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ABSTRACT

The "People Mover" is a relatively novel concept in transportation: a short, high capacity rail line, serving only the high density portions of a city. The Department of Transportation has recently decided to fund four such systems to test the effectiveness of the concept. They are expected to accomplish a number of desirable goals: reduction of pollution, congestion, and energy consumption; and revitalization of the downtown area. This paper concentrates on their energy goals.

I examine the energy impact of six of these systems, and find that five of these will use more operating energy than the combination of modes which they replace (the sixth breaks even, approximately). That is, even without taking account of the energy capital required to construct the systems, they have a net negative impact on energy consumption. My calculations are based on the patronage and mode split estimates of the transportation planners in these cities.

This negative energy impact does not, of course, imply that the systems should not be built. If they can make a significant impact on smog, congestion, or downtown revitalization at a reasonable cost, then they would be well justified despite their energy losses.

INTRODUCTION

In a previous paper (3), I analyzed a typical modern rail transit system, BART of San Francisco and showed that it caused a net negative effect on energy. This surprising 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.

It seems worthwhile to analyze the energy impacts of these people mover systems since 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 five (plus) billion being spent on the Washington METRO, these DPM (downtown people mover) systems look like a real bargain: they range in price from $25 to $167 million. Thus, in energy terms, these DPM systems seem to have inherently higher promise than full scale BART/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. An additional 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.

In the sections below I calculate the energy impact of six of these systems, and find that five of them will use more operating energy than the transportation modes which they replace (the sixth breaks even, approximately). That is, on current account, without looking at the energy-capital required to build them, these systems waste energy. My calculations do not involve any arbitrary assumptions, and the major "guestimate," the projected patronage of the systems, is taken directly from the forecasts made by the DPM planners.

I begin with a brief derivation of operating energy intensities for the various modes of urban transport and then take up a system by system analysis of the individual proposals.

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 (3).

Bus: Derived in (3), and modified to reflect operating-energy-only, to make it compatible with the DPM figures: 1.84 MJ/P-km (2810 Btu/PM).

Light-Rail and Heavy Rail: taken from an in-progress study of Cleveland being done by the Stanford Research Institute. Light rail = 1.44 MJ/P-km (2,200 Btu/PM); Heavy Rail = 3.46 GJ/P-km (5,270 Btu/PM).

Auto: Allowing for refinery losses, a gallon of gasoline equals 141 MJ. In 1980 we assume the average car will get 5.95 km/L (14 MPG), and carry 1.3 people; which implies 4.82 MJ/P-km. Since the 1985 fuel economy standards call for a new car 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 per car this implies 3.38 MJ/P-km (5150 Btu/PM); at 1.2 people/car this implies 3.66 MJ/P-km (5580 Btu/PM). In general we use the auto load factors called for by the planning report on each city whose DPM we evaluate. For one city we need a 1985 auto energy figure, and this is computed as the average of 1980 and 1990. (General note: The 1974 National Transportation Study gives average auto load factors of 1.3 for peak hour, and 1.58 as the "weekday average," for cities of one to two million population. And the DPM proposals shows that all of the DPM systems carry a substantial part of their load during off-peak hours, sometimes a majority of the load. The obvious implication is that we would be justified in using a much higher auto load factor than 1.2-1.3, and hence this would result in an auto energy of about 2.62 MJ/P-km. Thus the figures being used in the actual energy evaluation are strongly biased toward showing high efficiency for the DPMs.)

DPM: These are the hardest energy figures to predict accurately since there is little directly relevant empirical data. Three of the DPM proposals do estimate the energy efficiencies, though, and so I use their figures. The tables in the Los Angeles proposal imply an efficiency of 4.36 MJ/P-km. The tables in the St. Paul proposal imply an efficiency of 4.07 MJ/P-km. Houston calculates the efficiency of three possible systems, from different manufacturers: Westinghouse Sea-Tac = 4.36; Vought DPM = 3.70; 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, which is 3.98 MJ/P-km (6070 Btu/PM).

