Energy Requirements in Urban Transportation

by

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INTRODUCTION

Energy in all of its forms is one of the five life support systems that underlie the social and economic organization of a modern society and an urban one especially. Any major shortages in energy supplies will significantly modify the ways in which a society may operate as well as its future potential for stability and growth. This is especially evident in the area of transportation. On the one hand, transport is the means for exchange of raw materials and finished products while on the other, it is the means for linking labor with the production facilities. These two linkages are the essentials for any modern economy. Beyond the strictly economic production sector, it is also clear that the urban resident in particular, depends directly upon his own transportation for the whole range of goods and services that make urban living feasible. Any marked reduction in energy supplies that will reduce the mobility of the urban population will generate economic and social consequences that inescapably will reduce the standard of living for some portion of the residents of those regions.

At the present time, there is a major concern over the supply of petroleum energy. And since transportation is most sensitive to changes in petroleum supply, it is in this domain that the greatest concern is expressed. Since at least an imbalance in supply and demand relationship is likely to occur in the relatively near future, it becomes essential to examine the likely time frame of its occurrence and the magnitude of its effects. Furthermore, if those effects are to be minimized, it is also necessary to examine alternative policy options which offer means for conserving energy or reducing the demand. It is the purpose of this paper to evaluate the severity of the present petroleum energy situation as it may affect transportation in urban areas and then to evaluate certain policy options that appear to bring supply and demand into better balance.

ENERGY SUPPLY AND DEMAND

In order to dimension the magnitude of the energy supply and demand problem, it is necessary to place the supply and demand issues in perspective. Then it is necessary to evaluate the uses and users of energy and their magnitude of use. In order to do this, the data developed from four sources have been used. (Goss & McGowan, 1972; National Petroleum Council, 1972; Shell Oil Company, 1972; OEP Report, 1972). Total energy consumption by sectors is shown in Table 1. As may be seen, 24% of all energy consumed in the United States was for transportation. About 96% of this total was in the form of petroleum products. It should be recognized, that although the distribution of demand is about equal among the four classes of use, it is transportation that is most dependent upon petroleum and most sensitive to changes in supply.

Among transportation uses, the demand is shown in Table 2. As may be seen, approximately 80% of all transportation energy supplied by petroleum is for highway vehicles. This includes automobiles, trucks and busses.

As may also be seen from Table 2, approximately 50% of all transportation energy use is expended in urban areas. Of this total, approximately 31% of the national total is used for person movements in urban

Table 1

National Energy Use

Use:	Amount (10^{15} BTU)	% of Total U.S. Consumption
Utilities (Electricity Conversion)	11.6	17.1
Industry	20.0	29.5
Residential / Commercial	15.8	23.3
Transportation	16.3	24.0
Non-energy	4.1	6.1
Total	67.8	100.0 %

Table 2

% Transport Energy by Use

Use	% of all U.S. Trans Energy
Intercity, Rural Auto	26.4
Air	11.4
Intercity Rail	3.5
Waterway, Pipeline	1.4
Intercity Bus	0.2
Intercity Truck	7.0
Local Truck	14.9
Urban Auto	30.7
Urban Rail	0.1
Local Bus	0.6
Other	3.8

areas. This is shown in Table 3 along with the statistics of vehicle and passenger miles as well as energy consumption in BTU for each of the modes. The important aspects of these data are the facts first that 98% of the energy consumed in urban areas is consumed by automobiles. The second is that in terms of energy consumed per passenger mile, buses are consuming about six times the energy of automobiles or commuter railroads. This is due, of course, to the low average loading of buses over most of their route lengths. This will be discussed further.

This description of utilization of energy in transportation may now be compared with the supply problems emerging in petroleum. The estimates of demand in millions of barrels per day are shown in Table 4. This table contains three independent estimates of petroleum consumption. They are all reasonably consistent both in estimating consumption in 1970 and projected consumption for 1975. In all cases, the assumption is that demand will increase at a rate of about 4% a year.

The supply side is shown in Table 5. In order to obtain the needed quantitites of petroleum, the amount that must be bought in foreign markets will increase from 23% to about 50% by 1975. World oil reserves are certainly adequate to supply the 8-11 million barrels of crude oil that represents the U.S. deficit. There is some question whether the refinery capacity is or will be adequate to convert all the imported crude to meet the expected demand currently projected. Furthermore, there are some serious problems associated with the transporting of large quantities of refined petroleum products relating both to storage and transfer. In

Table 3

Current Performance of Urban Transport Modes

Mode	% of all U.S. Trans Energy	% of all pass Urban Trans Energy	Total Energy (BTU)	Veh-Miles	Pass.-Miles	Assumed Occup / Veh	BTU / Veh. Mi.	BTU / Pass. Mi.
Urban Auto	30.7	97.7	5.5×10^{15}	4.94×10^{11}	1.08×10^{12}	2.2	10223	4647
Urban Rail	0.1	0.3	2.0×10^{13}	3.37×10^{7}	4.59×10^{9}	135	588235	4355
Urban Bus	0.6	2.0	1.2×10^{4}	1.41×10^{9}	4.43×10^{9} 5.64×10^{9}	3(rev)pass 4 pass	85714	27088 21277
Total Urban Transport	31.3	100	5.64×10^{15}					

