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POSSIBLE AND LIKELY FUTURES OF URBAN TRANSPORTATION

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INTRODUCTION

IN THIS paper some of the effects of anticipated urban growth on urban transportation are examined. Current trends are analyzed in order to determine whether the current transportation system, with or without expansion, can handle future traffic loads at the 1960 level of congestion. We believe we show that it cannot do so and hence that fundamental changes in the system will have to be made.

Alternative ways of changing urban transportation systems are then examined. In our view only one of these is capable of keeping urban congestion at an acceptable level. This finding does not imply that urban transportation will move directly toward this solution. To the contrary, a great deal of trial and error is likely, and considerable amounts of money and effort will probably be wasted before the solution is generally adopted.

In the past the principal approach taken to meet increased urban transportation requirements has been to build more roads and highways. Increased road construction has in turn increased the amount of urban travel. As mass transit systems deteriorated, Federal and local governments have allocated more funds for urban roads. For example, of $5.35 billion spent in fiscal year 1967 for urban transportation, 30.4 per cent was allocated to urban transportation. Of this 90 per cent was used for urban highways and only 10 per cent was allocated to public transit [1]. New urban highways and roads have been filled with cars as soon as they have been opened. Nevertheless we still expect increased numbers and use of automobiles and trucks in the future. Therefore, unless either the system is changed or additional vehicle-carrying capacity is provided in cities, congestion can be expected to increase. How much additional urban streets and highways would be required to maintain 1960 levels of congestion and how much would these additions cost? If the cost or the amount of urban land consumed by additional streets and highways turns out to be excessive, then there will have to be a fundamental change in urban transportation systems. What changes are possible and of these which are the most likely and why? It is to these questions that this paper is devoted.

In attempting to answer these questions great accuracy and precision of data are not required because the conclusions reached are insensitive to even the largest errors one might expect. Hence, whenever alternative numbers are available we have used those that favor preservation and extension of the existing system.

A

EXTRAPOLATED REQUIREMENTS

The automobile currently accounts for about 85 per cent of all urban passenger travel. This percentage has been increasing and will continue to increase unless restrictions are introduced deliberately or are self-generated because of increases in (1) our adult population, (2) the number of automobiles per adult and (3) the miles per year that vehicles are driven.

The projected growth of our total and adult (over 20 yr) population is shown in Table 1.

TABLE 1. PROJECTED POPULATION GROWTH [2, TABLE A.1.3]

Year	Population (millions)	% over 20
1960	180.6	61.0
1970	206.0	60.9
1980	239.3	61.5
1990	288.6	60.9
2000	321.9	62.4

The projected number of automobiles per adult is shown in Table 2. These projections assume continued expansion of streets and highways at a rate that will not reduce recent trends of increasing usage of automobiles; that is, they assume "unconstrained" growth. They also assume that "saturation point" is not reached with respect to the number of automobiles per adult.

TABLE 2. PROJECTED NUMBER OF AUTOMOBILES PER ADULT [2, TABLES A.5.1 AND A.5.2]

	Projected No.		
Year	Low	Medium	High
1960	0.54	0.54	0.54
1980	0.76	0.79	0.91
2000	1.06	1.19	1.51

In the remainder of this paper we shall not use the high projection for the number of automobiles per adult because it appears to go beyond the saturation point. Bottiny [3] has suggested that a reasonable saturation point for automobile ownership is one automobile per licensed operator. It is difficult to imagine 1.51 automobiles per adult in the year 2000.

In order to estimate future "unconstrained" volume of automobile traffic it is also necessary to estimate average miles per vehicle per year. Data on past usage are shown in Table 3 which also includes data on vehicles other than automobiles.

TABLE 3. AVERAGE MILES PER VEHICLE PER YEAR [4, TABLE VM-210A]

Year	Automobiles	All passenger vehicles*	Trucks and trailers	All vehicles
1950	9020	9078	10,776	9369
1955	9359	9400	10,697	9615
1960	9446	9474	10,585	9652
1965	9255	9278	11,373	9674

* Includes buses and automobiles.

According to Lansing and Hendricks [5, p.23]:

> The relation between family income and thousands of miles travelled is surprisingly close to a straight line . . . it may be a good approximation to say that every dollar of additional income leads to one additional mile of travel.
>
> As people's income rises, the number of vehicle-miles which they travel may be expected to rise in proportion . . over a period of 10, 20, 30 yr one should project an increase in average vehicle-miles at approximately the same rate as average stability of the relation between income and mileage.

Lansing and Hendricks [5] also show that average automobile usage per year is higher for those who live in metropolitan areas than for the population as a whole. However, their result—13,000 miles *per family* in metropolitan areas—is not directly comparable with the *per-vehicle* data of Table 3. They also observe that the average number of miles travelled by suburbanites (14,000 miles per family) is substantially higher than that of urbanites (less than 9000 miles per family).

