Downtown People Movers and Energy

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The people mover—a short, high-capacity rail line serving only the high-density portions of a city—is a relatively new concept in transportation. The U.S. Department of Transportation recently decided to fund four such systems to test the effectiveness of the concept. They are expected to accomplish a number of desirable goals, including the reduction of pollution, congestion, and energy consumption and the revitalization of downtown areas. This paper concentrates on energy goals and examines the energy impact of six such systems. Research found that five of these systems will use more operating energy than the combination of modes that they replace, and the sixth will break even. Thus, even without taking into account the energy capital required to construct the systems, they have a net negative impact on energy consumption. The calculations used in this research are based on the patronage and mode split estimates of the transportation planners in the respective cities. This negative energy impact does not imply that the systems should not be built. Rather, they would be well justified, despite their energy losses, if they can make a significant impact on the reduction of smog and congestion or on downtown revitalization at a reasonable cost.

In 1976 I analyzed a typical modern rail transit system, Bay Area Rapid Transit (BART) of San Francisco, and showed that it had a net negative effect on energy (1). This conclusion resulted from the enormous amount of energy invested in building the system in the first place: BART does save a small amount of operating energy under some of the demand projections, but these savings are so small, compared to the energy capital investment, that it is impossible to repay the energy investment.

Nonetheless, it seems worthwhile to analyze the energy impacts of these people mover systems because they represent a promising new concept in transit thinking: a short, high-capacity rail line (actually, some are rubber tire on concrete guideway) serving only the high-density downtown portion of the city. Compared to the $2.28 billion (1974 prices) spent on BART, or the $5 billion or more being spent on the Washington Metro, these downtown people mover (DPM) systems look like a real bargain: they range in price from $25 to $167 million. Thus, in energy terms, DPM systems seem to have inherently higher promise than full-scale BART or Metro type systems. Their energy-capital cost is almost two orders of magnitude lower, and their downtown-only routing means that they serve areas with much higher average trip densities. Another advantage of their limited length is that they do not reduce travel time to the distant suburbs. Thus there is no incentive to further dispersal of population, acting through the motivation of searching for cheaper land, while keeping commute times short.

OPERATING ENERGY CONSUMPTION BY MODES

The energy estimates below represent operating energy consumption only; the effects of including vehicle and guideway construction energy are given in Boyce and others (2).

1. Bus. These are derived in Boyce and are modified to reflect operating energy only, to make it compatible with the DPM figures: 1.84 MJ/passenger-km (2810 Btu/passenger-mile).
2. Light rail and heavy rail. These are taken from an in-progress study of Cleveland being done by the Stanford Research Institute: light rail = 1.44 MJ/passenger-km (2200 Btu/passenger-mile), heavy rail = 3.46 MJ/passenger-km (5270 Btu/passenger-mile).
3. Automobile. Allowing for refinery losses, a gallon of gasoline equals 141 MJ. In 1980 we assume the average automobile will get 5.95 km/L (14 mpg) and will carry 1.3 people; these data imply 4.82 MJ/passenger-km. Because the 1985 fuel economy standards call for a new-automobile average of 11.7 km/L (27.5 mpg), it seems reasonable to project a fleet average of 8.50 km/L (20 mpg) by 1990; at 1.3 people/automobile, this implies 3.38 MJ/passenger-km (5150 Btu/passenger-mile); at 1.2 people/automobile, this implies 3.66 MJ/passenger-km (5580 Btu/passenger-mile). In general we use the automobile load factors called for by the planning report on each city whose DPM was evaluated. For one city we need a 1985 automobile energy figure, and this is computed as the average of 1980 and 1990. (The 1974 National Transportation Study gives average automobile load factors of 1.3 for peak hour and 1.58 as the weekday average for cities of one to two million people. The DPM proposals show that all of the DPM systems carry a substantial part of their load, sometimes a majority of the load, during off-peak hours. The obvious implication is that we would be justified in using a much higher automobile load factor than 1.2-1.3; hence, this would result in an automobile energy of about 2.62 MJ/passenger-km. Thus the figures being used in the actual energy evaluation are strongly biased toward showing high efficiency for DPMs.)
4. DPM. These are the hardest energy figures to predict accurately because little directly relevant empirical data exist. Three of the DPM proposals do estimate the energy efficiencies; their figures are used. The tables in the Los Angeles proposal imply an efficiency of 4.36 MJ/passenger-km. The tables in the St. Paul proposal imply an efficiency of 4.07 MJ/passenger-km. Houston calculates the efficiency of three possible systems from different manufacturers: Westinghouse Sea-Tac = 4.36; Vought DPM = 3.70; and Vought AirTrans = 3.58. Given the problem of making this kind of forecast, the number of different systems being examined, and the number of different forecasters, the five estimates seem remarkably close to each other. Lacking the detailed calculations behind each forecast, I have simply taken the average of the five projections, 3.98 MJ/passenger-km (6070 Btu/passenger-mile).

