Energy Conservation Potential of Staggered Work Hours

JAMES M. WITKOWSKI AND WILLIAM C. TAYLOR

Research was performed to evaluate the potential of staggered work hours to reduce work-trip fuel consumption and to evaluate the relation between the size and location of the participating work force and the level of fuel savings. The spatial organization of a hypothetical urban area was generated by using data from the literature and a computer simulation program designed to distribute population and employment activities throughout the urban area. By using this distribution and a defined transportation network, the program then generated the work-trip travel pattern and computed the transportation fuel requirements for automobile work trips and daily transit service. A base case was generated and used as the basis for comparison of the alternative policies. Several alternative temporal distributions of work travel were used to simulate the effect of staggered-work-hour programs. Tests were designed to determine the effect on the reduction in fuel consumption of the magnitude and location of the work force participating in the staggered-work-hour programs. The simulation results indicated that staggered-work-hour programs can significantly reduce automobile work-trip gasoline consumption. The effectiveness of the staggered-work-hour policies was shown to be influenced by both the number of participants in the program and the distribution of the participants throughout the urban area. The reduction in fuel consumption increased with the number of participating work travelers. The reduction also increased as the locations of the participating employment centers became more dispersed throughout the urban area. The staggered-work-hour programs also showed a strong negative influence on work-trip bus ridership.

Evaluation of strategies to reduce automobile fuel consumption in urban areas is of particular interest to transportation planners because these trips consume approximately 34 percent of the national total transportation energy (1). These trips also account for approximately 98 percent of the fuel consumption for urban passenger travel and account for 92-95 percent of the total vehicle person trips (1).

The objective of staggered- or flexible-work-hour programs is to shift work-trip travel away from the peak demand periods. The desired results are a reduction in peak highway and transit system loading, improved transportation levels of service, and reductions in energy consumption and vehicle emissions.

The capabilities of planners to evaluate quantitatively the potential benefits of transportation system management (TSM) actions with respect to transportation fuel consumption are limited. Each urban area exhibits its own particular characteristics and needs. Confronted with the question of which action or combination of actions can be used to successfully reduce gasoline consumption for urban travel while maintaining an acceptable level of service, the transportation planner must often rely on national statistics for cities ambiguously described as small, medium, or large. Whether or not the policy actions actually yield the estimated reduction in fuel consumption depends on the characteristics of the area being studied.

Several studies (2-5) have reviewed the potential of different TSM techniques to reduce urban congestion and, subsequently, to reduce gasoline consumption. In each of these studies, staggered work hours was determined to be an effective low-cost action to reduce congestion and gasoline consumption. Another conclusion was that proper coordination of staggered work hours and transit supply strategies could improve the effectiveness of TSM actions (2,4). These studies did not define a relation between the size of the participating work force and the level of fuel consumption, nor did they indicate the magnitude of the temporal redistribution of the work trips required to effect a significant reduction in gasoline consumption.

Only a few studies (6-8) have attempted to determine the impact of staggered-work-hour programs by simulating the redistribution of work trips during the peak period. None of these attempted to relate the results to reductions in energy consumption.

The goal of this study was to improve the capabilities of transportation planners to evaluate the short-term relation between specific TSM policies and fuel consumption for urban work trips. This would enable planners to assess more accurately the potential benefits of specific policies and aid in the selection of policies for implementation. It would also aid in planning for future energy contingencies.

This research focused on the work-trip fuel-conservation potential of staggered-work-hour programs. It was hypothesized that a potentially significant reduction in transportation fuel consumption for the urban work trip would result from the implementation of a staggered-work-hour program.

The level of effectiveness of alternative work schedules appears to be dependent on (a) the level of participation in the work force, (b) the relative location of the participating employment centers, (c) the degree of coordination of transit scheduling with the work-hours program, and (d) the configuration of the highway network.

The effect of staggered work hours on work-trip fuel consumption is evaluated in this research with respect to both the size of the work force participating in the program and the location of this work force in the urban area.

SIMULATION PROCESS

The primary requirements of the modeling system for this research were the following:

1. The capability to simulate modal choice as a function of the elements of travel time and cost, such as in-vehicle travel time, walk time, and, for transit passengers, waiting time (for automobile travel, it was important that travel time be related to highway congestion levels);
2. The capability to estimate energy consumption for both automobile and transit travel;
3. The capability to model the effects of staggered work hours on highway congestion and mode choice (the model had to be capable of simulating work travel over several distinct time elements so that the sensitivity of fuel consumption to the proportion of travelers during each time element could be tested).

The modeling system used is shown schematically in Figure 1. This system was adapted from the MOD3 modeling procedure used by Peskin and Schofer (9). MOD3 is a large-scale computer model that simulates the spatial development of an urban area, forecasts the passenger travel that takes place during a single day, and computes the energy consumption resulting from that travel. In effect, the model combines the elements of land use distribution, modal choice, and network assignment with an energy consumption module for work trips. Modal choice is estimated by using a binary logit formulation. The details of the structure of MOD3 are contained in the work by Peskin and Schofer (9). Details of the modifications to the program required for this research are contained in an earlier report (10).

The broken flow line in Figure 1 represents the

Figure 1. Basic requirements of modeling systems.