Unfortunately, it is not possible to combine the historical data of Table 3 with that obtained by Lansing and Hendricks so as to obtain a precise prediction of the average miles per automobile per year. Nevertheless it is possible to use the data they provide in a qualitative way together with expected rises in income and shifts to suburbs, and conclude that the average miles per automobile per year will continue to increase slowly, under the assumption of unconstrained growth.

Landsberg *et al.* [2] estimated that the disposable income per household will increase from about $6500 in the early 1960's to nearly $10,000 in 1980 and somewhere between $13,000 and $15,000 by the end of the century (p.80). In addition to this the trend toward increasing suburbanization is indicated by the relative growth rates of central cities and fringe areas within a Standard Metropolitan Statistical Area (SMSA). As can be seen from Table 4, it is in the urban fringe that the largest percentage increase of population is occurring.

TABLE 4. PERCENTAGE OF TOTAL INCREASE IN POPULATION IN THE U.S.A. [6]

Area	1950–1960	1960–1966
SMSA's		
Central cities	22	9
Fringe	66	75
Outside SMSA	12	16
U.S. Total	100	100

These two factors, increases of family income and suburbanization, combined with the results obtained by Lansing and Hendricks point in the direction of an increase in the average miles travelled by a family per year. Part of this increase will be due to increasing automobile ownership and part due to extended usage of the automobile. Following the policy of favoring the existing system we shall only take into consideration the historical growth and extrapolate it into the future, keeping in mind that further increases in the average miles per automobile per year are not only possible but are likely. Table 5 gives the extrapolated unconstrained growth in average miles per automobile per year, based on the average growth over the 15 yr period from 1950 to 1965.

TABLE 5. PROJECTED AVERAGE MILES PER AUTOMOBILE PER YEAR*

Year	Miles per automobile per year
1960	9446
1980	9759
2000	10,072

* Calculated from Table 4 by taking the average growth rate every 5 yr from 1950 to 1965 and extrapolating to 1980 and 2000.

Using the information contained in Tables 1–5, estimates of the total number of automobiles and vehicles miles can be prepared using the 59.49 million automobiles of 1960 as a base. This is done as follows:

Population over 20 × automobiles/adult = Total number of automobiles.

Total number of automobiles × average miles per automobile = Total vehicle miles.

The results of such calculations for each of the two growth rates of number of automobiles per adult are shown in Table 6.

TABLE 6. PROJECTIONS OF TOTAL AUTOMOBILE MILES (IN MILLIONS) FOR VARIOUS GROWTH RATES IN AUTOMOBILES/ADULT

Year	Growth rate	
	Low	Medium
1960	561,943	561,943
1980	1,091,544	1,134,581
2000	2,144,453	2,407,510

During the past fifteen years approximately 50 per cent of the miles travelled in a given year were in urban areas, as indicated in Table 7. Using different projection methods Smith *et al.* [7, p.36] estimate that by 1980 about 60 per cent of the total vehicle-miles travelled will be on urban roads and that by 2000 this will increase to about 65 per cent. Table 7 shows the historical percentage distribution of urban–rural miles for automobiles and all vehicles from 1950 to 1965. It can be observed that the percentage of urban vehicle-miles for automobiles and all vehicles has remained practically constant at about 50 per cent during the past two decades.

TABLE 7. PERCENTAGE DISTRIBUTION FOR URBAN–RURAL MILES TRAVELLED*

Year	Automobiles		All vehicles†	
	Urban	Rural	Urban	Rural
1950	50.2	49.8	47.6	52.4
1955	47.4	52.6	45.4	54.6
1960	48.4	51.6	46.1	53.9
1965	50.3	49.7	47.8	52.2

* Estimated from Table VM-201, Bureau of Public Roads [4].
† Includes automobiles, buses and trucks.

Continuing our policy of being conservative we shall assume that urban vehicle-miles will account for 50 per cent of the automobile vehicle-miles in 1980 and 2000 even though the estimates made by Smith *et al.* are significantly higher.

By applying these percentages to the data shown in Table 6 we can estimate unconstrained total urban automobile miles per year. The results are shown in Table 8.

Up to now we have considered unconstrained growth in traffic volume due to automobile travel, but buses and trucks will generate their share of traffic volume.

TABLE 8. URBAN AUTOMOBILE MILES PER YEAR (IN MILLIONS) FOR VARIOUS OWNERSHIP GROWTH RATES

	Growth rates			
	Low		Medium	
Year	Miles	% of 1960	Miles	% of 1960
1960	280,972	100.0	280,972	100.0
1980	545,772	194.2	567,291	201.9
2000	1,072,226	381.6	1,203,255	428.4

Projections of urban truck traffic are only available in specific studies of cities and these vary in the amount of detail they provide. The data from different sources are difficult to combine with the aggregated statistics provided by government agencies. Table 9 shows historical data and extrapolations to 1975 on the vehicle-miles travelled by buses and trucks and their relation to automobile vehicle-miles.