Table 4

Petroleum Demand

Source of Estimate	1970	1975
Shell	14.4 MMB/D (app.)	20 MMB/D (p. 20)
NPC	14.7 MMB/D	17.4 MMB/D
		17.5 MMB/D
		18.2 MMB/D
		19.7 MMB/D
	15.6 MMB/D	18.2 - 19.2 MMB/D
OEP	16.05 MMB/D	17.7 MMB/D

Table 5

Petroleum Supply

Domestic		1970	1975
Shell		11 MMB/D	9 MMB/D
NPC		11.3 MMB/D	9.8 MMB/D
			10.2
			10.2
			9.7
			9.6
Foreign			
NPC		3.4 MMB/D (23%)	7.2 MMB/D (42%)
			7.4 MMB/D (43%)
			8.5 MMB/D (48%)
			9.7 MMB/D (51%)
Shell	Refined Products	2 MMB/D	5.5 MMB/D
	Overseas Crude	.7 MMB/D	4.0 MMB/D
	Canadian Crude	.7 MMB/D	1.5 MMB/D
		3.4 MMB/D	11.0 MMB/D

addition, over the short run, at least, the United States is ill-equipped to import large quantities of petroleum, crude or refined. There are no facilities on any coast for handling VLCC tankers. Finally, there has not been a new refinery start in the United States in the past two years.

In summary, there is a clear imbalance in petroleum supply within the United States. There are adequate supplies to meet U.S. needs elsewhere in the world for a reasonable period of time. However, the dependence of the economic and social viability of the American society on imports poses serious economic and political problems. A dollar outflow of between 15 and 30 billion dollars for petroleum alone over the next 20 years can be disastrous in international monetary terms. For the short term, between 1973 and 1983, there is likely to be chronic petroleum shortages in the United States because of inadequate port facilities and refinery capability. Consequently, it would appear imperative to consider alternative means to reduce petroleum consumption.

URBAN TRANSPORT EFFICIENCY

In most metropolitan areas of the United States, approximately 50% of all travel is for work trips while the other half is for all forms of discretionary travel within the region. However, 65-75% of the total vehicle miles of travel are expended in work trips. In the Chicago area, the median trip length for work trips is approximately 13 miles, while for non-work trips within the urban area, the median trip length is 6-7 miles. Of the 6.7 million work trips projected for 1975 in the Chicago region, 60-90% will be made by automobile. The modal breakdowns for work trip travel are summarized in Table 6. Furthermore, the number of passen-

Table 6

Estimated Urban Vehicle Travel in Chicago

Mode	In-City Trips	Out-City Trips	Total Trips
Auto	1.81×10^6	2.6×10^6	4.4×10^6
Bus	$.87 \times 10^6$	$.1 \times 10^6$	1.0×10^6
Rail	$.35 \times 10^6$	$.3 \times 10^6$	$.65 \times 10^6$
Total	3.03×10^6	3.0×10^6	

gers carried by these automobiles is quite low compared to their capacity, with a median of 1.3 passengers for work trips and about two passengers for non-work trips.

The reasons, both for the dependence upon the automobile and the low load factors of all forms of urban transport, are fairly straightforward. First, there has been a steady diffusion of residential locations into low density suburban locations. Second, there has been a comparable diffusion of employment sites to locations outside the city. Consequently, the density of demand for travel from any zone of origin to any zone of destination has steadily declined. Hence, the number of people going from the same area to the same destination has diminshed continuously over the past 20 years. The likelihood of ride sharing thus must diminish,and hence, the low number of people per vehicle.

In addition, the concentration of mass transit on service to the city center rather than to suburban job locations has made public transportation increasingly disutile for the fastest growing segments of the metropolitan travel market. Substantively in Chicago, 85% of all work trips to the central busines district are now carried by public transport. However, these trips represent only 9% of all the work trips in the region. The city of Chicago is well endowed with transit capacity, unlike most other cities and the competitive position of that system is somewhat better than most other transit systems. However, it is playing, at present, a clearly limited role in serving the transport needs of the region.

Within the context of the use of transportation within any metropolitan region, it is reasonable to examine the potential performance of currently available people movers. These are shown in Table 7, which may be compared with the figures shown in Table 3, and indicate how far from optimal performance existing transport systems are being utilized. On the average, the automobile is costing 4647 BTU/passenger mile. If it could be fully loaded, it would use between 1300 and 2800 BTU/passenger mile. The picture is even worse for mass transit vehicles. Commuter rail is currently operating at 4355 BTU/passenger mile, while they could, if fully loaded, be using only 685 BTU/passenger mile. Urban buses consume energy with their present loadings of 21,277 BTU/passenger mile, when they could be operating at 1548 BTU/passenger mile under full load conditions. In sum, under present operating conditions, urban automobiles are running at about 50% of maximum efficiency. Commuter rail is running at 25% of maximum efficiency and urban buses at 5-10% of maximum efficiency.

It is clear from this analysis that there are fixed energy costs associated with all types of transportation systems. Unfortunately, the most mechanically efficient are operating at such low load factors that their actual energy expenditure is exorbitant. Simply expanding the length or numbers of mass transit routes will not improve the situation unless the loadings can be significantly increased over a large proportion of the route length. Similarly, the automobile can be made more efficient under present urban structure only if passenger loads can be increased. Given present urban structure increasing the loadings of autos or mass transit in present operating forms does not appear feasible. Consequently, it is becoming increasingly clear that rather radical changes in urban transport will be required to make reductions in transportation energy

Table 7

Optimal Performance of Various Modes as Commuting Modes

Modes	Occupancy	BTU / Seat-mile
Sub-compact auto	4	1300
Standard auto	6	2817
Commuter train (2-level)	360	722
Commuter train	–	650
Urban bus	42	1548

consumption.