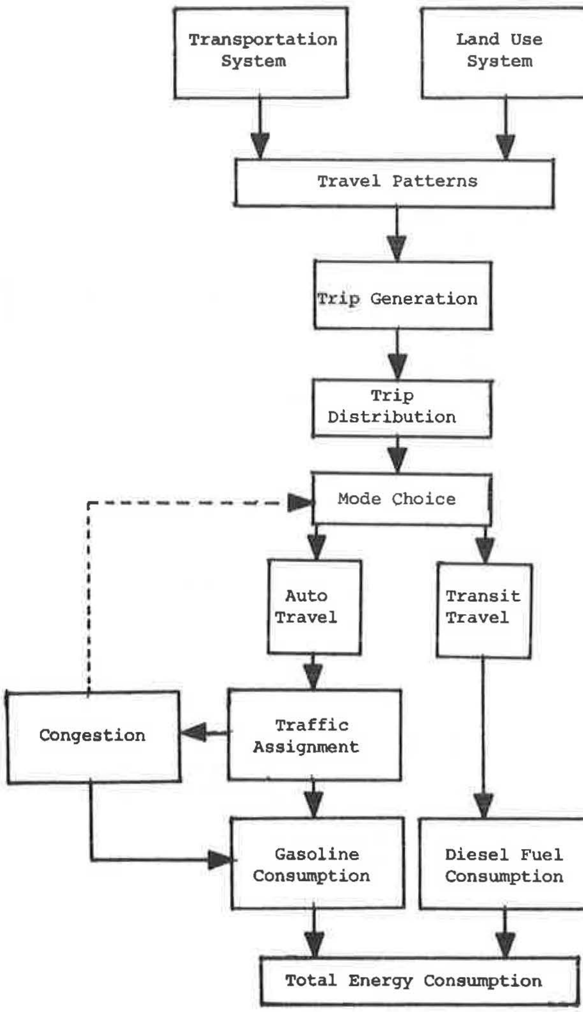
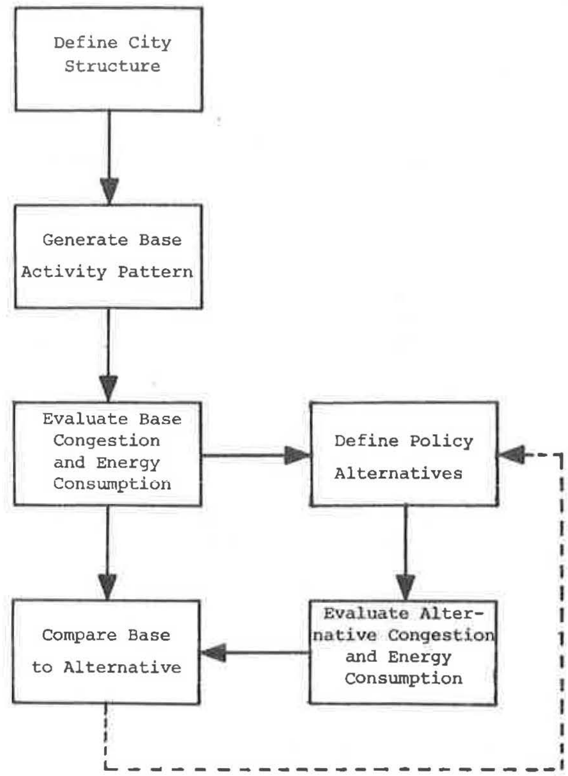


Figure 2. Overall simulation procedure.



feedback mechanism necessary to evaluate the impacts of traffic congestion on modal choice, network assignment, and energy consumption. The capability to evaluate the impacts of congestion or reductions in congestion was the heart of the modeling system. It was assumed that the overall patterns of work-trip travel demand were fixed and were unaffected by fluctuations in the cost or time required for travel. The results were interpreted as reflecting the short-term impacts that might be experienced in a situation where changes in living patterns were not immediately possible. The impacts on work-trip travel were confined to mode and route selection.

This research involved the simulation of the activity distribution and travel patterns for a hypothetical city. The overall evaluation procedure is shown schematically in Figure 2. The procedure consisted of the generation and evaluation of a base case and the evaluation of several staggered-work-hour programs in relation to base-case energy consumption. The dashed line in Figure 2 represents the feedback from policy evaluation to alternative policy selection.

City Characteristics

A concentric ring design slightly elongated along two of the major travel corridors was selected as the structure of the hypothetical city. The 52-zone structure is shown in Figure 3. The four central zones represent a central business district (CBD) with a total area of 1 mile^2. The CBD was surrounded by four concentric rings of development that had progressively increasing zone sizes toward the periphery. The total land area was approximately 100 miles^2. Total population for the test area was 100 000 and total employment was 40 000.

Population and service employment were distributed among the zones by using MOD3. The following table gives some of the input data required to describe the base activity pattern for the study area:

Item	Value
Persons working at home (%)	2.3
Value of travel time for work trips ($)	5.00
Price of gasoline per gallon ($)	1.00
Automobile occupancy rate for work trips (persons/vehicle)	1.3
Automobiles owned per household	1.3
Parking cost per day ($)	
CBD	
Work trips	2.50
Nonwork trips	1.00
Ring 2	
Work trips	1.25
Nonwork trips	.50
Elsewhere	0.00
Number of transit routes	12
Peak-period transit frequency of service (buses/h)	3
Transit bus trips per day on each route	43
Transit fare ($)	0.35
Transit transfer fare ($)	0.00
Population/employment ratio	2.5

Figure 4 shows the resultant employment distribution as generated by MOD3.

Figure 3. Zonal structure of simulated urban area.