Table 9 shows that the volume of traffic generated by buses can be neglected without introducing substantial error, and that the ratio of truck vehicle-miles to automobile vehicle-miles has remained, and is expected to remain, stable at a value between one-fourth and one-fifth. Therefore, when analyzing increases in traffic volume—the ratio of projected vehicle-miles in 1980 and 2000 to vehicle-miles in 1960—it is enough to take into consideration the volume of traffic (vehicle-miles) generated by automobiles.

TABLE 9. PAST AND EXTRAPOLATED VEHICLE-MILES (IN MILLIONS) FOR BUSES AND TRUCKS AND RATIOS TO AUTOMOBILES VEHICLE-MILES [4, 6]

	Trucks		Buses		Automobiles
Year	Vehicle	Ratio to automobile	Vehicle-miles	Ratio to automobile	Vehicle-miles
1950	90,552	0.25	4081	0.010	363,613
1955	108,817	0.22	4194	0.008	492,635
1960	126,409	0.21	4353	0.007	588,083*
1965	173,659	0.24	4684	0.007	709,800
1970	209,200	0.24	4760	0.005	891,800
1975	249,000	0.23	4890	0.005	1,084,000

* This figure differs from that given in Table 6 by 4.5 per cent due to differences in method of calculation.

Now to the question: how many additional miles of urban highways would be required to maintain the 1960 level of congestion? To answer this question we use information made available by the National Academy of Sciences [8]. The data apply to 1958 but little error results from using them for 1960. The measures used were explained as follows:

> In an overall consideration of the problem of road utilization, it is the latter group of highways (major roads) that is approaching capacity. Since the Federal-aid primary highway system roughly approximates the roads most intensively used, a comparison was made of its actual usage and its capacity.
>
> In order to estimate the degree of utilization of the Federal-aid primary system it was necessary to calculate the *practical* and the *possible* capacities of the system. Practical capacity represents the maximum number of vehicles that can pass a given point in 1 hr *under prevailing conditions, without unreasonable delay or restrictions to the driver's freedom to maneuver*. Possible capacity, on the other hand, represents the maximum number of vehicles that can pass a given point on a lane or roadway during 1 hr under the prevailing roadway and traffic conditions (p. 76, italics ours).

Table 10 gives the results obtained.

> The ratio of practical capacity to usage of 1.10 for the urban portions of the system indicates that they are being used to close to practical capacity. . . . The same picture is presented in a different way by showing the proportion of capacity actually in use. The urban portions of the Federal-aid primary system are operating at 90 per cent of their practical capacity. . . . The margin is uncomfortably thin (p. 77).

TABLE 10. RELATION BETWEEN HIGHWAY USAGE AND CAPACITY OF THE FEDERAL-AID PRIMARY SYSTEM [8, p. 77]*

	Rural	Urban	Total
Extent of system (miles	216,791	20,076	236.867
Average daily traffic (millions)			
Vehicle-miles			
Actual usage	571	257	828
Practical capacity	897	284	1181
Possible capacity	2460	443	2903
Ratio of capacity to usage			
Practical capacity	1.57	1.10	1.43
Possible capacity	4.31	1.72	3.51
Proportion of capacity used (%)			
Practical capacity	64	90	70
Possible capacity	23	58	29

* Developed by the Bureau of Public Roads from basic data as of December 31, 1958. Reasonable assumptions were made for lane width, percentage of commercial vehicles, percentage of sight-distance restrictions on two lane roads and percentage of green ("go") time at traffic signals in urban areas.

Practical capacity was determined for each type of roadway in vehicle per hour and expanded to average daily traffic (ADT) values, assuming the peak-hour volume as 15 per cent of the ADT for rural highways and 10 per cent for urban highways. The resultant ADT figures were then multiplied by the mileages on the system. Possible capacity was similarly developed.

The hourly fluctuations of traffic were taken into consideration; in other words, the capacity per hour was *not* simply multiplied by 24 to obtain daily capacity.

Rural capacity was calculated on the basis of uninterrupted flow while urban capacity, except for controlled-access divided highways, was based on interrupted traffic flow using intersection capacity curves. Average running speed was assumed to be 40–45 m.p.h. for rural highways and 30–35 m.p.h. for urban highways.

A 60–40 distribution of traffic by direction was assumed for multilane highways.