Energy Analysis for Los Angeles

The Los Angeles system will be 4.3 km (2.7 miles) long and will cost $167 million. It is projected to carry 81 400 daily trips in 1990, which will be about 151 000 passenger-km (93 620 passenger-miles) of service per day. The system is essentially a straight line and operates mostly on elevated guideways. It will have 11 stations.

Table 1 shows the basic patronage data projected for 1990 from the Los Angeles DPM proposal (4). The first column shows the composition of this patronage for two cases: a "null" case, where current trends are continued and no new transportation elements are constructed, and a "bus/DPM" case that assumes that the proposed DPM system is in operation. It is important to note that the total number of passenger-kilometers rises from 2.2 million in the null case to 2.3 million in the bus/DPM case. This is a trip-creation effect, and it represents an increase in welfare for the new trip takers (since they are enjoying better transportation services), but it is also an increased consumption of energy. The next column lays out the average vehicle occupancy figures for each mode. With one exception, the bus figure, these are all taken from the Los Angeles DPM pro-

Table 1. Patronage data for Los Angeles DPM system (1990).

System	Passenger-Kilometers (000s)	Vehicle Occupancy (no. of persons)	Vehicle-Kilometers Traveled (000s)	Vehicle Fuel Consumption	Implied Total Energy (GJ/day)
1990 Bus/DPM					
Automobile	1390.0	1.4	991.0	8.5 km/L (gas)	4350
Bus	708.0	11.5	61.6	1.96 km/L (diesel)	1300
Minibus	30.6	10.0	3.06	1.93 km/L (gas)	59
DPM	151.0	11.4	13.2	1.17 MJ/vehicle-km	633
1990 Null System					
Automobile	1590.0	1.4	1140.0	20.0	4990
Bus	565.0	11.5	49.1	4.6	1030
Minibus	43.4	10.0	4.34	4.5	84

Notes: 1 km = 0.6 mile, 1 GJ/day = 948 000 Btu/day, 1 km/L = 2.47 mile/gal, 1 MJ/vehicle-km = 1526 Btu/mile.
All demand projections provided by the City of Los Angeles (4).

posal. The proposal assumed an average bus load of 27 passengers/vehicle. According to the 1974 National Transportation Survey, the national average was only 11.5 passengers/bus, and I have chosen to use that figure instead, believing it to be more realistic. The next column then calculates the implied vehicle-kilometers per day.

Column four shows the assumed energy efficiencies of each vehicle. Again, with one exception, these are all taken from the Los Angeles DPM proposal. They assumed a 5.1-km/L (12-mpg) car. The 8.5-km/L (20-mpg) automobile I assume implies an Environmental Protection Agency (EPA) efficiency of about 10 km/L (23.5 mpg) for the average automobile. Because the federally mandated 1985 fuel efficiency is 11.7 km/L (27.5 mpg), it seems reasonable to assume that the fleet average will reach at least 10 km/L by 1990.

The final column then calculates the daily energy consumption with and without the DPM system. Energy consumption rises from a total of 6100 GJ/d without the DPM to a total of 6340 GJ/d with the DPM. That is, daily energy consumption rises by 240 GJ (210×10^6 Btu). (I did not modify the 1.17 MJ/vehicle-km DPM energy figure supplied by the proposal, though it includes only propulsion energy. It would be justifiable to increase this figure considerably: On the basis of BART's experience, the energy used to heat and light the DPM stations would increase system energy consumption by 42 percent.)