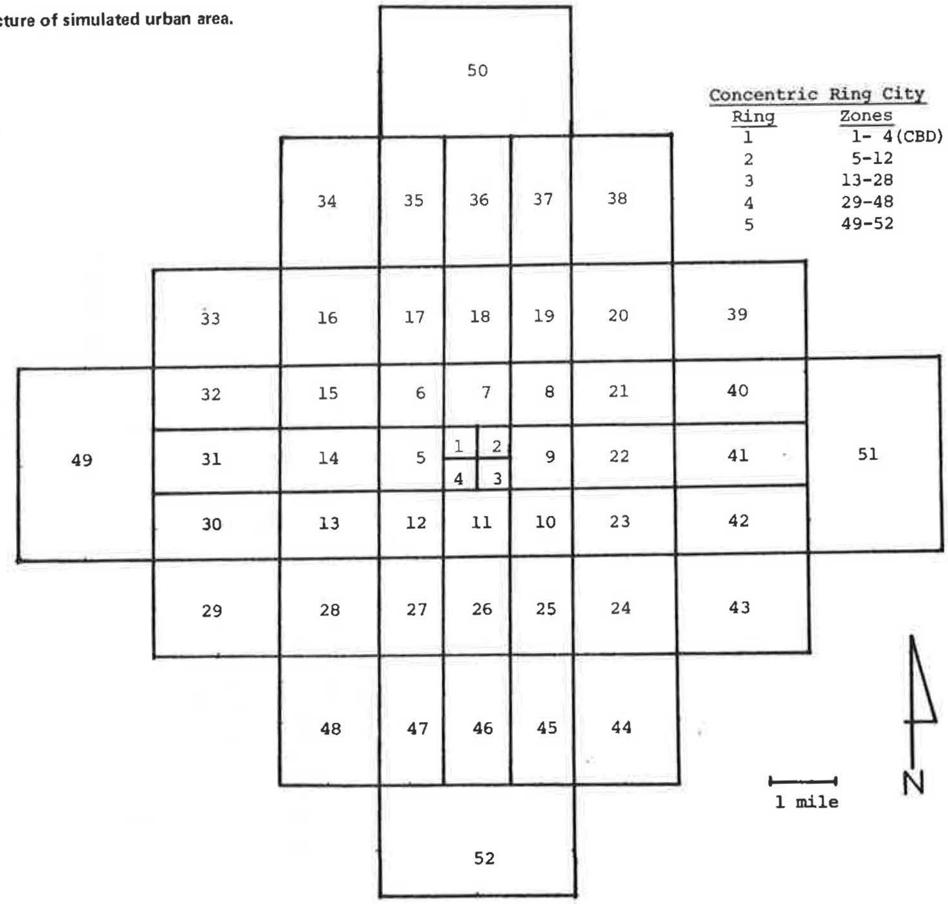


Figure 4. Total employment per zone for simulated urban area.

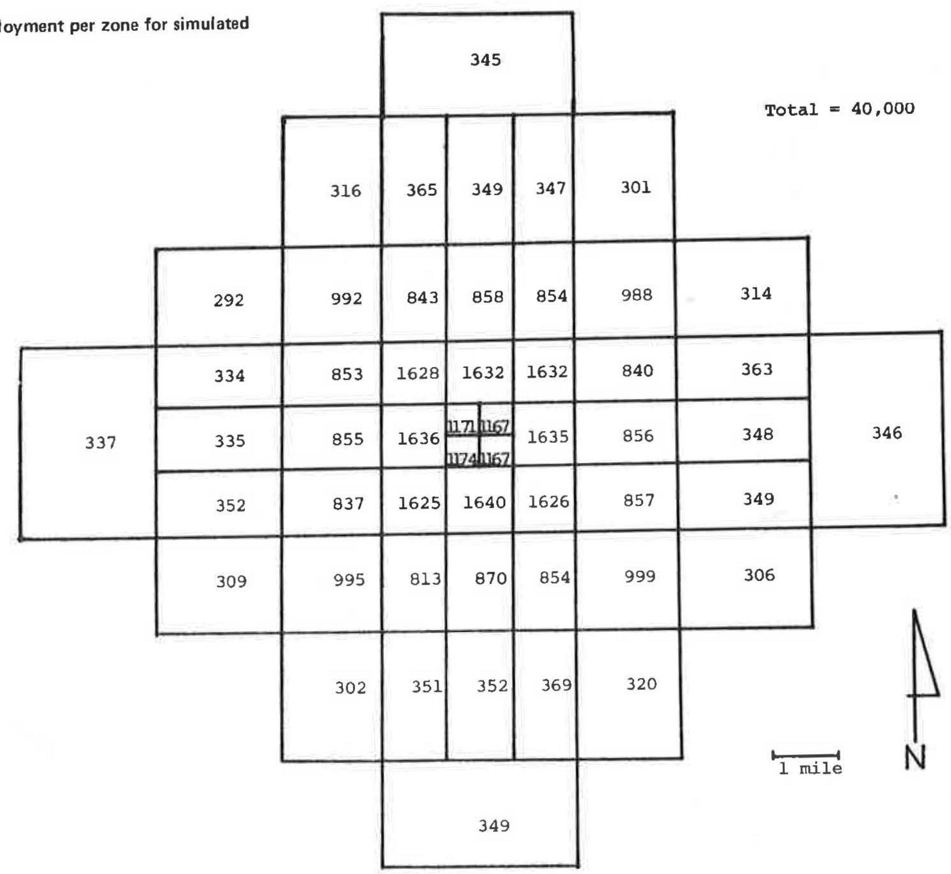
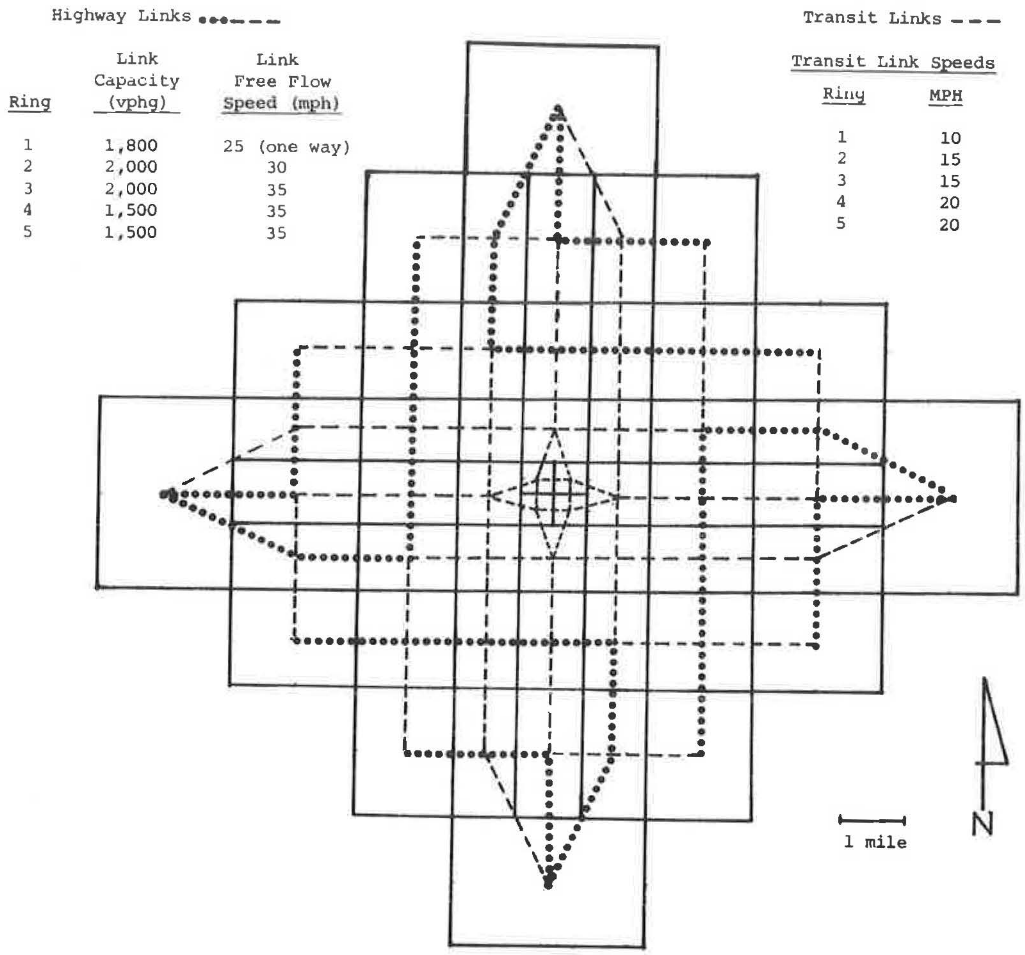


