, was written for this study. Details of the program, written in CPS PL/1, are contained in the full report (4). It takes up to 60 values; iterates the index 20 times; and produces the mean $\bar{I}_k$, standard deviation σ_k, and a 95 percent confidence interval for the index I. A pass using 50 values requires about 3.5 min of CPU time on an IBM 360/65. Program notation refers to k_i, which are importance weighting factors W_i, and to d_i, which are scaled attribute responses $(S_i X_{ki})$. The weighting factors b_i are set internal or external to the program, but the scaled responses d_i are set external to the program.

The major problem in evaluating environmental and socioeconomic values associated with highways is that subjective judgments are often required. Experts often disagree about the importance of different values and their impact, and this disagreement complicates the assessment of ecological costs and benefits.

In this study, we relied on expert opinion and value calculations as recorded in the series of reports by specialists and on the consensus of our panel that established the weighting factors. Most of all, however, imprecision was allowed for by assuming that changing attribute responses, opinions, or weights might vary by 50 percent. This is the e_{kji} factor in the index formula I_{kj} or as detailed previously. For the current study, all attributes were assumed to vary with the same amount of variability, namely 50 percent. This was an adequate assumption since no prior knowledge was available regarding variability of these attributes. Future studies that have access to the amount of variation possible in attributes should permit the error probability to vary for each attribute.

By using randomly varying values to determine the index several times, one can determine an average index $\bar{I}_k$ for the route in question and how much this index can be expected to vary. Standard statistical techniques can then be used to find the best route, given that there is some inexactitude in the values that go into the index. Note that the establishing of a confidence range should be mandatory in any statistical evaluation of impact data, even in strictly economic data that can also have a wide range of error. In this study, I_{kj} was assumed to be normally distributed. A 95 percent confidence region could then be placed about $\bar{X}_k$ by application of the t-distribution.

The form of the confidence interval is as follows

$$(\bar{I}_k \pm S_{\bar{I}_k}\ t\ 0.05,\ 19) \tag{9}$$

where $\bar{I}_k$ is the mean impact index for route k; $S_{\bar{I}_k}$ is the standard error associated with the mean impact index $\bar{I}_k$; and t is the proportionality of the t-distribution associated with $\alpha = 0.05$, and df = 19.

In summary, the weights selected were those chosen by the study group after much discussion and careful consideration. However, the possibility that any given weight is not properly proportional to other weights is provided for in the error control of the program, as described.

RESULTS

The results of the analysis in terms of the mean and 95 percent confidence interval for each of the alternative routes are shown in Figure 2. The main analysis resulted in a sharp separation of the routes into two groups of four each. The fact that both groups have negative values does not mean that a highway would be detrimental to the areas involved because these are relative, not absolute, values. A value close to zero merely indicates a relatively neutral or favorable impact in terms of a balance between economic and environmental factors, and values of -30 indicate a much less desirable choice, all things considered. The mean values (as shown in Figure 2) for the eight routes, in order of the ranking from best to poorest by the main stochastic run, are as follows:

Route	Ranking
T-1	-5.2
G-1	-5.4
G	-8.9
T	-10.3
O	-26.5
F-1	-27.3
F	-30.6
P	-33.2

Figure 2 shows little reason to choose between routes T and G. Route T-1 has a slightly lower mean, but the difference between it and the other three westerly routes is statistically insignificant. The slight advantage of T-1 was related to lesser impact of the family displacement and noise disturbance, all other components being almost identical for the T and G routes.

The remaining four alternatives, including the originally proposed route F, were not so closely bunched, but their mean indexes were significantly lower than for any of the westerly four. This indicates that these easterly routes would be inferior choices.

To determine more clearly the role played by the major groups of component values in the numerical value of the total index, trial runs were made in which one or more of the groups were omitted. When future impact values were left out so that only the immediate impact was considered, the routes ranked as follows:

Route	Ranking
T-1	-31.8
F-1	-32.2
F	-34.6
G-1	-34.8
T	-37.8
G	-39.1
O	-43.5
P	-44.2

Although T-1 was still ranked highest, the negative values were lower, and the T and G routes would not be statistically different from F. The reasons why consideration of the future resulted in much clearer separation of alternates will be discussed in the next section. When environmental factors only were considered (i.e., when strictly economic and human factors were left out and vice versa), the rankings and degree of separation of western from eastern routes differed little from the total run. This indicated that there was no undue bias toward either environment or man in the total run. Finally, a trial run was made to determine the effect of a higher weighting for safety, since one of the objections of the longer routes would be that the extra length might result in more lives lost in accidents. Increasing the relative weight of the safety factor did not reduce the superiority of the T and G routes over the shorter F route. As it turned out, the hazard of 3 extra miles (4.8 km) was more than balanced by the hazards posed by two long bridges that would have to be built across the lake on route F. Likewise, the cost of extra paving and higher land acquisition values along the T-1 route turned out to be less than the cost of these bridges. These various experimental manipulations illustrate both the use of the computer model as a tool and the kind of detailed analysis that can be made even with a simple linear program.