If urban traffic congestion is to be maintained at the 1958 level, and no major shifts of traffic from the Federal-aid highway system to other systems occur, we can estimate the additional highway miles (assuming a standard four-lane highway) in the Federal-aid system as follows. Using the low growth rate of automobiles per adult, for example, there will be about 3.82 times as many urban automobile-miles in 2000 as in 1960. We will need about this much more urban highway miles in the Federal-aid primary system to retain the 1958 level of congestion; that is

$$3.82 \times 20{,}076 = 76{,}690 \text{ miles.}$$

There were 20,076 miles in this system in 1960.

Table 11 shows the miles required in 1980 and 2000 for low and medium growth rates of automobile ownership.

TABLE 11. ESTIMATED MILES OF STANDARD URBAN HIGHWAY REQUIRED IN THE FEDERAL-AID PRIMARY SYSTEM TO MAINTAIN 1960 LEVEL OF CONGESTION

	Growth rate	
Year	Low	Medium
1980	38,987	40,533
2000	76,690	86,006

The Federal-aid system consists of the major roads that are used for the movement of people and goods *through* an area, as contrasted with movements having origin or destination *within* one area. These are the roads which carry a heavy traffic load and which provide access to residential locations, to the central business district, to industrial areas, to peripheral business areas and so on; that is, to the main destinations in urban areas. When traffic congestion increases in this system it also increases on other urban streets and highways not included in the system. It is for this reason that a major shift of urban traffic from the Federal-aid primary system to other urban roads is not expected.

Using the low growth rate of automobile ownership, about 55,000 (76,690 − 20,076) additional miles of urban highways will be required in 2000 in order to maintain the 1960 level of congestion. At the *very conservative* estimate of an average cost of $10 million per mile of standard four-lane urban highway (Fitch *et al.* [9, p. 14]) the total investment required over the next 30 yr would be approximately $550 billion, or an average of $18.3 billion per year. This constitutes more than a threefold increase in the *total* expenditure for transportation facilities in 1967 (approximately $5.35 billion). This amount ($18.3 billion) is more than *ten times* the amount spent on urban highways in 1967 ($1.4 billion). Such an increase in expenditures is virtually impossible but it is not the only obstacle to unconstrained growth of automobile usage.

The amount of land that can be allocated to roads, highways and parking spaces in urban areas, particularly in the Central Business District, also limits such growth. Fitch *et al.* [9, p. 14] quote Senator Harrison Williams on this subject as follows:

> Even if we were to try (to solve urban transportation problems by highways alone) with an urban highway program averaging $10–20 million a mile in high density urban areas, there is every possibility that the remedy would only succeed in killing the patient —by replacing valuable tax ratable property with nontaxable concrete and asphalt, by

creating huge downtown parking demands which would further remove land for commercial and cultural purposes, and by slowly carving away the activities that created the demand for access in the first place.

In most cities the proportion of land devoted to streets and parking in downtown areas already exceeds 40 per cent of the total land available. Table 12 shows the relevant percentages for five metropolitan areas.

TABLE 12. PROPORTION OF CENTRAL BUSINESS DISTRICT LAND DEVOTED TO STREETS AND PARKING [7, p. 59, TABLE 11]

CBD	Year	Percentage of CBD land devoted to		
		Streets	Parking	Streets and parking
Los Angeles	1960	35.0	24.0	59.0
Chicago	1956	31.0	9.7	40.7
Detroit	1953	38.5	11.0	49.5
Minneapolis	1958	34.6	13.7	48.3
Dallas	1961	28.5	12.9	41.4

Clearly, these percentages cannot be increased 3.82 times. Many cities, of course, have smaller percentages, and additional highways (e.g. ones bypassing the CBD) need not generate additional parking requirements. Nevertheless, it is clear that the space constraint would be reached for increases of even less than twice current allocations.

Proposals have been made to use two-level highways in order to avoid the space problem. The costs associated with doing so are much higher than those for surface-level highways. Thus, if construction of the "required" conventional roads is economically infeasible, as we have demonstrated, building elevated highways would be even less feasible.

Thus it does not appear to be practicable to expand the existing urban road and highway system in order to cope with the "unconstrained" growth of traffic volume over the next 30 yr because of the expenditures of money and amounts of space such expansion would require.

We have not considered such social costs as might arise from increased accident rates, increased air pollution and decreased attractiveness of the environment. Consideration of these costs would only provide additional support to the conclusion that we will not be able to solve the urban transportation problem by expanding the highway and road system.

There are, of course, other types of solution which have been proposed and we will consider them. But first we should give some attention to two reasons that have been used to argue that growth of transportation requirements in the future will be less than they have been in the past: increased suburbanization and decentralization of urban areas and the emergence of visual-auditory communication media (e.g. the picture-phone).

Possible retarders of increased demand for transportation

There has been a considerable spread of population to the suburbs with associated formation of shopping, recreational, industrial and commercial centers outside of central-city areas. This movement is a consequence in part of the increased personal mobility provided by the automobile and the urban decay resulting from exodus of the more affluent from the city proper. Present patterns of change in central metropolitan areas are likely to remain essentially the same for many years and the trend toward levelling metropolitan density of population is likely to continue. The Central Business District will not generally increase in dominance and will be subject to increasing competition from outlying facilities around which most of the affluent will be gathered.