Figure 5. Highway and transit network for simulated urban area.



The highway network used in the simulation is shown in Figure 5. The network was a grid pattern and consisted solely of arterial streets connecting zone centroids. Local streets were assumed to handle intrazonal trips and therefore are not depicted. The vast majority of the highway network consisted of two-way links; the exceptions were those one-way links connecting the CBD zones. Freeway links were omitted from the city structure since, for cities of the size simulated, there are usually few, if any, freeway links used for intraurban travel. It was assumed that 90 percent of the specified link capacity was available for work trips during the peak period and that an average of 50 percent of traffic-signal cycle time was green on each arterial.

The transit network, also shown in Figure 5, is representative of urban bus routes in U.S. cities in terms of route spacing and average link speeds. The focal point of the network was the CBD, and the network was designed so that each zone had access to transit. All routes began and ended at the city periphery. Where possible, the use of multiple routes serving any single zone was avoided to enhance the capability of monitoring changes in interzonal transit ridership that resulted from individual policy alternatives.

Peak-Period Travel

To facilitate the testing of staggered-work-hour programs, the total evening peak travel period was segmented into five discrete time elements and the work-trip travel for each time element was simulated. Trip interchanges were multiplied by a factor of two to represent morning and evening peak-period travel. The sum of the energy consumed during these five time elements represented the total for both peak periods.

The peak travel period was specified to have a length of 2.5 h and was divided into five half-hour periods. Half-hour time periods were selected for three basic reasons:

1. Half-hour periods are adequate to describe the peaking characteristics of urban work travel. Simulating more time periods of a shorter duration would have resulted in only a small increase in descriptive capability at a substantial increase in computer costs.
2. O'Malley and Selinger (11) stressed that a travel time period shift of at least 30 min was necessary with a staggered-work-hour program to obtain a definite change in commuting habits.
3. The use of half-hour time periods eliminated the potential problem of vehicles from different time periods interacting on the network. This condition could not be accounted for by MOD3.

The base-case temporal distribution of evening work travel is shown in Figure 6 for computer run 1. The general shape of the distribution is similar to the distributions found in studies of urban work trips (7,11), although the peaking characteristic of the base case is slightly less exaggerated than that found in the literature. It was found that loading the simulated network with more than 50 percent of the total work trips during a half-hour period re-

Figure 6. Staggered-work-hour simulation runs.

Run No.	Zones Involved	Percent Participation	Temporal Distribution for Zones Involved: Time Period 1	2	3	4	5	Temporal Distribution for All Zones: Time Period 1	2	3	4	5
1	ALL	Base Case	--	--	--	--	--	.10	.15	.50	.15	.10
A1	ALL	60	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
A2	1-4	10	.10	.175	.45	.175	.10	.10	.153	.494	.153	.10
A3	1-4	30	.125	.20	.35	.20	.125	.103	.156	.482	.156	.103
A4	1-4	50	.175	.20	.25	.20	.175	.109	.156	.470	.156	.109
A5	1-4	60	.20	.20	.20	.20	.20	.112	.156	.464	.156	.112
A6	1-12	10	.10	.175	.45	.175	.10	.10	.161	.478	.161	.10
A7	1-12	30	.125	.20	.35	.20	.125	.111	.172	.434	.172	.111
A8	1-12	50	.175	.20	.25	.20	.175	.133	.172	.390	.172	.133
A9	1-12	60	.20	.20	.20	.20	.20	.144	.172	.368	.172	.144
A10	1-28	10	.10	.175	.45	.175	.10	.10	.170	.460	.170	.10
A11	1-28	30	.125	.20	.35	.20	.125	.120	.190	.380	.190	.120
A12	1-28	50	.175	.20	.25	.20	.175	.160	.190	.300	.190	.160
A13	1-28	60	.20	.20	.20	.20	.20	.180	.190	.260	.190	.180
A14	1-48	10	.10	.175	.45	.175	.10	.10	.174	.452	.174	.10
A15	1-48	30	.125	.20	.35	.20	.125	.124	.198	.356	.198	.124
A16	1-48	50	.175	.20	.25	.20	.175	.172	.198	.260	.198	.172
A17	1-48	60	.20	.20	.20	.20	.20	.197	.198	.210	.198	.197
B1	ALL	NA						.112	.156	.464	.156	.112
B2	ALL	NA						.133	.172	.390	.172	.133
B3	ALL	NA						.144	.172	.368	.172	.142
B4	ALL	NA						.160	.190	.300	.190	.160
B5	ALL	NA						.109	.156	.470	.156	.109
C1	6,10,14, 15,16,17, 22,23,24, 25,30,31, 32,33,39, 40,41,42, 43,49,51	10	.10	.20	.45	.15	.10					
	8,12,13 18,19,20, 21,26,27, 28,34,35, 36,37,38, 44,45,46, 47,48,50, 52	10	.10	.15	.45	.20	.10					
	1,2,3, 4,5,7, 9,11	10	.10	.175	.45	.175	.45	.10	.175	.45	.175	.10

NA = Not Applicable

sulted in unrealistically high levels of congestion.