ALTERNATIVES FOR ENERGY CONSERVATION

From the previous discussion, it is obvious that petroleum energy utilization for urban transportation is highly inefficient under present operating conditions. Furthermore, in the face of the physical and economic problems associated with petroleum supply, major energy conservation measures will have to be undertaken over the short run. Over the long run, American dependence upon petroleum, for transportation especially, will have to be ended. Clearly, such a conclusion must mean serious dislocations and changes in mobility within urban areas especially. The fundamental question then becomes: what alternatives are available that will reduce the demand for petroleum and what kinds of reductions can be obtained from them? In the end, it is the selection of certain policies for implementation that will determine the magnitude and duration of any dislocations that petroleum shortages may incur.

It would appear reasonable, therefore, to examine a range of alternatives, evaluate the benefits to be derived and select one or more for exploitation that appear to be the most cost effective. The purpose of this part of the report is to carry out a series of scouting calculations on a series of possible alternatives for reducing petroleum energy demand in urban transportation. It should then be possible to, at least, order the classes of alternatives in terms of their potential pay off for conserving energy.

The first step in this process was to identify a set of energy conservation means. There are two constraints that operate in this selection.

One relates to the technical, not political feasibility of the alternative. If the alternative can be physically implemented, it can enter the set for evaluation. The second constraint relates to time. If the alternative can be implemented within the next decade, then it can enter the set. Thus, power from hydrogen fusion does not appear to enter the state of the art prior to the year 2000 and hence was excluded.

We have also chosen to exclude strictly economic mechanisms for control. Whether one is talking of pricing policies, taxation or rationing supply, it appears to us that the externalities of these devices alone would appear to be very great. More importantly, the nature of urban travel demand is such that major modification of transport usage is unlikely by economic controls alone. In essence, there is today, little elasticity of transport demand. Also eliminated from consideration were those alternatives for which no mechanism for enforcement was included. Increased automobile occupancy is an example. Although obviously advantageous, the conditions for obtaining or ensuring significantly increased occupancy are not practically possible. Finally, different propulsion systems were not considered, since with the exception of the fuel cell-electric motor, none offer significant energy savings. Consequently, only those alternatives were considered which could reduce transport demand or increase the efficiency with which the projected demand could be met.

Within these constraints, six alternative possibilities were identified for further evaluation. These are listed in Table 8. As may be seen, they fall into three classes of policies. One is land use and

Table 8

Means of Reducing Energy Consumption

1. Land Use Zoning
2. Optimize Traffic Flow
3. Increased Utilization of Mass Transit
4. Vehicle Size Limits
5. Personal Rapid Transit System
6. Substitution of Communication for Transportation

organization. Two is modification of existing urban transport technology. Three is technological innovations for satisfying urban transport demand. Each of these six were evaluated using data from the Chicago metropolitan region. Hence, all the energy savings derived in these analyses apply to that region.

1. Relocation of residences relative to work places

Since 50% of all urban trips are work trips and these trips account for approximately 75% of the total vehicle miles of intra-urban travel, anything that reduces the median trip length must yield significant energy savings. One way in which this can be accomplished is to ensure that residential location choices are made in relation to work place location. If it were possible to control residence location such that no worker was more than five miles from his work site, then the median work trip length would be reduced by two-thirds of that presently experienced in the Chicago region. This may be examined parametrically by evaluating the reduction in oil consumption for different median trip lengths (shown in Table 9). These estimates are based upon no changes in mode split from the present. This leads to a conservative estimate since for relatively short and spatially concentrated work trip travel, mass transit would once again be appropriately sized to efficiently serve the market.

A more realistic assumption upon which to evaluate a restructuring of spatial locations of residence relative to employment sites is to assume that the changes would occur slowly over the decade. This seems reasonable since any desirable spatial goal probably cannot be obtained without an incentive policy such as a tax benefit for living proximally

Table 9

Effects of Median Trip Length Change on Energy Consumption*

	Median Trip Length (Miles)			
	4	7	10	13 (current)
Auto Energy Use	33630	58860	84100	109310
Rail Energy Use	1880	3300	4710	6120
Bus Energy Use	11780	20620	29460	38300
Total Energy Use (BBI/d)	47290	82780	118270	153730

* in Barrels/day

to employment, or a low interest loan to buy or move to proximal housing. Conversely, a transportation tax or a graduated income tax on travel could be instituted. Jointly, such policies might generate a slow redistribution. If one assumes that such incentive programs would generate such shifts and conservatively at a rate of say 10% a year, we can analyze the effects on petroleum consumption over the next decade. The data shown in Figure 1 are based upon a reduction in median work trip length of 10% a year from thirteen miles, now the figure in the Chicago metropolitan area. As may be seen, the savings would be significant over that time period, i.e., (65%).