On the basis of the complete study, it was recommended that one of the T or G routes, preferably T-1, be selected. The Georgia Department of Transportation accepted this recommendation and proceeded with public hearings and additional engineering plans for route T-1. Engineers with the regional office of the Federal Highway Commission became interested in our study and joined with us to rerun the program with some changes in the weighting of factors they considered important. These new runs produced the same result, a clear separation of the two groups of routes as shown in Figure 2. As of this writing, the Federal Highway Commission has approved the T-1 route.

DISCUSSION OF RESULTS

In retrospect, two features of this study that seemed to have encouraged acceptance of the results by government, political leaders, and the general public were the strong emphasis (i.e., weighting) given to future impact and the establishment of confidence limits (Figure 2), based on the possibility of a wide margin of error in any one of the 56 component values. Strong weighting of the future resulted in clear separation of alternates because the future impact differed markedly from present impact in a number of important categories. For example, routing the highway parallel to an existing main artery and along the outskirts of existing towns, villages, and suburban areas, such as long routes T or G, results in an immediate negative impact in terms of displacement of people and higher land acquisition costs. However, if we look to the future, people in these preexisting centers will benefit greatly because an Interstate highway is an irresistible magnet for economic development. Furthermore, conditions are favorable for orderly economic development that benefits local people since the incorporated towns and villages either have, or can soon establish, services such as water and sewage systems and land use zoning. Furthermore, old strip mines and other blighted areas along routes T and G would be greatly improved by a well-engineered and well-landscaped double highway with a wide median strip (as is recommended). In contrast, routing the highway through the recreational wilderness now present along route F would have little immediate impact either on the quality of the wilderness or on people (since few live there). However, in the future, the quality of the natural area would be increasingly degraded by an economic development that would likely be exploitive and speculative and that would benefit large landholders and outside interests rather than local people. Since, in the long run, the quality of urban areas depends on the quality of the buffer life support system (i.e., water, air, fiber, and food in the environment), it makes common as well as economic sense not to route major highways through such greenbelts needed for future use by large metropolitan centers such as Atlanta. It was not until all the individual factors had been carefully and objectively weighted, scaled, and incorporated into a totality program that this kind of logic became evident.

As already indicated, the computer program was set to assume that there might be 50 percent error in any value. Although it seems highly unlikely that data and expert opinions would be doubted, it is prudent to start with a large error factor. In this case, a clear separation was obtained even with the large error factor. Therefore, it was not necessary to consider reducing the error estimate to reach a decision.

Although a linear vector approach proved to be adequate for this study, some form of matrix analysis (2, 3) would undoubtedly provide greater flexibility and sensitivity in cases where component values for the options prove not to be so divergent. However, the usefulness of more complex procedures depends greatly on the quality and comparability of the data; far better impact reports than many of those made available for this study would be needed. We would strongly recommend that special training courses in computerized impact analysis be set up at academic centers designed especially for personnel of state, federal, and private consultant agencies who will be increasingly called on to make decisions that are in the best long-term public interest.

The ultimate success of a totality approach such as that used in this study may often depend on follow-up procedures. For example, when the highway was rerouted along T and G (Figure 1) as recommended, a superb opportunity for land use zoning was presented, since a large recreational greenbelt would then lie in the V between the developing urban corridor (Atlanta to Chattanooga) on the west and the commercial, recreational developments (e.g., resorts, second homes) that are springing up along the Blue Ridge Parkway extension to the east. Thus, Georgia has an opportunity to set aside all of the area around and north of Lake Allatoona as a permanent greenbelt for metropolitan Atlanta. This could be done by expanding the state parks already located in the area or by acquiring easement rights from large landowners (chiefly timber companies) to ensure permanent natural areas for public use. If these follow-up actions are not taken now, there will inevitably be pressure in the future to extend highways and urban development northward, thus splitting up and ultimately destroying a valuable natural resource that was saved, so to speak, by the earlier decision to locate I-75 to the west.

Shortly after the results of this study and the decision on it by Georgia DOT were made known to the public, an editorial cartoon appeared on one of the Atlanta TV programs (5) depicting economics (in the form of a coin purse) and ecology (in the form of wildlife) dancing together over the caption, "We both won by the decision to reroute I-75."

CONCLUSIONS

Our experience with this and similar studies leads us to think that, although short-term economic considerations (especially when exploitive and speculative) usually result in environmental degradation, long-term cost-benefit analyses (in which all costs are considered) will generally be beneficial to the environment. In other words, what is good for the environment will also be good for a long-term stable economy. It would be hard to fault such a concept as a goal for the upcoming generation who must make what Boulding (5) calls the "great transition" in the country's economic and ecologic game plans.

The decision to reroute I-75 has been followed by a series of events in Georgia that we think are indicative of a transition to a new era of planning that involves not only greater consideration of the environment but also greater citizen participation in the planning process. Brief mention of these transportation decisions will show how attitudes have changed from the days when road building was strictly a matter of power politics.