The highway congestion index (HCI) was used as a measure of average network congestion. The HCI is the mean of all the congestion indices computed for each link of the network. The congestion index for each link is defined as the ratio of the link free-flow travel speed to the link travel speed when adjusted by the link volume of traffic. As the level of congestion increases, so does the HCI.

Policy Analysis

Staggered-work-hour policies were designed to evaluate the relations between both the magnitude of the participating work force and the level of urban work-trip fuel consumption. These policies were divided into two groups:

1. Group A--Shift travelers away from the peak half-hour in increments of 10, 30, 50, and 60 percent of the peak half-hour demand and vary the zones involved; and
2. Group B--Apply the total temporal distribution of work travel resulting from group A policies to all of the zones in the study area.

Group A policies served a dual purpose. The first was to evaluate the relation between the magnitude of the participating work force and work-trip fuel consumption. The basic test structure was to shift work travelers away from the peak half-hour period incrementally and evaluate the change in fuel consumption resulting from the temporal shift. Trips were shifted to the time periods immediately adjacent to the peak half-hour in equal amounts until the adjacent time periods each contained approximately 20 percent of the work trips originating from the zones involved in the staggered-work-hour program. Additional shifts from the peak half-hour were made in equal amounts to the half-hour periods beginning one hour before and after the beginning of the peak half-hour period. For example, as shown in Figure 6 for run A2, a total of 10 percent of the peak half-hour trips originating from zones 1-4 were shifted to the adjacent time periods 2 and 4. Areawide, 49.4 percent of the total work trips still occurred during the peak half-hour for this run, where all zones except zones 1-4 maintained the base temporal travel distribution. Similarly, for run A3, 30 percent of the work trips originating in zones 1-4 during the peak half-hour were shifted to other time periods. This was continued until a uniform temporal distribution of work travel was created for the participating zones.

The second purpose of group A policies was to test the impact of the location of the participants on fuel consumption. The simulation began with only the CBD zones (zones 1-4) participating (runs A2-A5) and progressed outward from the CBD, adding adjacent rings of zones to the staggered-work-hour program in successive program runs. For example, in Figure 6, run A8 involved the distribution of a total of 50 percent of peak half-hour trips to other time periods for zones 1-12 (rings 1 and 2). Areawide, this resulted in 39 percent of the work trips being made during the peak half-hour compared with 50 percent for the base case.

The purpose of policy group B was to test the impact of concentrating the staggered-work-hour program in selected zones as opposed to dispersing the same overall temporal distribution of trips over all zones. For five cases (runs B1-B5), the overall temporal distribution of work travel that resulted from the staggered-work-hour simulations for selected group A policies (runs A4, A5, A8, A9, and A12) was applied to all zones. For example, as shown in Figure 6, the overall temporal distribution for run B5 is the same as that generated for run A4. For run B5, all zones had the travel distribution specified in Figure 6, whereas in run A4 all zones except zones 1-4 had the base temporal trip distribution shown for run 1.

A variation of the staggered-work-hour policies was designed to coordinate the staggered-work-hour shift along selected transit corridors. This is policy group C. The purpose of this variation was to enhance the influence of the transit system on work travelers involved in the variable-work-hour program.

For run C1, 10 percent of the travelers originating in the zones along the five transit routes that traverse a general east-west direction were shifted from time period 3 (the peak half-hour) to time period 2. The same percentage of travelers originating in zones along the five transit routes that traverse a general north-south direction were shifted from time period 3 to time period 4. Zones that had transit routes along both major corridors (zones 1-4, 5, 7, 9, and 11) were given a 5 percent shift of peak half-hour travelers to both time periods 2 and 4. This run is also described in Figure 6. The policy structure described for run C1 was also used in later experiments as a basis for comparing the results of combined staggered-work-hour and transit policies.

POLICY EFFECTS ON FUEL CONSUMPTION

The total work-trip energy calculation contained data on transit fuel consumption for an entire day's travel. Since transit energy consumption is computed by MOD3 as a daily total, the contribution of transit energy consumption from each individual time element cannot be specified. However, this is not a major drawback in the analysis because the daily transit energy consumption was only 3 percent of the combined energy consumption for daily transit and automobile work trips.

The results of the simulation of the staggered-work-hour programs on automobile work-trip and daily transit energy consumption (hereafter referred to as total energy consumption) are shown in Figure 7. The results show that there is a strong relation between the percentage of work travelers shifting away from the peak half-hour period and the percentage decrease in total energy consumption. The smooth curve shown was manually fitted to the data and represents the approximate relation between work-trip travel-time shift and potential energy savings. This relation asymptotically approaches a 12.2 percent energy savings for work travel at the point where the temporal distribution of work travel is uniform over the length of the peak period.

The curve in Figure 7 indicates that the potential for energy savings from staggered-work-hour programs appears higher than the 1 percent savings indicated by previous research (3). For example, a 10 percent shift of work travelers away from the peak half-hour resulted in a 4 percent savings in energy. A 10 percent shift appears to be a realistic goal for such a program based on earlier studies (6,11).

The results also indicate that a greater savings in energy can be realized through a staggered-work-hour program that covers a dispersed area of influence rather than being concentrated in a small area. For example, in Figure 7, the data points marked by the symbol "+" represent group B policies. Group B policies have the same total number of participants in the staggered-work-hour program as specific group A policies. However, group B policies are applied to the entire urban area whereas those in group A are concentrated. In four of five simulations, the citywide program resulted in a greater reduction in energy consumption than the associated program in a more concentrated area. The magnitude of the difference between the group A and group B policies decreases as the total area of participation for group A policies increases.