2. Optimize Traffic Flow

Some of the most significant wastes of energy occur as a result of traffic congestion. Energy consumption is highest under conditions where automobiles (and buses) must make repeated accelerations. The loss is even higher for vehicles idling under stopped traffic conditions. If the flow of traffic can be smoothed and stops minimized, significant savings in energy consumption may be obtained. These benefits are potentially available with the instituion of better street capacity utilization, area-wide traffic control systems, and electronic aid systems in the highway and the vehicle. Work over the past decade would suggest that such systems are within the state of the art and can be installed in existing highways and vehicles. Such systems as automatic routing systems, inter-vehicle spacing control systems, ramp metering and merge control systems and network traffic surveillance and control systems are not cheap except relative to new highway construction. The best estimate

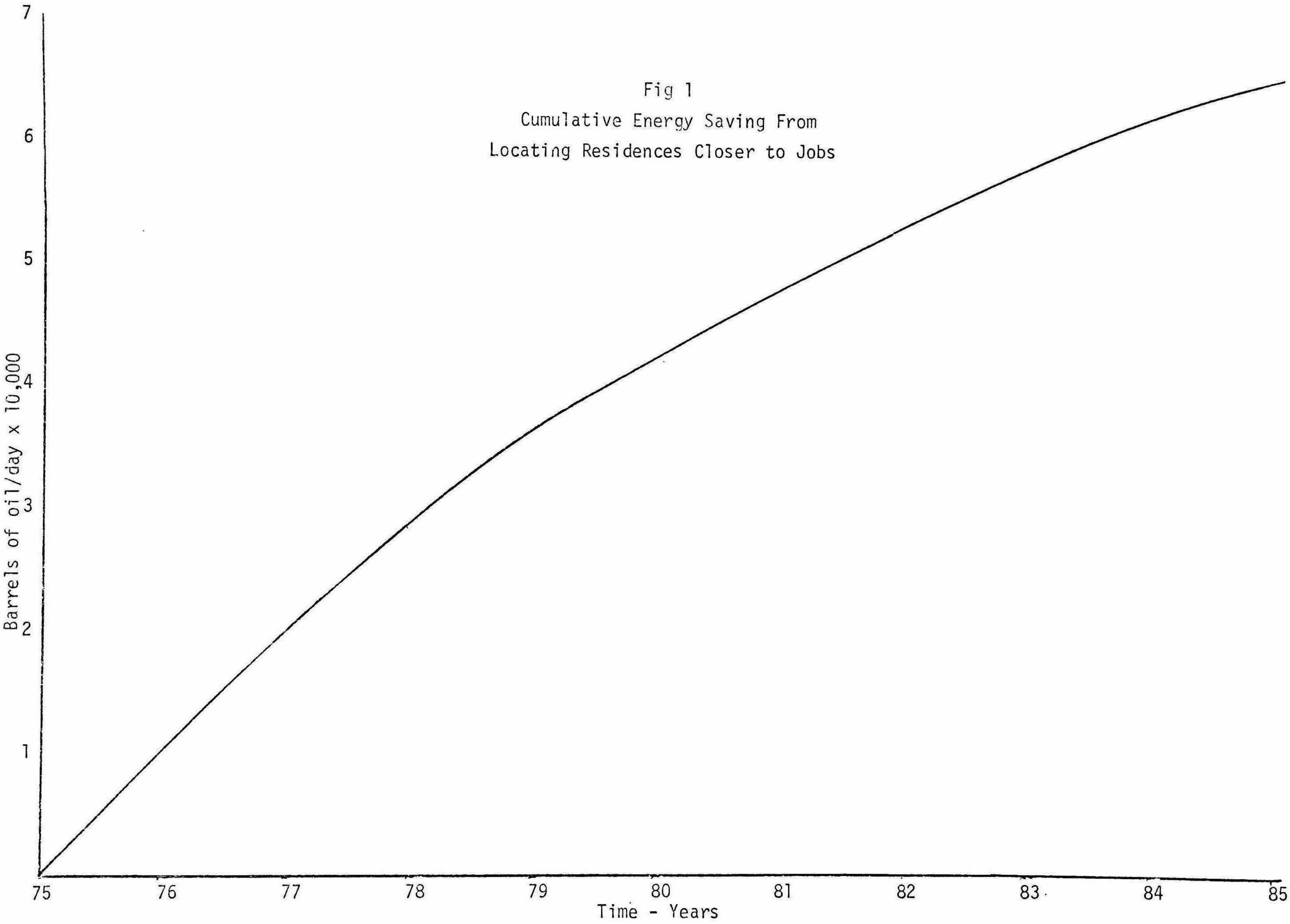

Fig 1
Cumulative Energy Saving From
Locating Residences Closer to Jobs

for a region the size of Chicago would be between 1-10 billion dollars.

Such systems, if fully implemented, appear to generate an effective increase in street capacity of somewhere between 20-30%. On the assumption that the average speeds on the network would remain at 15-20 miles per hour, optimizing traffic flow would generate a saving of 1100-1200 BTU/pas. mi. In the Chicago region, this would mean a saving of approximately 10^{11} BTU/day or approximately 17,000 barrels of oil per day.

3. Increased Utilization of Mass Transit

From an energy consumption standpoint, mass transit is attractive because it is a relatively insensitive consumer of energy in relation to loading. Hence, from a passenger mile standpoint, a fully loaded bus or commuter train consumes the same amount of energy as an empty one. (For buses, this is not strictly true, (Rice, 1970) but for our purposes it is a reasonable assumption.) The question is how, in this metropolitan region or any other one, can work trip travelers be made to shift to these modes? From recent work done in the Chicago region (Transportation Center, 1973) the issue is one of utilization of the transit capacity in those ways that most efficiently link residences in city and suburb to work places in city and suburb. At present, transit provides this accessibility only for work places in the city. As was shown in that study, 80% of the residences in Cook County region can reach only 5% of the employment sites in the region within an hour by mass transit. If however, all the existing capital investment were coordinated and integrated, it would be capable of linking 80% of the residences to 20 to 35% of the employment sites in the region.

