Small Car Automatic Transit

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•WITH continued urbanization there is mounting concern about circulation and its relation to the quality of metropolitan living. Air pollution, traffic fatalities, and the relative immobility of a substantial part of the population are some of the deficiencies. Such problems have spurred millions of dollars worth of federally sponsored research in quest of a transport breakthrough.

No one knows whether we shall be able to achieve new systems that can transport persons in metropolitan areas quickly, safely, and economically in such a way as to meet the real needs of the people and at the same time contribute to good city planning. It may turn out that great improvements in circulation would be feasible only with great changes in our environment and habits, changes on a par with those that have attended the dominance of automobiles. Thus, to have the styles of living that are popular today, it may be necessary also to accept environmental conditions much as they now are. Nonetheless, it is possible too that technological developments complementing a shift in social attitudes could bring about the transport breakthrough sought.

One candidate among ideas for a breakthrough is driverless, individualized transport. In the form in which this concept is discussed here it is referred to as small car automatic transit, or simply "SCAT." In familiar terms it is a merging of taxi-like aspects with features of the Minirail transit installations at the Expo 67 in Montreal. Defined formally, SCAT is a system of small cars capable of unattended operation individually over an urban network of exclusive trafficways. (In this paper cars run only on tracks, vehicles are driven on roads, and dual-mode conveyances are adaptable to either. Transport refers to all powered modes, as used for trips within a metropolis, and transit is any transport mode that places on its user no driving or parking responsibilities and no social relationship to a driver.)

Small car automatic transit is examined primarily in the physical context of the middle-sized metropolis. Such places, according to one viewpoint, should be planning even now for rapid transit. Timely development of SCAT technology, however, could open a new course for transit investment. Rather than the traditional one or two high-capacity transit lines connecting a handful of stations, a broad network of SCAT facilities would connect a great many localities—with a service having attributes of rail transit. Accordingly, the SCAT route networks considered here are roughly comparable with the routes of present-day bus transit operations.

DESCRIPTION

The concept under consideration is shown in Figure 1, an unsophisticated illustration from a decade-old proposal. A SCAT installation comprises a fleet, facilities, and plant—with a work force to maintain service. The small automatic cars of the fleet are anonymous; unlike private automobiles, no SCAT car retains a special relationship to any one person. In an installation, the facilities are the public portion: the trafficways and stations, and the route junctions where cars may change course. The plant includes car storage yards and maintenance shops.

Although SCAT technology might be applied to a single looped route (resembling the Expo Minirails), the usual installation is better thought of as a network of trafficways

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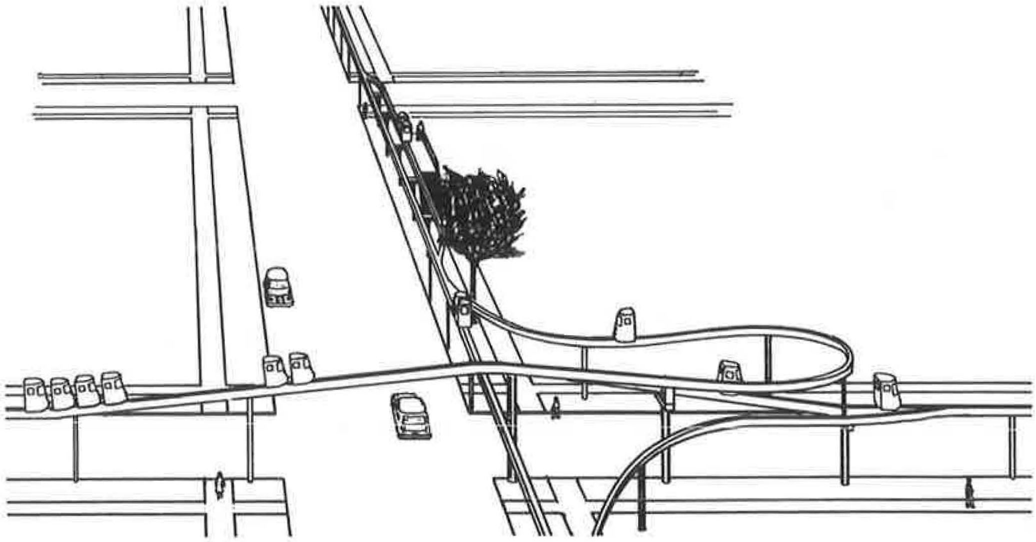


Source: Northwestern Engineer, XVI (August, 1957), p. 14.