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 of service per day. The system is essentially a straight line, and is mostly on elevated guideways. It will have eleven 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 which assumes that the proposed DPM system is in operation. It is important to note that the total passenger-kilometers rise 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 proposal. The proposal assumed an average bus load of 27 passengers per vehicle. According to the 1974 National Transportation Survey, the national average was only 11.5 passengers/bus, and I have

TABLE 1: LOS ANGELES SYSTEM

1990 BUS/DPM SYSTEMS	Passenger-km P-km/day x 10^3	Vehicle Occupancy (# of Persons)	Vehicle-km Traveled V-km/day x 10^3	Vehicle Fuel Consumption	Implied Total Energy GJ/day
Auto	1390	1.4	991	8.5 km-L (gas)	4350
Bus	708	11.5	61.6	1.96 km/L (diesel)	1300
Mini-Bus	30.6	10.0	3.06	1.93 km/L (gas)	59
D.P.M.	151	11.4	13.2	1.17 MJ/V-km	633
	2280				6340 GJ/day
1990 Nullsystem					
Auto	1590	1.4	1140	20	4990
Bus	565	11.5	49.1	4.6	1030
Mini-Bus	43.4	10.0	4.34	4.5	84
	2198				6100 GJ/day

Note: All demand projections come from (4).

chosen to use that figure instead, believing it to be more realistic. The next column then calculates the implied vehicle-miles 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) car I assume implies an EPA efficiency of about 10 km/L (23.5 MPG) for the average car. Since 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. We see that energy consumption rises from 6100 GJ/day without the DPM, to 6340 GJ/day with the DPM. That is, daily energy consumption rises by 240 GJ (210 x 10^6 Btu).

(I did not modify the 1.17 MJ/V-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, taking account of the energy used to heat and light the DPM stations, would increase system energy consumption by 42%.)

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 P-km of service per day. The system is T-shaped, and is mostly on elevated guideways. It will have ten stations.

Table 2 shows the source of the 70,000 DPM passengers, and is taken from the St. Paul proposal. To calculate the implied energy savings we must assume a former transportation mode for each of these diverted passengers. I do so as follows: A) for DPM passengers who now Park-N-Ride, using peripheral lots: I assume they were all former auto users, and hence the energy saved is equivalent to a decrease of that many auto trips. B) Home in CBD to Work or Shopping: these are people who live in the CBD area, 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 cars, and half from buses. C) Bus Mode Change: these are people who take the bus up 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 otherwise. D) Downtown Employees: these are the daily trips, mostly at noon, made by people who work in the CBD, to other CBD locations. Although it is obvious that 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. E) 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 cars.

That is, 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

TABLE 2: ST. PAUL (1990)

Projected Source of DPM Trips	Number of Trips	Mode Which Would Have Been Used in Absence of DPM
Internal Circulation (e.g. downtown employees, shoppers)	31,370	50% bus, 50% walk
Park-N-Ride (i.e., park in peripheral lot and then take DPM)	15,300	auto
Bus Mode Change at Periphery	13,500	5000 auto-mode change 8500 bus
Hotel guests	840	taxi
Home in CBD to Work or to Shopping	9,000	50% bus, 50% auto

	TOTALS
# of Former Auto Passengers now on DPM	37,260
# of Former Bus Passengers now on DPM	37,040
# of Former Walkers now on DPM	14,900

average length) by walking. These figures are summarized at the bottom of Table 2.

The St. Paul proposal assumes that the DPM will make downtown distribution so attractive to current auto users that 5000 of them will drop their automobiles altogether, and make a total transit trip to work: switch from car to bus for the line-haul, then transfer from bus to DPM in the downtown area. The top part of Table 3 shows the resultant energy savings from switching 5000 auto 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 busses. The resultant line-haul energy savings amount to 145 GJ per day, since buses are more energy efficient than autos.