Energy Analysis for St. Paul

The St. Paul system will be 4.18 km (2.6 miles) long and will cost \$56 million (6). It is projected to carry 70 000 daily trips in 1990, which will be about 90 000 passenger-km of service per day. The system is T-shaped and operates mostly on elevated guideways. It will have 10 stations.

The table below shows the source of the 70 000 DPM passengers, and is taken from the St. Paul proposal:

Projected Source of DPM Trips	No. of Trips	Mode Used in Absence of DPM
Internal circulation (downtown employees, shoppers)	31 370	50 percent bus, 50 percent walking
Park-n-ride (park in peripheral lot and then take DPM)	15 300	Automobile
Bus mode change at periphery	13 500	5000 automobile-mode change, 8500 bus
Hotel guests	840	Taxi
Home in CBD to work or to shop	9 000	50 percent bus, 50 percent automobile

To calculate the implied energy savings we must assume a former transportation mode for each of these diverted passengers. I do so as follows:

1. For DPM passengers who now use park-n-ride and peripheral lots—I assume they were all former automobile users, and hence the energy saved is equivalent to a decrease of that many automobile trips.
2. Home in central business district (CBD) to work or shopping—representing people who live in the CBD area and who now use the DPM for their trips. Although it is obvious that without the DPM most of these trips would have been made by walking or by bus, I assume that half would have come from automobiles and half from buses.
3. Bus mode change—representing people who take the bus to the periphery of the CBD and then switch to the DPM. The energy saving from this mode change is calculated as if they would have continued their trips on the bus.
4. Downtown employees—representing people who work in the CBD and who make daily trips, mostly at noon, to other CBD locations. Most of these trips would not have been made at all in the absence of the DPM, or else the person would have walked. I have calculated the energy savings as if half the trips would have been made via bus.
5. Hotel guests—probably half of these trips would have been made by walking, in the absence of the DPM, but I have calculated the energy savings on the assumption that all the trips were diverted from automobiles.

In summary, I am being quite generous to the DPM system in assuming that it is not responsible for any trip creation, and that none of its passengers would have made these relatively short trips—1.3 km (0.8 mile)—by walking. The estimate of former automobile passengers now using DPM is 37 260; former bus users now on DPM number 37 040; and people who walked to their destination but now use DPM total 14 900.

The St. Paul proposal assumes that the DPM will make downtown distribution so attractive to current automobile users that 5000 of them will drop their automobiles altogether and travel to work on public transit only—i.e., switch from automobile to bus for the line-haul and then transfer from bus to DPM in the downtown area. Table 2 shows the resultant energy savings from switching 5000 automobile users to buses. I have assumed an average trip length of 16.1 km (10 miles) for these trips, which is quite generous, even given that they are going to be express buses. The resultant line-haul energy savings amount to 145 GJ/day, because buses are more energy efficient than automobiles.

Table 2 also calculates the energy consequences of the expected modal shifts in the CBD portion of town. Because the DPM is less energy efficient than the modes that it replaces and because there is a substantial amount of new trip creation and diversion of former walk-mode people, the net energy impact is negative—a loss of 171 GJ/day.

Thus the end result of the line-haul energy savings and the CBD energy losses is a net energy loss of 26 GJ/day (25×10^6 Btu/day), compared to operation without the DPM system. (As in the Los Angeles case,

Table 2. Energy savings projection for St. Paul (1990).

Study Period	Mode Used	No. of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/passenger-km)	Energy Consumption (GJ/day)
Line-haul portion of trip					
Before	Automobile	5 000	16.1	3.66	294
After	Bus	5 000	16.1	1.84	149
CBD-distribution portion of trip					
Before	Automobile	25 640	1.29	3.66	120
	Bus	28 685	1.29	1.84	68
	Walk	15 865	1.29	0	0
After	DPM	70 010	1.20	3.98	359

Note: 1 km = 0.6 mile, 1 MJ/passenger-km = 1526 Btu/passenger-mile, 1 GJ/day = 948 000 Btu/day.

this ignores the energy cost of heating and air conditioning the DPM stations, which is considerable.)

Energy Analysis for Cleveland

The Cleveland system will be 3.2 km (2 miles) long and will cost $52 million (3). It is projected to carry 46 400 trips in 1980. It is essentially a square loop around the CBD and operates entirely on an elevated guideway.