The influence of a dispersed program compared with a concentrated program is more clearly shown in Figure 8. Here, the curves represent the trend of energy consumption versus percentage of traveler shift for each successive ring of zones added to the program. As successive rings of zones were included in the staggered-work-hour program, the trend was for a greater reduction in energy use for a given percentage shift in travelers from the peak half-hour. This difference became less pronounced as a larger percentage of travelers participated in the program. However, there was virtually no change in energy consumption with increased participation in staggered work hours when the program was concentrated in the CBD (ring 1).

The anomaly of the relation between staggered-work-hour participation and energy use for the CBD can best be explained by the fact that the majority of the simulated work trips to these zones were relatively short in length (generally only to the second or third ring) and were routed over only a few highway links. In addition, the highway links within the CBD were relatively uncongested. The combination of short trips and uncongested links resulted in no change in energy consumption. This result is consistent with the literature, which suggests that the effect of a concentrated program on congestion is lost within approximately 2 miles of the program location (8,12).

Similar results were obtained when congestion was treated as the dependent variable. All staggered-work-hour programs tested had a direct impact on highway congestion except those policies concentrated in the CBD zones, as shown in Figure 9. The percentage reduction in congestion resulting from staggered-work-hour policies increased as the program became more dispersed and included more zones. The maximum decrease in mean network congestion (based on the HCI) was approximately 44 percent.

The relation between highway congestion and energy consumption generated by the simulation is shown in Equation 1. This regression relation exhibits a strong linear tendency, resulting in an r^2 value of 0.97 (using the data from all of the simulation runs):

$$y = 0.20 + 0.27x \quad (1)$$

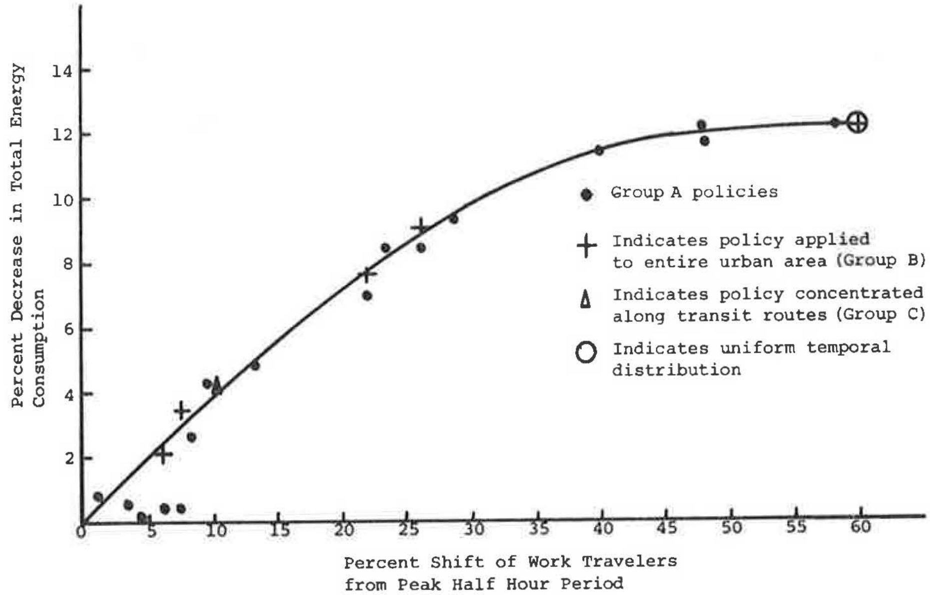


Figure 7. Impact of staggered-work-hour policies on total energy consumption.

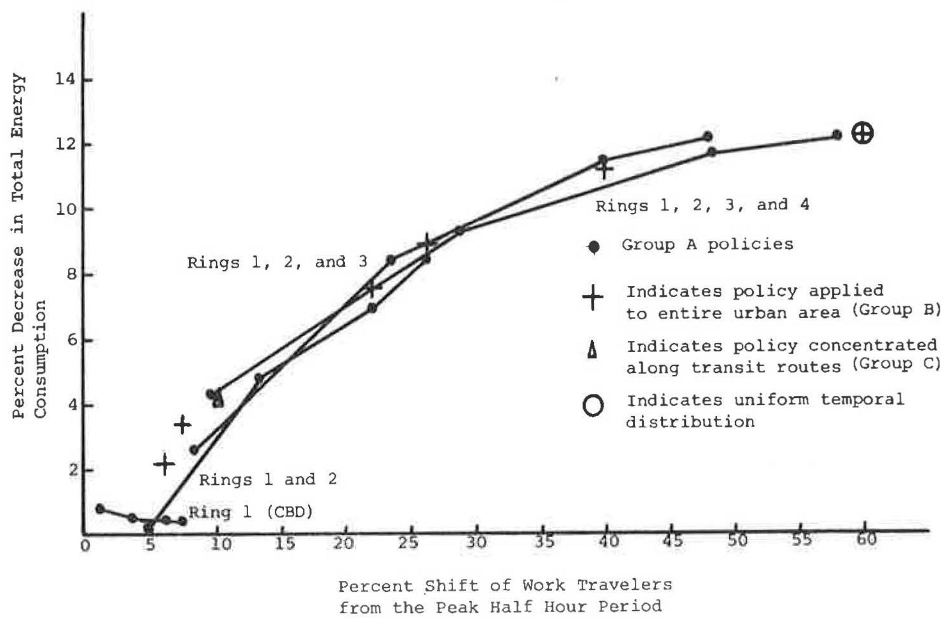


Figure 8. Impact of staggered-work-hour policies on total energy consumption by location of participating zones.

where $\hat{y}$ is the estimate of the percentage reduction in total energy consumption and x is the percentage decrease in the weighted mean HCI. The maximum reduction in energy consumption was approximately 12 percent for a reduction of 44 percent in the HCI.