The Institute of Ecology was also asked to evaluate alternate methods of handling the muck that has to be removed when highways are built across wetlands. Based on the recommendation of this study, procedures in the construction of I-95 on the Georgia coast were modified to minimize damage to valuable coastal marshes. In another case, Georgia voluntarily altered the route of an Interstate connector to avoid cutting through a scenic ridge with unusual flora; in this case, the decision came 2 days before a scheduled hearing was held on a court suit based on the contention that an impact study such as that done for I-75 had not been carried out for alternate routes.

Finally, in the fall of 1972 the governor of Georgia appointed an ad hoc study commission of knowledgeable citizens to determine whether an outlying freeway should, or should not, be extended as a tollway to downtown Atlanta. The commission used our vector approach in that about 30 value components were established, and each member of the commission personally weighted the values. In this case computer analysis was not necessary because members of the commission came to the same conclusion when making a total analysis although they differed greatly in the importance given to some of the values (commission members included business and professional leaders, planners, a chamber of commerce official, an environmentalist, and a spokesman for the neighborhood directly affected by the proposed highway). The preservation of inner-city neighborhoods, the strong public opinion against the road, and the fact that plans for rapid transit and improved bus service offered transportation alternatives all weighed heavily in the unanimous decision to recommend that the tollway not be built. On the same day that the commission made its report, the governor and the director of the transportation department announced that the tollway would not be built.

The most encouraging feature of these events is the strong indication that an orderly means of structuring citizen involvement in complex planning problems is about to evolve. Fielding (6), a social scientist, used the term value analysis for this emerging strategy, which he says

> ... differs from cost-benefit and goal-matrix methods in that it does not presume in advance that a social welfare function for a freeway exists. Instead it assumes that an attitude is developed during the planning process. Value analysis assists diffusion of reliable information about freeway proposals and develops a behavioral commitment for the decision within the affected community.

The kind of systems ecology described in this paper may yet provide a technological assessment link between science and society.

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APPENDIX

ANATOMY OF IMPACT ASSESSMENT

During the past 2 years, numerous conferences and workshops have been held all over the country for the purpose of developing some kind of state of the art for preparing environmental impact statements, as required by the National Environmental Policy Act of 1969. At one such workshop conference, scientists and engineers primarily interested in the practice of impact assessment examined in detail the matrix approach (2), the linear vector approach described in this paper, and other proposed approaches. On the basis of this workshop, E. P. Odum prepared the following outline of how to assess various environmental impacts.

The Component Approach
(Linear Vector or Matrix)

1. Make a list of the components or values (the inventory data base).
2. Scale component values and indicate whether they are positive or negative to permit summation.

Stop 1.

3. Weight each component value (multiply by factor proportional to importance). Give specially sensitive components (red flags) extra weighting.
4. Sum scaled and weighted values to obtain impact index.

Stop 2.

5. Introduce error factors by computer program.
6. Do a sensitivity analysis (experiment by computer program with changed weights, errors; leave out or add components judged to be of key importance or of much public interest).

Stop 3.

7. Add additional weights for future or secondary impact where importance values change with time. Try nonlinear functions (as in Battelle approach).

Stop 4.

If interactions and forcing functions are more important than components or if scale of problem is large and complex or if the ultimate decision does not involve a simple choice of alternates (i.e., A, B, C; go-no go), then go to the next approach.

The Systems Approach

1. Make a list of the properties (state variables) that relate to the function of system as a whole (for example, in an aquatic system, the rate of production as a system property rather than dissolved oxygen as a component).
2. Make a list of causal or forcing functions, such as energy sources and investment money.
3. Construct a flow diagram or model by connecting properties (shown as boxes) and forces (circles) with flow lines and appropriate interaction functions (shown as triangles or other distinctive symbols).
4. Indicate where interactions are multiplicative, threshold, feedback, or otherwise not simply additive.

5. Quantify (put numbers on) each major function.
6. Validate the procedure. Run simulations with an analog computer to adjust network behavior to achieve reasonable mimic of real-world system.
7. Do a sensitivity analysis, if needed.
8. Generate performance curves to predict effect of development options, pollution perturbations, or whatever impacts are relevant.
9. If greater detail or precision is required, program with a digital or hybrid computer.

One goes only as far as needed to achieve the goal. Impact statements for many situations need go only to stop 1 or 2. Linear vector analysis through stop 4, as described in this paper, would seem adequate for most situations where there are clear-cut options or alternatives. The procedure is easy to follow and easily explained to the public. This is important since all workshop participants agreed that the public must now be continuously involved in the decision-making process. For more extensive or complex situations, one must shift as far as possible to a true systems analysis where the behavior of the whole rather than of the parts is stressed.

We can begin to see that the present practice of making impact assessments for each and every proposed development, as now required by the National Environmental Policy Act of 1969, is a stop-gap approach that must evolve as rapidly as possible into regional land use planning. Practical success in such an endeavor will require a whole new order of yet-to-be-developed systems procedures, changes in public attitudes, laws, and economic incentives. To meet this challenge, researchers in the sciences and humanities must find a common language and work together. This may involve use of energy as a common denominator in the assessment of the impact of fuel-powered systems on natural, solar-powered systems at the regional level. Energy can also serve as a common language for economic and ecological considerations, thus extending cost-benefit, trade-off, or balance-sheet analyses to include the nature and work of people (7, 8).

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