The bottom portion of the table calculates the energy consequences of the expected modal shifts in the CBD portion of town. Since the DPM is less energy efficient than the modes which it replaces (see the Appendix), and since 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 per day.

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

TABLE 3: ST. PAUL (1990)

LINE-HAUL PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	5000	16.1	3.66	294
AFTER	Bus	5000	16.1	1.84	149

Net Savings on Line-Haul = 145 GJ/day

CBD-DISTRIBUTION PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ-P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	25640	1.29	3.66	120
	Bus	28685	1.29	1.84	68
	Walk	15865	1.29	0	0
AFTER	DPM	70010	1.29	3.98	359

Net Loss on CBD-Distribution = 171 GJ/day

NET ENERGY EFFECT OF BUILDING DPM = 145 - 171 = -26 GJ/day

Energy Analysis for Cleveland

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

As a result of building the DPM, 9,140 auto trips per day are diverted to transit. The top portion of Table 4 calculates the net line-haul energy savings from the auto to bus mode shift--134 GJ per day. (Notes: A) data in the Cleveland proposal indicate an average trip length of about 8 km for all former auto users. I split this as 4.8/6.4/9.7 under the assumption that the faster modes would have the longest trips. B) The energy efficiency figures for rail are taken from an in-progress study of Cleveland being done by Stanford Research Institute. C) I use Cleveland's assumption of 1.3 persons/car.)

The DPM picks up an additional 37,300 trips/day for CBD distribution, as shown in the bottom part of Table 4. The Cleveland proposal indicates an average DPM trip of about 1.6 km, and I use this figure for the replaced mini-bus trips. Since the DPM system is configured as a small, square loop, the 1.6 km average trip implies considerable circuity with respect to auto trips, and I calculate an equivalent auto trip of 1.1 km. The net energy used for CBD distribution as a result of the new mode shifts is 208 GJ per day.

Thus, the end result of the line-haul savings, and the CBD lossess, is a net energy loss of 74 GJ per day (70 x 10^6 Btu/day).

TABLE 4: CLEVELAND (1980)

LINE-HAUL PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	1220	6.4	4.82	37.9
	Auto	2700	4.8	4.82	62.8
	Auto	5220	9.7	4.82	243.
AFTER	Light Rail	1220	6.4	1.44	11.3
	Bus	2700	4.8	1.84	24.1
	Heavy Rail	5220	9.7	3.46	174.

Net Savings on Line-Haul = 134 GJ/day

CBD-DISTRIBUTION PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	10300	1.1	4.82	55.9
	Mini-Bus	10400	1.6	2.01	33.7
	Walk	16600	1.1	0	0
AFTER	DPM	46400	1.6	3.98	298

Net Loss on CBD-Distribution = 208 GJ/day.

NET ENERGY EFFECT OF BUILDING DPM = 134 - 208 = -74 GJ/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 per day by 1985.

Table 5 shows the source of these DPM trips, and Table 6 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 per day. This is the best energy performance of any of the DPM systems, and 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 2,229 trips per day come from people who formerly walked. This compared to roughly 16,000 former walkers per day in Cleveland, Jacksonville, or St. Paul. If the Houston system actually draws 3,000 former walkers per day, instead of the 2,229 projected, then it would incur a net loss of operating energy, as the other DPM systems do.

Energy Analysis for Jacksonville

The Jacksonville DPM will be 3.0 km long, will cost $41 million, and is expected to carry 89,200 passengers per day in 1990.

Table 7 shows the source of these DPM trips, and Table 8 analyzes the energy consequences with and without the DPM system. (Notes: the proposal gives no figures for trip lengths so I assumed that they would be

TABLE 5: Houston (1985)

Projected Source of DPM Trips	Number of Trips	Mode Which Would Have Been Used in Absence of DPM
Internal Circulation (e.g. downtown employees, shoppers)	5,229	3000 minibus 2229 walking
Park-N-Ride (i.e., park in peripheral lot and then take DPM)	2,987	auto
Bus Mode Change at Periphery	25,071	1855 auto-mode change 23,216 bus

TOTALS

# of Former Auto Passengers now on DPM	4,842
# of Former Bus Passengers now on DPM	26,216
# of Former Walkers now on DPM	2,229

TABLE 6: HOUSTON (1985)

LINE-HAUL PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	1855	14.3	4.10	109.
AFTER	Bus	1855	14.3	1.84	49.