These changes in metropolitan form will absorb part of the "unconstrained" growth in volume of traffic. There will be a wider dispersion of destinations over the metropolitan area and this may alleviate traffic congestion. However, these changes in metropolitan structure will have a minor effect on the urban transportation problem. They will only divert demands imposed on specific parts of the urban transportation system and distribute them more evenly over the whole metropolitan area. This conclusion is reinforced by the fact that these changes in metropolitan structure have been taking place over the past few decades while traffic congestion has been increasing.

It also appears unlikely that new developments in communication technology will have a significant effect on urban transportation demands. In fact, it is quite likely that they will increase these demands. Before considering why, note the more conservative conclusion of Fitch *et al.* [9, p. 170]:

> We must recognise the possibility that developments of advanced forms of communication, such as facsimile reproduction and closed circuit television, might obviate the need for much business-oriented transportation as we know it today. Still, there is no reason to believe that it will make the journey-to-work unnecessary . . . and it is the journey-to-work which is at the center of our urban-transportation problem today.

Introduction of the telephone did not decrease the demand for face-to-face interaction; it increased it. The ability to see distant and strange place on television did not reduce the desire for travel; it increased it. The picture-phone is more likely to increase our desire to be with others than to decrease it. Furthermore, it is currently estimated that it will not be until about 2000 that the picture-phone will be as common as the telephone is today.

Therefore we conclude that neither of these two developments is likely to have a major effect on the nature of transportation problems that metropolitan areas will have to face in the remainder of this century.

Now we consider various types of solution to the urban transportation problem that have been proposed.

PROPOSED SOLUTIONS

A wide range of possible solutions to the urban transportation problem have been proposed. These vary from improvements in the organization and operation of existing systems to the creation of complete new forms of transportation in urban areas. It lies beyond the scope of a paper to analyze all the solutions that have been proposed. Therefore we concentrate on those which have been developed far enough to attract serious attention by transportation planners and public officials.

Most of the solutions that have been offered deal with specific transportation modes, either existing or new. In spite of the recent emphasis on the "systems approach" to transportation problems most concrete proposals still refer to individual modes or to geographical subsystems.

We can classify the proposed solutions into two broad categories: those which involve existing mass-transit systems or some modification of them, and those which involve changes in automobile design and/or usage. Modifications in the way transportation systems operate in urban areas are also considered under these two headings.

Mass-transit systems

Urban mass-transit systems have clearly not developed adequately in response to changing conditions. Routes have tended to remain unaltered despite large population shifts and important changes in land use. Increased automobile ownership and the growth in demand for individualized transportation have also contributed to the decline of mass transit systems. Table 13 shows this decline from 1940 to 1966 using two indicators: revenue passengers and vehicle-miles operated.

TABLE 13. DECLINE OF MASS TRANSIT SYSTEMS [1]

	Revenue passengers (millions)	Vehicle-miles operated* (millions)
1940	10,503.7	2596.0
1966	6671.0	1983.6
Change	−3832.7	−612.4
% change	−36.5	−23.6

* Includes subway and elevated rail, street cars, trolley buses and motor buses.

The decline has been felt in all mass-transit modes. Not a single mode has increased or even maintained its level of operation in the past two and a half decades, but some modes have declined faster than others. Another important indicator of this decline is the number of abandonments and changes of ownership that transit companies have experienced. According to Fitch *et al.* [9, p. 44]:

> Between 1954 and 1961, 159 transit companies were sold; 54 were abandoned with new carriers stepping in to provide service and 77 were abandoned with no replacement. The abandonments with no replacements generally occurred in smaller cities.

In the largest metropolitan areas mass transit has required substantial public support, but with the exception of San Francisco and Washington D.C., large amounts of funds for expansion have not been available. Recent congressional action, however, may provide up to $30 billion to improve these systems over the next 12 yr.

As they exist now, mass-transit systems show several serious deficiencies. They are inherently rigid and lack the flexibility of other modes. Except for motor buses all mass modes require substantial investments in order to provide additional routes or to modify existing ones. They cannot economically provide service to low density sections which constitute a large portion of metropolitan areas and they almost invariably require some travel to the vehicles. The convenience and comfort provided by mass transit are usually lower than that provided by the automobile. Safety, which is higher in mass transit, has little effect on the model choice of the urban traveller. Although travelling time between points in urban areas is generally lower when the points are close to mass-transit stations, this advantage is usually lost when origin and/or destination are not close to a stop, and this is usually the case.