As a result of building the DPM, 9140 automobile trips /day are diverted to transit. Table 3 calculates the net line-haul energy savings from the automobile-to-bus mode shift—134 GJ/day. [Data in the Cleveland proposal indicate an average trip length of about 8 km (4.9 miles) for all former automobile users. I split this as 4.8/6.4/9.7 under the assumption that the faster modes would have the longest trips. The energy efficiency figures for rail are taken from an in-progress study of Cleveland being done by Stanford Research Institute. I use Cleveland's assumption of 1.3 persons/ automobile.]

The DPM picks up an additional 37 300 trips/day for CBD distribution, as shown in Table 3. The Cleveland proposal indicates an average DPM trip of about 1.6 km (1.0 mile), and I use this figure for the replaced minibus trips. Because the DPM system is configured as a small, square loop, the 1.6-km average trip implies considerable circuity with respect to automobile trips, and I calculate an equivalent automobile trip of 1.1 km (0.7 mile). The net energy used for CBD distribution as a result of the new mode shifts is 208 GJ/day. Thus, the end result of the line-haul savings and the CBD losses is a net energy loss of 74 GJ/day (70×10^6 Btu/day).

Energy Analysis for Houston

The Houston system will be 1.6 km (1 mile) long, will cost $40 million, and is expected to carry 33 287 passengers/day by 1985.

The table below shows the source of these DPM trips:

Projected Source of DPM Trips	No. of Trips	Mode Used in Absence of DPM
Internal circulation (downtown employees, shoppers)	5 229	3000 minibus, 2229 walking
Park-n-ride (park in peripheral lot and then take DPM)	2 987	Automobile
Bus mode change at periphery	25 071	1855 automobile-mode change, 23 216 bus

Table 4 analyzes the energy consequences with and without the DPM system. The end result of the line-haul energy savings and the CBD energy losses is a daily net gain of 2 GJ/day. This is the best energy performance of any of the DPM systems. The relatively favorable results are due to Houston's assumption that there will be only a very small number of internal circulation trips during the day. On all of the other systems for which we have data, the peak-hour load on the DPM occurs at lunch time due to internal circulation trips by downtown employees.

The favorable energy result occurs because the Houston DPM proposal assumes that only 2229 trips per day come from people who formerly walked. This compared to roughly 16 000 former walkers/day in Cleveland, Jacksonville, or St. Paul. If the Houston system actually draws 3000 former walkers/day instead of the 2229 projected, then it would incur a net loss of operating energy, as in the other DPM systems.

Energy Analysis for Jacksonville

The Jacksonville DPM will be 3 km (1.9 miles) long, will cost $41 million, and is expected to carry 89 200 passengers/day in 1990.

The table below shows the source of these DPM trips:

Projected Source of DPM Trips	No. of Trips	Mode Used in Absence of DPM
Internal circulation (downtown employees, shoppers)	14 900	Walking
Park-n-ride (park in peripheral lot and then take DPM)	16 100	Automobile
Bus mode change at periphery	46 300	1855 automobile-mode change, 23 216 bus
Other automobile	11 900	Automobile

Table 5 analyzes the energy consequences with and without the DPM system. [The proposal gives no figures for trip lengths, so I assumed that they would be about the same as those for Cleveland. Because the Cleveland trips had a high proportion of rapid-rail mode users, one would normally expect that Cleveland's trips would be longer than those of a bus transit system; thus, my assumption is relatively conservative. The Jacksonville proposal gives no figure for the expected automobile-to-bus line-haul mode shift. My assumption here was that it would be about 20 percent of the total downtown bus patronage. I believe this is already generous, but even doubling the figure to 40 percent (i.e., 40 percent of the line-haul bus patrons are newly attracted automobile drivers who switched because of the chance to transfer to the DPM at the end of their journey) would not change the final conclusion.]

The end result of the line-haul energy savings and the CBD energy losses is a net daily energy loss of 131 GJ (124×10^6 Btu).

Energy Analysis for Detroit

The Detroit DPM system will be a 3.7-km (2.3-mile) loop, will cost $55 million, and is expected to attract 92 000 passengers/day in 1990.