If such an integration of service were initiated in the region, some significant modal shift from automobiles to mass transit could be expected. A reasonable estimate of the possible shift would be of the order of 10-20%. Under present assumptions, each suburban auto user drives a median 19 miles per work trip, while city auto users drive a median of 7 miles per work trip (Transportation Center, 1972). This is the equivalent of 88,293 BTU/trip and 32,529 BTU/trip respectively, assuming an average of 4647 BTU/mile for automobiles. Then a 20% shift in suburban drivers to mass transit and a 15% shift of city drivers to transit would generate a saving of 9430 barrels of gasoline per day.

4. Vehicle Size Limits

One of the major costs in energy is the fact that somewhere in the order of two-thirds of the urban travel by automobile is done in full size vehicles. Since a full size vehicle consumes energy at a rate three times that of a sub-compact, it seems reasonable to examine the energy savings from a policy that required all urban travel by automobile to be done in small vehicles.

In order to make this estimate for work trips in the Chicago region, the total number of vehicles making work trips may be estimated for the region. There are approximately 4.4×10^6 person trips made by automobile in this region per day and they involve approximately 1.75×10^6 separate vehicles. Given a median trip length of 13 miles, this means that there are approximately 6.2×10^7 auto miles of work trip travel. Two thirds of these trips are made by vehicles consuming 16,900 BTU/mi., and one-third are made by smaller vehicles consuming 5200 BTU/mi.

If the proportions of large and small vehicles could be reversed, a substantial energy savings should be obtained. Calculations were made for this mix and were found to generate a saving of 37,000 barrels of oil/day. This represents a 35% reduction in total work trip energy consumption.

5. Personal Rapid Transit System

A new technology for urban transportation that may offer energy savings is personal rapid transit. For this evaluation an electric powered, dual-mode system was used. Basically, this assumed a 1500 lb. vehicle driven at a speed of 20/mph no more than one mile to a guideway. The vehicle would enter the guideway and be routed through a network at a speed of 20/mph to within one mile of a work site. It would then be returned to manual control for the final leg to the work site. It is assumed that in manual operation standard storage battery, electric motor propulsion would be used while on the guideway, power would be supplied directly from the guideway. It is also assumed that the vehicle would be rubber tired. This is not the most efficient PRT, but it would be the most flexible.

For our calculations within the Chicago region, it will be assumed that there is a 40 x 50 mile grid of guideways on one-mile spacing. Such a network of 4000 miles would make 99% of all jobs accessible to at least 90% of all residences within the metropolitan region. Such a configuration would permit all work trips to be made by a PRT carrying one passenger. Thus, all internal combustion transport systems would be supplanted by the PRT. Such a configuration of the PRT leads to very high densities of vehicles, but it does appear feasible.

Calculation of the energy requirements for each vehicle was calculated by two different equations (Ayres & McKenna, 1972; Huerner, 1938). Both lead to approximately the same results. Assuming a constant travel speed of 20/mph, the energy to operate the system on the guideway would be approximately 300 BTU/vm including 15% losses in energy transfer or auxiliaries.

On the assumption that the energy supplied to the PRT comes from a fossil fuel generating plant located 30-50 miles from the network, the transmission losses would be in the order of 50% while the normal generation efficiency is 35%. Using these figures, we could conclude that the PRT would expend 1700 BTU/pas. mi. vs. 4647 BTU/pas. mi. for present mix of automobiles. In the Chicago region, assuming that 95% of all work trips by automobile are replaced by the PRT system, we can compute the energy savings. For this it is assumed that the trip lengths are unchanged as are the total number of trips. Vehicle occupancy for the present case was assumed to be two persons per vehicle, while for the PRT, occupancy was assumed to be one person. On this basis for the 6.7 x 10^6 daily work trips, the savings from a PRT would be 22,000 barrels per day.

6. Substitution of Communication for Transportation

Another alternative for reducing the petroleum consumption from urban transportation is to make more efficient use of modern communications technology. In theory, much of the non-manufacturing employment involves information processing and transfer, as well as decision making.

Such activities require access to data and analysis capability, and these activities cannot be carried out without bringing large numbers of people together in one place for long periods of time. If the data can be transferred from storage to the individual worker rather than the other way around, much travel would be obviated. Certainly the technology is within the state of the art to permit such a substitution.

At the present time, 69% of total employment within the Chicago metropolitan area is in non-manufacturing jobs. (TC, 1972). Taking a conservative position, approximately half of that employment could carry out their functions with advanced communication technology. It would appear reasonable to distribute communication centers for this work force throughout the region such that the work trip could be reduced from a median of thirteen miles to approximately two. With this kind of spatial distribution, it is then possible to calculate the energy savings from this form of travel reduction. In the Chicago region, this amounts to a reduction of 1.16×10^6 trips per day from 13 to 2 miles, costing 1.08×10^{10} BTU. At present, there are 2.33×10^6 non-manufacturing employment trips requiring 14.04×10^{10} BTU. With substitution of communication a savings of approximately 6×10^{10} BTU would be obtained. The net savings in energy within the Chicago region would be 10,220 BB/d.