Actual cost-per-passenger-mile is generally lower on mass transit than in a single-passenger automobile. But with several passengers, the cost of the automobile is considerably reduced. The low cost of mass transit is partly due to the fact that most such systems have been fully depreciated and hence only maintenance and operating costs are taken into account. The cost of using new systems will either have to be higher or these systems will have to be heavily subsidized. The automobile appears to be less expensive than even the current system to most automobile owners because they usually consider only the incremental costs of a trip which are generally lower than that of any form of mass transit.

It is important to keep in mind the fact that the decline in mass transit has occurred simultaneously with the extraordinary growth in urbanization. On this subject the Department of Housing and Urban Development [1, 12] concluded that:

> . . . during the last 25 yr of unprecedented urban population growth, public transportation (mass transit), excluding commuter railroads, has lost almost 4 billion revenue passengers. Because of the failure of public transportation to respond either to an increased demand or to new types of transit requirements, and because the automobile has distinct advantages over mass transportation as it is now known, for most adults the private automobile has become the primary mode of travel within urban areas.

More recently, however, John Volpe, Secretary of Transportation, said, "public transportation, as I see it, is the great untapped resource for making the city conform to human needs . . . public transportation will be safe, clean, comfortable, stylish and efficient . . ." (Boston, Massachusetts, September 21, 1970). But in at least some places where public transit has been made safe, clean and so on, as in Cleveland's new rapid transit system, it has failed to attract the expected number of users. As a result, there have been many suggestions which are intended to yield more successful systems. A comprehensive inventory of such proposals is provided by the Department of Housing and Urban Development [10]. We consider the more important of these briefly.

Buses now carry about 70 per cent of all urban public transportation passengers. Most cities in the United States are entirely dependent on them for mass transportation. Improvements suggested for bus systems range from operational improvements (such as assigning exclusive bus lanes in cities, gearing traffic controls to favor buses rather than automobiles and using computers to assist in scheduling) to changes in bus design; for example, reintroduction of double-deck buses, extra-long articulated buses and the establishment of dual-mode bus systems capable of operating on streets and rail tracks.

However, unless these improved systems become the only available means of urban transportation, they are expected to do little more than improve the level of current services; they are not likely to divert a large number of urban travellers from other modes currently in use.

Suggested improvements for mass rail transit follow the same patterns as those for buses. Operational improvements include the design of automatic control systems, changes in fare-collection procedures, modifications in vehicle components such as automatic couplers, brakes, suspensions and so on. Design improvements include changes in vehicles and guideways. The two most developed examples of such improvements are Pittsburgh's Transit Expressway and San Francisco's Bay Area Rapid Transit System (BARTS).

The Transit Expressway is an unconventional system that consists of driverless, rubber-tired vehicles that operate over a concrete guideway at a maximum speed of 50 m.p.h. It uses light-weight cars seating 28 persons with standing room for 26. It is capable of economically serving peak demands of 5000–16,000 passengers per hour, one way. It has been implemented as a demonstration project in a 9000 ft long track in South Park (in Pittsburgh) and is likely to be extended once some design problems are overcome.

The BART system is basically a wide-gauge commuter rail system which incorporates new technologies including automatic fare collection and controls. It is the only large-scale improvement of mass transit which is currently under way in the United States. It is designed to be a component of a large urban transportation system for the Bay Area. B.R. Stokes, General Manager of the Oakland BART district, described the system as follows [11, p. 13].

> The system aims at a truly balanced transport pattern for the Bay Area: freeway to accommodate the normal flow of auto traffic and rail rapid transit to handle the bulk of the peak-hour commuter traffic. It will be a completely grade-separated system based on about 13 miles of downtown area subway construction, 31 miles of aerial structure, 4 miles of underwater tube, 24 miles of surface track and more than 3 miles of tunnel through the East Bay hills into the commuter pockets of Contra Costa County.

It is yet to be seen if this system lives up to its designers' expectations. However, taking into consideration the historic decline of mass-transit systems, their inherent characteristics and the possibility of implementing new systems, it is unlikely, with a few possible exceptions such as San Francisco and Washington, that such systems will become a dominant component of urban transportation. If a change in government policy is implemented this may result in a larger number of passengers using mass transit than would otherwise, but this is unlikely to significantly affect the total number carried by other modes, particularly the automobile.

Some pin their hopes on less conventional mass transit concepts, the most highly developed of which is the dial-a-bus or demand-activated bus system proposed by the Stanford Research Institute. This is a hybrid system, somewhere between an ordinary bus and a taxi. It would pick up passengers at their doors or at a nearby bus stop shortly after they have telephoned for service. A computer would "know" the location of the vehicles in the system, how many passengers were on each and where they were going. It would then select the right vehicle and dispatch it to the caller in accordance with some optimal routing program (yet to be developed). The Department of Housing and Urban Development [1, p. 59] points out that

> . . . the dial-a-bus might do what no other transit system does: handle door-to-door travel demand at the time of the demand. This means that the system would attract more off-peak business than does conventional transit.