The reduction in the HCI would have resulted in an even greater decrease in energy consumption had a modal shift to automobile travel not occurred as a result of the decrease in network congestion. The relation between the percentage change in bus ridership and the percentage change in the HCI generated by all of the simulation runs can be expressed by the following linear regression equation:

$$\hat{y} = -0.65 + 0.21x \quad (2)$$

where $\hat{y}$ is the percentage change in bus ridership and x is the percentage change in the weighted mean HCI.

The regression analysis resulted in an r^2 value of 0.91, which indicates good linear correlation. This result indicates that a decrease in congestion due to the implementation of a staggered-work-hour program would have a negative impact on work-trip bus ridership unless steps were taken to deter the modal shift. The possibility still exists that during an energy shortage transit ridership would increase even with the implementation of a staggered-work-hour program. Under conditions of normal fuel availability, this does not appear likely.

Automobile work trips were affected by the reduction in congestion resulting from the staggered work hours. The parameters most affected by the staggered-work-hour policies were automobile work-trip time and speed. Figure 10 shows the relation between the percentage of work travel shifted during the peak half-hour period and the decrease in automobile work-trip travel time. The family of curves again suggests that concentrating these programs in a small area (the CBD) is less effective than a more dispersed approach. There is a distinct advantage in reduced work-trip travel time through the implementation of staggered-work-hour programs. The amount of the decrease in travel time depends on both the location of the program and the number of participants.

The relation between the reduction in mean automobile work-trip travel time and the savings in energy resulting from the simulated staggered-work-hour programs is as follows:

$$\hat{y} = 0.02 + 0.74x \quad (3)$$

where $\hat{y}$ is the percentage decrease in total energy

Figure 9. Impact of staggered-work-hour policies on highway congestion.

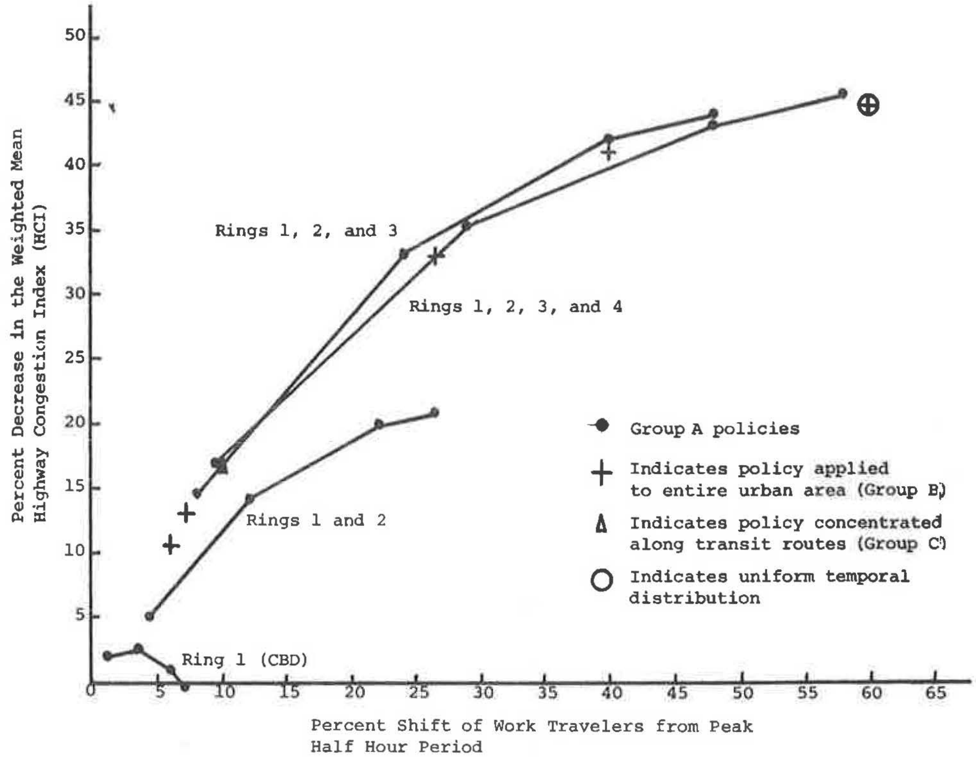
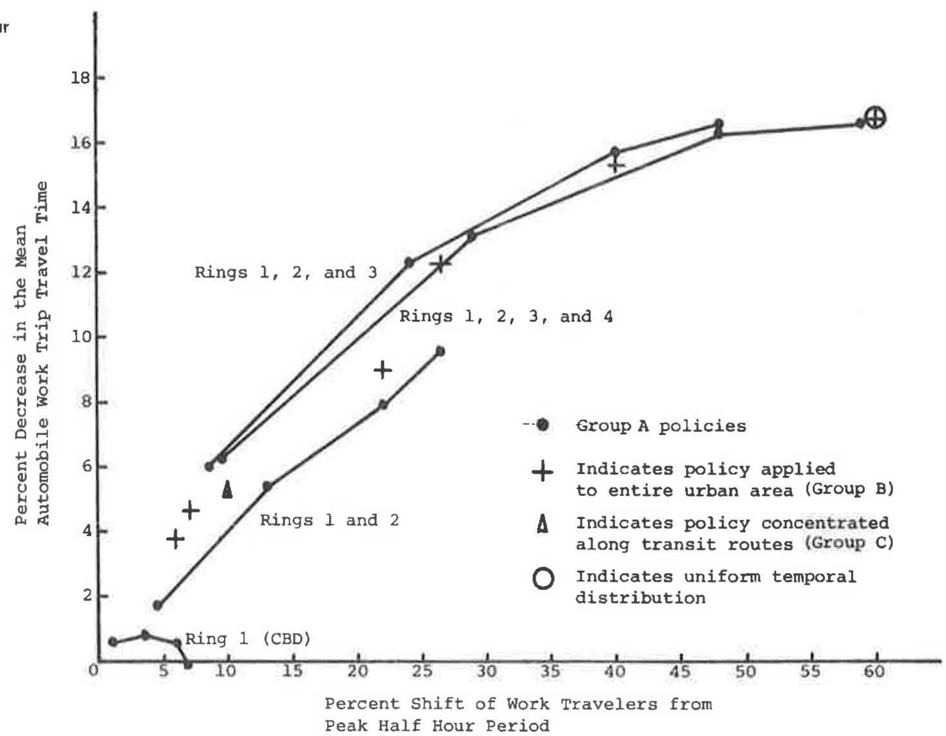


Figure 10. Impact of staggered-work-hour policies on automobile work-trip travel time.



consumption work trips and x is the percentage decrease in mean automobile work-trip travel time. The r^2 value for this relation was 0.96.