The results of the analyses of these policy alternatives may be generalized from the Chicago region to the nation as a whole. Considering the size of this region and the amount of travel, it would appear that the Chicago area accounts for approximately 10% of the total urban travel in the United States. Multiplying all the savings from each of the policy alternatives by 10 provides an order of magnitude estimate of the savings nationwide, if implemented.

FEASIBILITY OF THE ALTERNATIVES

Table 10 summarizes the results of these scouting calculations for all six of the alternative policies. From this table, it is obvious that certain of the policies appear to generate greater savings than others. However, all are within the same order of magnitude, and hence, a selection may be based upon other criteria.

In the sense used here, these other criteria are those determining feasibility of implementation. Basically, for any policy to be implemented, it must be feasible in at least four domains. One is technical feasibility. That is, the technology for implementing the policy must be operational or capable of being made operational consistent with policy goal.

A second criterion of feasibility is economic. That is, is the capital requirements for the policy within an acceptable range of the investor? This is, of course, a relative matter and involves consideration of not only initial capital outlay, but also rates of return and social benefits to be derived from such capital expenditure. In essence, cost feasibility requires a traditional economic investment analysis to determine the true rate of return for any such policy implementation.

A third criterion is temporal. This involves the question of how long from the initiation of a policy decision the system could be implemented at a scale where the benefits could be realized from it. Again, this is a relative matter for it always requires time to install and

Table 10

Savings from Alternatives

Alternative	Savings Chicago SMSA (BBI/day)	Savings National (BBI/day)	Feasibility
Land Use Zoning	21,000	210,000	17
Optimize Traffic Flow	17,200	172,000	22
Utilize Mass Transit	9,430	94,300	23
Limiting Vehicle Size	37,400	374,000	19
PersonalRapid Transit System	21,800	218,000	16
Replace Transportation by Communication	10,220	102,000	17

make any physical or social technology operational. The benefits grow proportionately with time as more and more of the system is installed. Clearly, the more rapid that installation, the more advantageous the system and hence, that alternative that requires least time is the most preferable.

The fourth criterion is political feasibility. Any major change in social structure implies political controversy. Any policy that causes major changes in on-going social institutions is likely to generate social conflict. Consequently, the likelihood of implementation of a policy option is and must be sensitive to its socio-political consequences.

In most cases, there is usually no quantitative or "objective" means to determine the feasibility of a policy option in all four domains. Certainly, in the case of the six alternatives evaluated in this report, their feasibility in all but the technical domain must be a matter of judgment.

If subjective judgment is accepted as a necessity in policy decision, then it would appear that such judgments should be made explicit and where possible quantitative. Such a method has been proposed using rating scales (ASCE, 1972) for each of the criteria defined above. Effectively, this method suggests that feasibility is the sum of the ratings on each of the four criterion dimensions. This has been used here to evaluate the six policy alternatives. The mean value is shown in the last column of Table 10. The higher the numerical value, the greater is the feasibility. Although the proposed methodology for estimating feasibility requires a nominal size sample, which is violated in this case, it does demonstrate the application of the methodology. As may be seen, there is not a high degree of agreement between the energy savings as calculated and the estimate of feasibility of implementation. This, of course, is not an unusual occurrence at the technology-policy interface.

CONCLUSIONS

The present analysis represents an attempt to evaluate the potential effectiveness of six alternative policy options for conserving energy resources. The alternatives involve different means of reducing energy expended in urban work trip travel. A simple policy analysis procedure was used composed of two parts. One was to determine the likely energy savings from an arbitrary set of policy options available for implementation in the next 2 - 5 years. The second was to estimate the feasibility of implementing each of these alternatives in metropolitan regions. By feasibility is meant the technical, capital, temporal and political ease of installing and operating the given policy option.

Three major conclusions emerge from this analysis. First, is that sufficient data is available to realistically evaluate the benefits of alternative strategies for energy saving in urban transportation. For general comparative purposes, data is available not only on the performance of vehicles and vehicle systems, but also on the spatial, temporal patterns of travel demand. Consequently, it is a fairly direct matter to carry out policy evaluations with reasonable confidence in the energy estimates. Furthermore, the data base is generally adequate to dimension operational system requirements, and hence provide reasonable estimates of capital and time requirements to obtain benefits of any desired degree from the selected alternative.

A second conclusion from this analysis is that there are significant differences among the six alternatives in terms of potential energy savings. Since 98% of the energy expended in urban work trip travel in metropolitan travel is by automobile, anything that reduces its use or increases its energy efficiency provides energy savings. Thus, simply improving the flow of traffic which reduces energy wasted in idling or in accelerating, produces significant energy savings. Similarly, reduction in vehicle weight by increasing the proportion of sub-compact cars also produces substantial savings. The other alternatives also produce savings but except for the PRT, they cannot change the basic need for highway transportation as a mode of work trip travel. Consequently, even under optimistic assumptions, these alternatives provide limited benefits. However, it should be pointed out that this evaluation was unidimensional and did not consider the savings possible from the implementation of two or more of the alternatives simultaneously. Indeed, several of the alternatives evaluated here can be so implemented and the energy savings are additive.