The Detroit proposal does not give enough data to make possible a calculation like those done for the other systems. However it does show that 70-76 percent of the total trips will be secondary trips. These trips

Table 3. Energy savings projection for Cleveland (1980).

Study Period	Mode Used	No. of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/passenger-km)	Energy Consumption (GJ/day)
Line-haul portion of trip					
Before	Automobile	1 220	6.4	4.82	37.9
	Automobile	2 700	4.8	4.82	62.8
	Automobile	5 220	9.7	4.82	243.0
After	Light rail	1 220	6.4	1.44	11.3
	Bus	2 700	4.8	1.84	24.1
	Heavy rail	5 220	9.7	3.46	174.0
CBD-distribution portion of trip					
Before	Automobile	10 300	1.1	4.82	55.9
	Minibus	10 400	1.6	2.01	33.7
	Walk	16 600	1.1	0	0
After	DPM	46 400	1.6	3.98	298.0

Note: 1 km = 0.6 mile, 1 MJ/passenger-km = 1526 Btu/passenger-mile, 1 GJ/day = 948 000 Btu/day.

Table 4. Energy savings projection for Houston (1985).

Study Period	Mode Used	No. of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/passenger-km)	Energy Consumption (GJ/day)
Line-haul portion of trip					
Before	Automobile	1 855	14.3	4.10	109
After	Bus	1 855	14.3	1.84	49
CBD-distribution portion of trip					
Before	Automobile	4 842	0.899	4.10	18
	Bus	26 216	0.899	1.84	43
	Walk	2 229	0.899	0	0
After	DPM	33 287	0.899	3.98	119

Note: 1 km = 0.6 mile, 1 MJ/passenger-km = 1526 Btu/passenger-mile, 1 GJ/day = 948 000 Btu/day.

Table 5. Energy savings projection for Jacksonville (1990).

Study Period	Mode Used	No. of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/passenger-km)	Energy Consumption (GJ/day)
Line-haul portion of trip					
Before	Automobile	9 260	6.4	3.66	218
After	Bus	9 260	6.4	1.84	110
CBD-distribution portion of trip					
Before	Automobile	37 260	1.6	3.66	219
	Bus	37 040	1.6	1.84	110
	Walk	14 900	1.6	0	0
After	DPM	89 200	1.6	3.98	568

Note: 1 km = 0.6 mile, 1 MJ/passenger-km = 1526 Btu/passenger-mile, 1 GJ/day = 948 000 Btu/day.

are defined as "primarily during off-peak transit periods ... (for) job related, ... ship, ... dine, ... personal business (trips)." That is, they replace trips that would have been made by walking or not made at all. This is by far the highest percentage of such trips among any of the DPM systems. Because such trips are one of the major causes of the apparent energy loss from DPMs, it is obvious that a more complete set of numbers is very likely to show an energy loss for Detroit, too.

Energy Analysis for Baltimore

The Baltimore DPM system will be 2.7 km (1.8 miles) long, will cost $25 million, and is expected to carry about 20 000 trips per day in 1980.

Although Baltimore does not give enough patronage data in the proposal to permit our analysis, they have done such an analysis themselves. They concluded that a people mover system in downtown Baltimore will result in greater energy consumption than in the present case. The reasons for this are (a) electromechanical transport is being used as a substitution for walking, and (b) the availability of the system induces a number of trips that would not otherwise occur, or results in more lengthy trips than if walking were the only other alternative.

Energy Analysis for St. Louis

The St. Louis DPM system will be 5.9 km (3.7 miles) long, will cost $41 million, and is expected to carry 18 000 trips per day. Their DPM proposal does not contain enough patronage data to permit an energy analysis.

SUMMARY AND CONCLUSIONS

In my analysis of BART, I discovered that it caused a net consumption of energy (counting both operating energy and construction energy). In the analysis of these small-rail DPM systems, I conclude that there is also a net consumption of energy: They use more energy—current, operating energy—than the combination of modes that they replace. It is worth noting that an analysis of the Lindenwold Line in Philadelphia (2) also concludes that the system being analyzed is a net consumer of energy. Furthermore, operating-energy losses are only a part of the story for these systems, since it does not take into account the large quantity of energy invested to build them in the first place.