SUMMARY

For the activity pattern simulated by this research, it has been shown that staggered-work-hour programs can reduce highway network congestion and hence reduce automobile work-trip energy consumption. The reduction in total energy consumption (automobile work trips plus daily transit) was a maximum of approximately 12 percent with a uniform temporal distribution of work trips. A more realistic goal of a 4 percent reduction in total energy could be achieved with only a 10 percent shift in work travelers away from the peak period.

However, the effectiveness of a variable-work-hour program also depended on the location of the program. It has been shown through simulation that concentrating the program in a small area, such as the CBD, was less effective (approximately 85 percent) in reducing energy consumption than a program that involved the same number of travelers working at locations that were evenly dispersed over the urban area. This result is consistent with other research efforts (8,12) that have indicated that the effectiveness of a staggered-work-hour program was lost within approximately 2 miles of the workplace.

Under the conditions simulated, staggered-work-hour programs had a negative impact on work-trip transit ridership. The decrease in congestion during the peak half-hour period resulted in a proportional decrease in automobile travel time, which in turn resulted in a modal shift to the automobile. A 10 percent shift in travelers from the peak half-hour resulted in a 12-17 percent change in the HCI, depending on the location of the staggered-work-hour program. This resulted in a 2-3 percent decrease in work-trip bus ridership. The maximum decrease in transit ridership was approximately 9 percent as a result of the uniform temporal distribution of work travel.

This research study involved several limitations that may restrict the application of the results. The limitations stem primarily from the simulation technique and its scope of application. Details of these limitations are contained in earlier reports (9,10).

A hypothetical urban structure was used for the simulation. The shape and size of the area simulated may have had an impact on policy effectiveness. This possibility was not investigated in the study. Whether or not the policies tested would be more or less effective for a larger urban area, or in an area that had a different spatial distribution of population and employment, is unknown.

The relation between policy effectiveness and alternative transportation infrastructures also remains to be investigated. Changes in the highway network structure or the addition of expressways may alter policy effectiveness. This may also be true for alterations in the transit network structure, such as changes in route configuration or the addition of a rapid transit system. Changes in transit supply and efforts to coordinate supply changes with the staggered-work-hour program could also affect the results.

The algorithm for transit fuel consumption did not explicitly consider the number of transit stops per mile or the effect of highway congestion on transit speed. These considerations could alter work-trip modal choice, although the direction of this impact is unknown.

Planning for energy contingencies is a complex process. The evaluation of many policy alternatives is necessary for each individual urban area. The results of this research indicated that staggered-work-hour programs could be a valuable tool in reducing work-trip energy demand and should be given consideration as an operationally inexpensive method of reducing gasoline consumption.

The high potential for energy savings through implementation of staggered work hours indicated by this study suggests that further research should be done to expand on these results. This should be done with the objective of answering the questions raised by the limitations of the research, to further expand the modeling system, and to test other TSM policy alternatives individually and in combination.

REFERENCES

1. Energy, the Economy and Mass Transit. Office of Technology Assessment, U.S. Congress, Dec. 1975.
2. J.H. Dupree and R.H. Pratt. Low-Cost Urban Transportation Alternatives: A Study of Ways to Increase the Effectiveness of Existing Transportation Facilities--Volume I: Results of a Survey and Analysis of Twenty-One Low-Cost Techniques. Office of the Secretary, U.S. Department of Transportation, Jan. 1973.
3. A.M. Voorhees and Associates, Inc. Guidelines to Reduce Energy Consumption Through Transportation Actions. UMTA, Rept. UMTA-IT-06-0092-74-2, May 1974.
4. R. Remak and S. Rosenbloom. Peak-Period Traffic Congestion: Options for Current Programs. NCHRP, Rept. 169, 1976.
5. J. Gross, M. Kocis, and G. Cohen. Preliminary Techniques for Estimating the Net Energy Savings of TSM Actions. Planning Research Unit, New York State Department of Transportation, Albany, Oct. 1978.
6. J.M. Betz and J.N. Supersad. Traffic and Staggered Working Hours. Traffic Quarterly, Vol. 19, No. 2, April 1965.
7. G.L. Santerre. An Investigation of the Feasibility of Improving Freeway Operation by Staggering Work Hours. Department of Civil Engineering, Texas A&M Univ., College Station, M.S. thesis, May 1966.
8. A.A. Tannir. The Impacts of Flexible Work Hours and Compressed Workweek Policies on Highway Networks, Transportation Economics, Organizations and Employees. New York State Department of Transportation, Albany, Preliminary Res. Rept. 129, Aug. 1977.
9. R.L. Peskin and J.L. Schofer. The Impacts of Urban Transportation and Land Use Policies on Transportation Energy Consumption. Office of University Research, U.S. Department of Transportation, Rept. DOT-TST-77-85, April 1977.
10. J.M. Witkowski. An Analysis of the Energy Conservation Potential of Variable Work Hours and Alternative Transit Policies for the Urban Work Trip. Department of Civil Engineering, Michigan State Univ., East Lansing, Ph.D. dissertation, Dec. 1980.
11. B.W. O'Malley and C.S. Selinger. Staggered Work Hours in Manhattan. Traffic Engineering and Control, Vol. 14, No. 9, Jan. 1973.
12. R. Safavian and K.G. McLean. Variable Work Hours: Who Benefits? Traffic Engineering, Vol. 45, No. 3, March 1975.