It is unlikely, however, that this system will be able to offer service at a cost to the user that is competitive with the automobile or, if it could, that it would significantly reduce peak-hour congestion. The main benefits that might be obtained from the dial-a-bus system would derive from its provision of mass transit to low-density residential areas, particularly during off-peak hours.

New automotive systems

As mentioned earlier, the automobile accounts for about 85 per cent of all urban passenger travel and its predominance is most likely to continue. It provides flexibility, speed, comfort and convenience, although they present problems with respect to safety, space, cost and air pollution. In spite of these problems transportation analysts generally agree with Berry *et al.* [12, p. 124] in that

> . . . of all modes of transportation, the private automobile is best suited for most urban passenger trips because of its inherent flexibility in meeting the needs for involvement

of people between widely scattered points of origin and destination. Projected suburban growth in population, industry and business will result in increasing reliance on the automobile for urban area travel.

There are no signs that this increasing reliance on the automobile will diminish sometime in the near future as a result of traffic congestion or the inconveniences derived from widespread usage of the automobile. Quite to the contrary, there is some evidence that urban dwellers would prefer to relocate their jobs or residence rather than switch from the automobile to another transportation mode. The department of Housing and Urban Transportation [1, p. 41] noted that:

> The experience of recent years contradicts the belief that traffic congestion will set itself a limit to car ownership. If there is to be any chance of coexisting with the automobile in the urban environment, *a different sort of automobile is needed* with improvements in the supporting systems (italics ours).

The present design of the automobile, the 5–6 passenger family car, is a compromise intended to satisfy a wide variety of needs. Automobiles are used for inter- and intra-city travel, to travel to and from work, for recreation, shopping and so on.

Of considerable importance is the fact that the number of two-car families has increased from 7 per cent in 1950 to 25 per cent in 1966. This and other facts we shall consider below suggest a functional differentiation between an intra- and inter-city automobile. Families that own or use more than one car would obtain distinct advantages by using special-purpose automobiles better suited for specific needs; for example, cars better suited to the characteristics of central city traffic.

A major improvement in automotive systems is suggested by the figures on automobile occupancy in urban areas. For example, average occupancy rates in metropolitan Philadelphia are approximately 1.5 passengers per car, ranging from 1.2 for commuting trips to 1.6 for non-work trips [13, p. 91]. The average capacity of an automobile, on the other hand is about 5. It is apparent that substantial reduction in automobile congestion could be achieved if the average occupancy of automobiles, particularly for work trips, were increased. Car pooling, however, reduces the advantages of door-to-door travel by automobile. A less inconveniencing alternative would involve the use of a small urban automobile, what has been referred to by some as an "urmobile".

This alternative has been explored in several studies (see, for example [1, 14]). It is generally acknowledged that at higher speeds and in free-flowing traffic the effect of reduced vehicle length on congestion is very small. For example, at 40 m.p.h. the majority of the road space can be said to be "occupied" by safety space between vehicles, and, according to McClenehan and Simkowitz [15] the effect of reducing car length by half on expressway traffic would be an increase of flow by no more than 10 or 15 per cent. Greater increases would occur on heavily used city streets: as much as a 70 per cent increase in flow would be achieved when congestion reaches the not uncommon level of 15 vehicles per light. If only a fraction of long cars is replaced by small ones, the resulting flow is approximately a linear interpolation between the two extremes.

Relatively little is known about the effect of car width on traffic flow. Experiments carried out by the Ministry of Transport in England [14, p. 13] show that a lane width $2\frac{1}{2}$–3 ft wider than the car itself represents a reasonable minimum for safety purposes. They also show that in mixed traffic conditions when small and large cars travel together, the small ones usually travel behind the larger ones using the same road space.

A considerable increase in passenger density could be obtained by use of short (less than 10 ft) narrow (about 3–3½ ft) two-passenger vehicles (one seated behind the other). In the hypothetical case that traffic were made up exclusively of such vehicles, an increase of at least 2.2 (2.0×1.1)* on expressways (two vehicles per normal lane and a 10 per cent increase in flow due to shorter cars)* and 3.4 (2.0×1.7)* on city streets could be obtained. If shoulders of four-lane expressways were used for one lane of such vehicles their capacity would increase by 2.7 ($2.2 + 0.5$) times the additional lane would be used for one narrow car, which would have half the width of a normal car. On city streets with two moving lanes for current automobiles and one for parking, the increase would be 5.1 ($3.4 + 1.7$). This hypothetical case excludes trucks and buses, but shows that, at least in theory, it is possible to deal even with the 4.28 medium forecasted increase in requirements for the year 2000, if the use of small cars were generally adopted.