Figure 1. Individualized transit facilities and cars.

interconnected at junctions. The facilities are effectively separated from external interference. Any car can go anywhere on them, with or without an occupant, permitting the recirculation of empty cars according to localized demands. Except as necessary, however, cars do not keep traveling, but remain in stations (or in yards) available for use. Because people board and leave cars only at stations, mainline traffic is able to move freely past stations and is essentially non-stop. After a person has occupied a waiting car, closed its door, and pressed its starting button, automatic controls take the car out into a gap in the mainline traffic. The car travels along the route it is on unless commanded to turn, which the rider accomplishes merely by pressing a turn button in the car. (The additional feature of destination preselection and automatic routing is regarded as an option which might be worth its expense.) By commanding a turn, when approaching his destination, the rider causes his car to enter the station and bring itself to a stop. The car is simply left there, to be used by anyone else or perhaps to be called away by a station downline that momentarily lacks cars.

To recount the features of small car automatic transit, service is available at all stations at all times. Like a self-service elevator, a SCAT car is easily operated, but it is occupied exclusively and not shared with unfamiliar individuals. The cars always remain a part of the installation; nobody parks a car nor does he drive one home. Thus, the breadth and coverage of service is closely related to the facilities provided.

SCAT NETWORKS

Most of the route mileage of an extended SCAT installation is likely to serve that portion of the metropolis, here termed the city, which is characterized by its density and relatively regular and permeable street pattern and which includes many square miles of residential settings as well as the central business district (CBD). Given peoples' interwoven travel directions, SCAT routes might reasonably conform to a grid-like arrangement rather than following the strongly radial pattern of conventional transit. Figure 2 illustrates a portion of a so-called citywide SCAT network, with cell size increasing from one or two blocks in the downtown core to perhaps half a mile at the margins of "city" development.

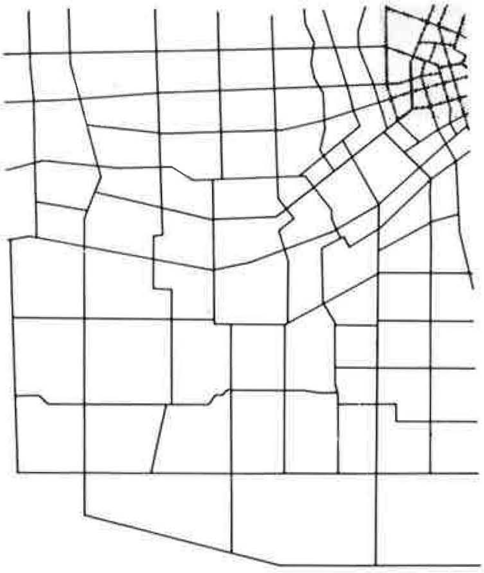


Figure 2. Portion of citywide route network.

The merits of the grid have been recognized in the Transgrid concept (1). As proposed, the Transgrid has essentially a uniform cell size all over the metropolis. Thus, only two or at best four of the individual routes can serve the CBD, and they obviously will need capacity considerably higher than that for routes at the periphery of the Transgrid. This suits the Transgrid principle of adaptability to entirely different technologies for the individual lines; and because they are therefore "uncoupled," patrons change route by getting off and transferring. By contrast, the single SCAT technology allows universal "coupling" or interconnection of routes. This facilitates spacing the network to local conditions, lets riders avoid transferring, and permits servicing the entire fleet in one shop.

Two elementary types of SCAT route junctions are shown in Figures 3 and 4. Their curving "junctures" function like storage and turning lanes in a road junction, letting mainline traffic stay essentially free-flowing. If two-way routes consisting of side-by-side mainlines are involved in a junction, it is likely to be appreciably more complicated as in Figure 5, a one-way/two-way junction that requires both an overcrossing and a turnback. The geometrics of a two-way/two-way junction would be formidable in the restricted space usually available. Thus, the avoidance of junction complexity pleads for a SCAT network composed primarily of one-way routes, despite some inconvenience to users.