How reliable are these DPM energy calculations? The major element of uncertainty is the patronage forecasts. In this case they are just estimates, not measured amounts, but they are estimates supplied by the agencies that wish to see these systems built. I am not aware of any transit system in the United States that ever ended up carrying as many people as were forecast for it. Thus, I believe that my use of these patronage estimates is, if anything, a bias in the direction of showing DPM effectiveness. An additional factor is that all of the DPM energy calculations were based on operating energy alone. Because our experience with other transit systems shows that we can expect an additional 30-40 percent energy consumption to heat, air condition, and light stations, this again is a bias in the direction of showing DPM effectiveness. I believe these net energy calculations are quite fair to the DPM systems.

This does not mean that DPM systems should not be built, however. Energy saving is only one of the reasons for building them. Certainly the trip creation implied by all of these new downtown circulation trips represents a net social benefit, and makes the city a much more attractive place for those who work or live there. In the case of DPMs in particular, the primary goal is the revitalization of the downtown area. If a DPM can actually accomplish such rejuvenation, and if the dollar subsidy required to construct and operate it is seen as acceptable by the voters, then surely it is a good idea to construct them despite their slightly adverse impact on energy consumption.

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Energy Intensity of Various Transportation Modes

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This paper is an overview of the existing literature related to the energy intensity of various transportation modes, including intracity (automobiles, buses, automated guideway transit systems, vans, and heavy and light rail transit) and intercity (airplanes, automobiles, buses, trucks, rail, waterways, and pipelines) modes for passenger and freight movement. Energy intensity has been correlated with operating conditions such as speed, load factor, and type of commodities being moved. Statistical and engineering approaches have been used to estimate energy intensity. Energy intensity values vary considerably according to operating conditions, types of hardware, trip characteristics, load factors, and types of commodities being shipped. Suggested energy intensity values for several transportation modes are discussed.

The United States currently uses petroleum at the rate of 2.8 to 3.5 million m^3/d, of which more than one-third is imported. Likewise, the transportation sector, which represents nearly one-fifth of the gross national product, has increased its use of petroleum and is almost entirely dependent on it. Because very few countries are oil exporters, the United States is particularly vulnerable to another oil embargo. This situation prompted the establishment of a department of energy and led the executive and legislative branches of the national government to express serious concern about the overall energy situation. Also, the Energy Conservation and Policy Act of 1975 aimed at reducing petroleum dependence and improving the efficiency of the existing transportation system.

If we are to reduce the use of petroleum, we must know how much petroleum each mode uses to move passengers and freight and how we can reduce petroleum use while maintaining reasonable passenger and freight mobility. The latter needs to be thoroughly investigated in terms of the impact of alternative fuels on the various modes. How to improve the output of passenger- and kilogram-kilometers to decrease petroleum used for general energy demands should also be studied. This can be accomplished by improving the technical and the operational efficiency of the transportation system. Improving efficiency involves such strategies as converting to diesel fuel, reducing vehicle weight, and improving aerodynamic and rolling characteristics of the various modes. Improving operational strategies means improving load factor, mode shift, and empty haul.

This paper discusses transportation output (i.e., kilogram- or passenger-kilometers) and energy input. The yardstick known as energy intensity (EI) helps us to compare various modes quantitatively from the point of view of energy use. Transportation energy efficiency can be defined as output divided by input, or 1/EI.

One way to define transportation output is by means of passenger-kilometers for passenger operation and kilogram-kilometers for freight operation. Airlines and trucking associations have raised serious questions about this definition because it does not take into account quality-of-service parameters such as travel time, convenience, and reliability. For example, a kilogram of coal shipped by barge at 10 km/h cannot be compared with a kilogram of flowers moved from Los Angeles to New York in a controlled environment. Although important, issues such as this one cannot be addressed within the scope of this paper.

EI represents kilojoules expended by a particular mode in moving people or freight or both. On a macrolevel, the energy used may be the total amount of energy used in a year for moving a certain number of passenger-kilometers by airplane. On the other hand, the energy expended at a microlevel may be the amount of fuel used to fly a certain type of airplane between certain cities at a certain altitude and speed. It is important to note that the energy in this definition refers