The third conclusion from this analysis is that none of the alternatives evaluated in this analysis provide any substantive savings in energy in the context of total energy demand. In face of the fact that the deficit from domestic sources of supply will be the order of 11 million barrels of oil a day by 1975, savings of 90 to 350 thousand barrels a day represent only 1 to 3% of that deficit. In part this is due to the limited efficiencies of the alternatives themselves. Only the

PRT system offers an escape from dependence on petroleum which probably makes it the most attractive alternative for the longer time horizon. In part, the lack of significant savings in urban transportation is due simply to the fact that although it represents about 60% of all travel, only half of that is generated by person movements. The rest is largely created by goods movements within metropolitan regions. In fact, the ubiquity of transportation both in method of movement and in diversity of goods and people being moved means that any one segment of travel accounts for a relatively small proportion of total energy usage. It is possible that the 7% of total energy used for urban passenger movements can be saved using systems like PRT which are not linked to petroleum as a source of energy. However, the costs to obtain this order of saving seem rather high and the effect on the overall petroleum deficits would be marginal. In sum, only small energy savings appear likely from a feasible set of transport energy conservation programs. Consequently, it would appear that if significant savings in energy are required, they are likely to be more readily obtained in the industrial and residential sectors, rather than in transportation.

Appendix:

Derivation of Energy Savings from Various Alternatives

1. Land - Use Zoning (3 - 10 years)

<u>Example</u>: Zone residences in accompaniment with work places
Tax incentives for employee relocation

<u>Source of Saving</u>: Shorter median trip length

<u>Order of Magnitude Estimate of Possible Saving</u>:

Table 8:

$$\text{Energy use} = [\#\ \text{trips by car}]\ [\text{average trip length}]\ \left[\frac{4647\ \text{BTU}}{\text{pass-mile}}\right]$$

$$+[\#\text{trips by rail}]\ [\text{average trip length}]\ \left[\frac{4355\ \text{BTU}}{\text{pass-mile}}\right]$$

$$+[\#\ \text{trips by bus}]\ [\text{average trip length}]\ \left[\frac{27{,}088\ \text{BTU}}{\text{pass-mile}}\right]$$

and convert to BBI

Note:
Figure is
deliberately high

Assume:

Modal split is constant.

Fig. 1

Assume essentially no employment growth

Total Saving = [Base yr. energy use] - [subject year energy use]

Base yr. Energy Use = [#car trips] [BTU/auto pass-mile] [Average trip length]

$$+[\#\text{Bus trips}]\left[\frac{\text{BTU}}{\text{Bus pass-mi.}}\right][\text{average trip length}]\ +$$

$$[\#\ \text{Rail trips}]\left[\frac{\text{BTU}}{\text{rail pass-mi.}}\right][\text{Average trip length}]$$

Thus:

$$[4.4 \times 10^6][4647][13] + [1.0 \times 10^6][21277][13] + [.65 \times 10^6][4355][13]$$

=

and similarly

Year	Med. Trip Length	Energy Use (BBI/day)	Cumulative Saving
0	13	9.99×10^4	0
1	11.7	8.99×10^4	1×10^4
2	10.5	8.07×10^4	1.92×10^4
3	9.45	7.26×10^4	2.73×10^4
4	8.50	6.53×10^4	3.46×10^4
5	7.65	5.88×10^4	4.11×10^4
6	6.9	5.30×10^4	4.69×10^4
7	6.2	4.76×10^4	5.23×10^4
8	5.6	4.30×10^4	5.69×10^4
9	5.05	3.88×10^4	6.11×10^4
10	4.55	3.50×10^4	6.49×10^4

2. Optimize traffic flow 2-5 years

Example: Electronic control of traffic
Better matching of expressway capacity to street capacity
Exclusive bus lanes

Source of Saving: more efficient auto operation

Ordor of Magnitude Estimate of Possible Saving:

In general; $$\text{Saving} = \left(\#\ \frac{\text{auto trips}}{\text{day}}\right)\left(\#\ \frac{\text{BTU}}{\text{pass-mi}}\ \text{improvement}\right)\left(13\ \frac{\text{pass-mi}}{\text{auto trip}}\right)\left(1\ \frac{\text{Barrel crude}}{5.8 \times 10^6\ \text{BTU}}\right)$$

Calculation in report

Assume auto efficiency improves to

$$3500\ \frac{\text{BTU}}{\text{pass-mi}} \Rightarrow \frac{4647 - 3500}{4647} = 25\%\ \text{Improvement}$$

Then, substituting,

$$\text{Saving} = \frac{(4.4 \times 10^6)\ (1147)\ (13)}{5.8 \times 10^6}\ \frac{\text{Barrel}}{\text{day}}$$

$$= 17{,}220\ \text{BBI/day}$$

3. Increased Utilization of Mass Transit

Example: Ban autos in certain areas

Source of Saving: Fewer auto trips, compensated for by use of currently excess capacity

Order of Magnitude Estimate of Possible Saving

Assume: extra passengers will not cause an increase in energy/$_{\text{veh-mi.}}$ for trains or busses

Energy Saving = [# of non city auto pass diverted] *
[Average non-city work trip length] *
[Auto energy used / mile]
+[# of city auto pass diverted] *
[Average city work trip length] *
[Auto energy used / mile]

Calculation in report:

Assume 20% of sub auto pass to transit
15% of urb. auto pass to transit

$$E.S. = [.52 \times 10^6] (19) (4647) + (.27 \times 10^6) (7) (4647)/_{5.8 \times 10^6}$$

$$= 9430 \text{ BBI/day}$$

4. LimiTing Vehicle and Engine Size

Example: Horsepower limit

Source of Saving: Less non-functional Power

Order of Magnitude Estimate of Possible Saving

$$\text{Saving} = \left[\text{Fleet Efficiency } \left(\frac{\text{BTU}}{\text{veh-mi}}\right) \text{ before } - \text{Fleet Efficiency } (\text{BTU}/_{\text{veh-mi}}) \text{ after}\right]$$

$$(\#\ \text{veh-mi/day})$$

Assume: 65% of autos at $\frac{16{,}900 \text{ BTU}}{\text{v-mi.}}$

35% of autos at $\frac{5200 \text{ BTU}}{\text{v-mi.}}$

$$\text{Fleet Efficiency} = (.65)\ (16{,}900) + .35\ (5200) = \frac{12800 \text{ BTU}}{\text{v-mi.}}$$

Suppose one reverses proportion:

$$\text{Fleet Efficiency} = (.65)\ (5200) + (.35)\ (16{,}900) = \frac{9295 \text{ BTU}}{\text{veh-mi.}}$$

$$\text{Savings} = (3505)\ \underset{\substack{\#\text{auto veh}\\ \text{miles}}}{(6.2 \times 10^7)}\ \text{BTU/day} = 37{,}410\ \frac{\text{Barrel}}{\text{day}}$$

(Note: the above efficiencies do not agree with Table 3, as this is a hypothetical fleet)

Area Savings:

Assume only auto trips diverted

Assume a) all urban auto work trips now made by PRT and

b) 200,000 suburban work trips <u>not</u> by PRT

Total Saving =

[# in-city trips] [average length - 2] [auto eff - PRT eff]

(PRT has no advan
on street)

+[# out-city trips - 200,000] [average length - 2] [auto eff - PRT eff]

$$= \left.\begin{array}{l}(1.8 \times 10^6)\ (5)\ (2967) + \\ (2.4 \times 10^6)\ (14)\ (2967)\end{array}\right\} \underline{\text{BTU}}$$

assuming shorter trips more likely for PRT

$= 1.26 \times 10^{11}$ BTU/day

= 21,800 Barrels/day

5. Personal Rapid Transit System (10 Years)

<u>Example</u>: 1500 lb. dual mode, 20 mph, single passenger vehicle

<u>Source of Saving</u>: More efficient mode since reserved right-of-way, nearly constant speed, level rail.

<u>Order of Magnitude Estimate of Possible Saving</u>:

(Ayres + McKenna, Ch. 3, e.g., 3.14)

Energy Used/veh. mi. (hp-hr/mi.) $= \left\{\gamma + \frac{1}{2}\left(\frac{1 - F}{\sqrt{2\pi}}\right) \alpha\sigma_a \right\} W + \delta\alpha_v A v_o^2 e^{2\sigma_v^2}$

Where α, γ, δ, are constants appropriate to a VW (p. 47)

$\alpha = 12.15 \times 10^{-5}$

$\gamma = 5.76 \times 10^{-5}$

$\delta = .292 \times 10^{-5}$

$\sigma_a = 1.98$ mph/sec , $\sigma_v = .4$ mph

(From Pittsburgh driving study)

F = proportion of time at cruising speed

Then: Total Energy Saving =

(# trips) $\left(\frac{\text{Auto Use} - \text{PRT use}}{\text{mile}}\right)$ (Average length of trip)

However, we will assume that PRT differs from a VW only when it is on the reserved right-or-way. Otherwise, we assume no saving. Also, generating and transmission losses must be included in "PRT use/mi."

<u>Calculation in report</u>

Assume: $A = 20 \text{ ft.}^2$ $v_o^{11} = 20$ mph

$F = .99$ $W = 1500$ lb.

$$\frac{\overline{P}}{V} = \left\{ 5.76 \times 10^{-5} + \left(\frac{.01}{2}\right) \frac{12.15 \times 10^{-5}}{\sqrt{2\pi}} \quad (1.98) \right\} \quad 1500$$

$$+ \quad (.292 \times 10^{-5}) \; (.4) \; (20)^2 \; (C^{.32}) \; (20)$$

$$\doteq \quad (.087 \; + \; .013) \; \frac{\text{hp - hr}}{\text{mi.}} = \; .1 \; \frac{\text{hp-hr}}{\text{mi.}}$$

Assume: 15% mechanical loss

$$\frac{\overline{P}}{V} = .115 \quad \text{hp-hr/mi.} \quad = \quad 294 \quad \text{BTU/mi.}$$

Assume: 50% transmission loss

35% generator efficiency

Fuel Energy required = 1680 BTU/mi.

6. Replace Transportation by Communication

Example: Consolidated local business centers

Home and/or local time-shared computer -

Xerox centers

Source of Saving: Fewer trips

Shorter trips

Order of Magnitude Estimate of Possible Saving:

Assume 50% of non-manufacturing employment changed to local centers,

median trip = 2 miles

In Chicago, this amounts to 1.16×10^6 trips

Assume only auto trips affected

Hence:

$$\text{Saving} = (\#\text{ trips shortened})\left(\#\ \frac{\text{miles shortened}}{\text{trip}}\right)\left(\frac{\#\text{BTU}}{\text{pass-mi.}}\right)$$

$$= (1.16 \times 10^6)\ (11)\ (4647)\ \text{BTU / day}$$

$$= 10220\ \text{BBI / day}$$

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