Parking requirements would also be greatly reduced. For example a normal car takes more than 20 ft along the sidewalk. Three 10 ft long cars could be parked in the space normally required for two normal cars. Furthermore, if the cars are narrow, additional road space would be left free for vehicular traffic. Parking-space requirements would be further reduced if the door or doors were either sliding on the side, or at the front or back. The latter would permit face-in parking with high density.

A large variety of small automobiles are under development now (see [16, 17]). In many cases the new designs incorporate changes which will reduce polluting effects of cars. They can be made to hook on to each other in train-like fashion to facilitate towing or taking the family along on a trip. Their reduced maximum speed and acceleration capabilities increase their safety.

The advantages of using small cars for intra-city traffic are dependent on the restrictions imposed on the use of large vehicles. During a transitional period vehicles of different sizes could mix together. Eventually use of city streets and highways would be limited to small cars from, say 7.00 a.m. to 7.00 p.m. on week days. Trucks are already kept off city streets during these hours in Mexico City.

An important indication that the automobile user is moving toward smaller cars is provided by the nature of car sales from 1957 to 1967. In 1957, 32 per cent of the automobiles sold were four door sedans, while the smaller two-door hard-tops accounted for only 19 per cent of the sales. This situation was reversed in 1967 when almost twice as many two-door cars were sold as four-doors. Furthermore, the sale of small imports, compacts and sub-compacts has been increasing steadily [18].

Many benefits may derive from publicly or privately owned fleets of small cars that would be available for short-term rental. These cars could be made available as "U-Drive-It" taxis which one could obtain from one garage and leave at another. The pick-up and drop-off points could be widely dispersed over the city. The commuter could drive to a point on the urban fringe in his large automobile and pick up a smaller one for use in the city (see [19]).

It is clear that a change to small urban automobiles (whatever their particular characteristics may be) can be accomplished within a decade with tolerable transitional problems. Furthermore, such a change would require little public expenditures and would yield economies to the individual without loss of convenience or comfort. Most important, it could reduce congestion significantly and permit less restricted increases in use of automobiles than would

* Using McClenehan and Simkowitz figures for the increase in traffic flow with short cars.

otherwise occur. Finally, their advantages would be enhanced by many of the changes in highways and traffic control that are currently under study.

Automatic control of traffic would permit an increase in speed and a reduction in the space between cars without jeopardizing safety. According to Flory [11, p. 69]

> ... first, a stage of improved communication ... to enable (the driver) to make decisions better and faster; second, a stage where some of the decisions are made for him and he is given warning if he is approaching a dangerous condition; and third, a stage where the system actually takes control over the car either on a continuous basis or as a limit-type operation which could physically take control if the driver failed to respond properly to the warning system.

This stage-by-stage approach would permit solution of the difficult problem of compatibility with vehicles without automatic controls in mixed-traffic situations.

Several designs for integrated vehicle-media systems have been proposed. One is for a Personal Rapid Transit (PRT) system. Such a system is described by the Department of Housing and Urban Development [1, pp. 60–65] and consists of automatic individualized vehicles travelling over exclusive guideways which extend over the metropolitan area. Another proposal involves a dual-mode vehicle that combines the characteristics of flexible individualized transport with those of a fast economic mass-transit system. The vehicle would travel for part of its journey over normal streets mixing with other vehicles, and part of it over fixed guideways presumably under automatic control.

Some cities, like Toronto and San Jose, have already installed computer controls over the cycle time of traffic lights in an attempt to maximize traffic flow under changing conditions. As these systems are improved other cities are likely to follow suit.

CONCLUSIONS

We have tried to show that enough new streets and highways cannot be built in urban areas to meet future transportation requirements. Our analysis indicates that urban transportation systems will evolve in the following ways:

Few radical changes are anticipated in the configuration of transportation systems. The automobile will continue to be the most heavily used mode of transportation for both intra- and inter-city travel, but some changes in its nature and usage are virtually inevitable. These changes will involve a reduction in size and capacity (and possibly ownership) of vehicles used for intracity travel during work days. Improved systems for communicating traffic information to the driver and gradual introduction of automatic traffic control and eventually vehicle control is likely.

Metropolitan structure will keep on changing and additional peripheral activity centers will appear, which will distribute more evenly the demands imposed on urban transportation systems. New developments in communications technology will be implemented but they will not have a significant influence on demands for urban transportation.

Mass-transit systems will be improved in some areas but in general they will hold their own and not significantly affect modal mix. Experiments with exotic systems are likely but these will probably develop for special rather than general purpose transportation.

The development of urban transportation systems will increasingly require regional cooperation. The current trend toward establishment of regional transportation authorities is likely to continue and gain strength.

The automobile dominates the urban transportation scene for a while, but we must learn to adapt it, rather than adapt to it, if we are to have satisfactory urban transportation systems.

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