Net Savings on Line-Haul = 60 GJ/day

CBD-DISTRIBUTION PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	4842	.899	4.10	18.
	Bus	26216	.899	1.84	43.
	Walk	2229	.899	0	0
AFTER	DPM	33287	.899	3.98	119.

Net Loss on CBD-Distribution = 58 GJ/day

NET ENERGY EFFECT OF BUILDING DPM = 60 - 58 = 2 GJ/day about the same as those for Cleveland. Since the Cleveland trips had a high proportion of rapid rail mode, 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 auto to bus line-haul mode shift. My assumption here was that it would be about 20% of the total downtown bus patronage. I believe this is already generous, but even doubling the figure to 40% (i.e., 40% of the line-haul bus patrons are newly attracted auto 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 x 10^6 Btu).

Energy Analysis of Detroit

The Detroit DPM system will be a 3.7 km loop, costing $55 million, and is expected to attract 92,000 passengers per day in 1990.

The Detroit proposal does not give enough data to make possible a calculation like those done above. However it does show that 70-76% of the total trips will be "secondary trips": defined as "primarily during off-peak transit periods . . . (for) job related . . . shop . . . dine . . . personal business (trips)." That is, these are mostly trip creation, and 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, and since 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.

TABLE 7: JACKSONVILLE (1990)

Projected Source of DPM Trips	Number of Trips	Mode Which Would Have Been Used in Absence of DPM
Internal Circulation (e.g. downtown employees, shoppers)	14,900	walking
Park-N-Ride (i.e., park in peripheral lot and then take DPM)	16,100	auto
Bus Mode Change at Periphery	46,300	1855 auto-mode change 23,216 bus
Other auto	11,900	auto

TOTALS

# of Former Auto Passengers now on DPM	37,260
# of Former Bus Passengers now on DPM	37,040
# of Former Walkers now on DPM	14,900

TABLE 8: JACKSONVILLE (1990)

LINE-HAUL PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	9260	6.4	3.66	218
AFTER	Bus	9260	6.4	1.84	110

Net Savings on Line-Haul = 108 GJ/day

CBD-DISTRIBUTION PORTION OF TRIP

	Mode Used	Number of Trips/Day	Trip Length (km)	Energy Efficiency (MJ/P-km)	Energy Consumption (GJ/day)
BEFORE	Auto	37260	1.6	3.66	219
	Bus	37040	1.6	1.84	110
	Walk	14900	1.6	0	0
AFTER	DPM	89200	1.6	3.98	568

Net Loss on CBD-Distribution = 239 GJ/day

NET ENERGY EFFECT OF BUILDING DPM = 108 - 239 = -131 GJ/day

Energy Analysis for Baltimore

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

While Baltimore does not give enough patronage data in the proposal to permit our analysis, they have done such an analysis themselves, and they conclude:

> "A People Mover system in downtown Baltimore will result in greater energy consumption than in the present case. The reasons for this are two-fold: 1. Electro-mechanical transport is being used as a substitution for walking. 2. 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 of St. Louis

The St. Louis DPM system will be 5.9 km 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 a regional rail transit system, 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 which they replace. It is worth noting that an analysis of the Lindenwold Line in Philadelphia (1) also concludes that the system being analyzed is a net consumer of energy, on current account. 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. Since 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, 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. Since our experience with other transit systems shows that we can expect an additional 30-40% energy consumption to heat, air condition, and light stations, this, again, is a bias in the direction of showing DPM effectiveness. That is, I believe these net energy calculations are quite fair to the DPM systems.

<u>This does not mean that DPM systems should not be built, however.</u> 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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