In an actual SCAT installation, each station would be located with regard to factors such as the local street pattern, maximum walking distance, and proximity of traffic generators. Although station placement is thus indefinite, one may assume that a car traveling along a route would pass a station about midway between successive junctions. In the citywide SCAT network (which is grid-like) this arrangement of stations, despite their wide spacing, tends to optimize coverage and walking distance. The workability of more frequent SCAT stations is under consideration, in response to a suggestion for station capabilities every 20 feet along a route (2, p. 2).

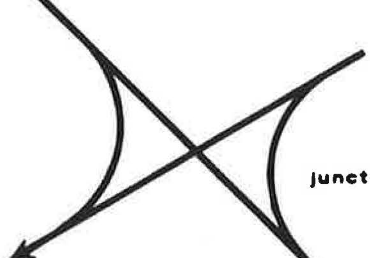


Figure 3. Simple route junction: intersection.

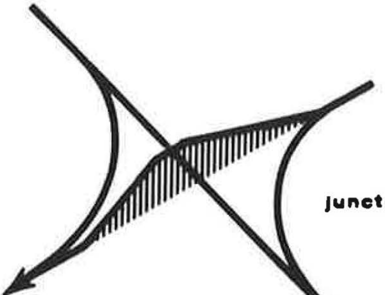


Figure 4. Simple route junction: overcrossing.

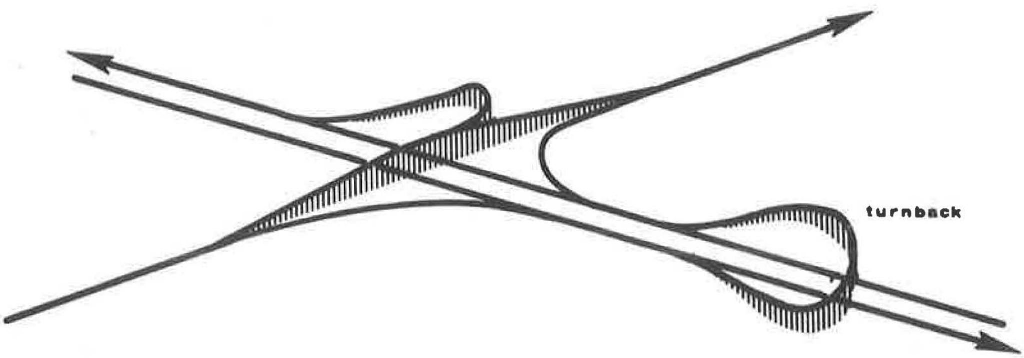


Figure 5. One-way/two-way junction.

Analysis of urban transport systems has developed the notion of a hierarchy of networks differing in their celerity and accessibility, and variously suited to longer or shorter trips. As Haikalis notes, there is no real need for systemwide uniformity in operating speed (2, p. 4). Yet a hierarchy of three standard speeds seems desirable in engineering terms, and is conceptually simple. The standard operating speeds proposed for SCAT service are:

On express routes	45 mph
On the regular network	27 mph
On most facilities in downtown	11 mph

Express SCAT service would tend to attract much traffic to facilities of inherently lower capacity. Fortunately, this tendency would be offset by the absence of any stations on express mainlines and by the limited number of connections with the regular network. Ideally, the spacing of express routes should reflect an appraisal of the economic and social costs of speed as well as its farebox value; probably a spacing of 2 to 3 miles would be appropriate between the two-way express facilities. If their siting were governed by special restrictions, however, the SCAT express network might be shaped almost entirely to such freeways, railroads, suburban highways, and other linear features as were available.

The usefulness of a network expands with its size, justifying extension of SCAT routes beyond the citywide network out into the periphery of the middle-sized metropolis. While this suburban portion is sure to have some older towns (resembling tiny cities), most of it is recent development—chiefly commercial-industrial frontage along highways and residential subdivisions elsewhere. Shaped by dependence on automobiles, the road pattern and less dense spread of the contemporary suburban setting are factors adverse both to walking and to transit service. In light of economic and right-of-way considerations in this setting, suburban SCAT routes would probably be confined to the arterial highways.

Figure 6 illustrates the idea of a metropolitan SCAT network—as applied to the CBD and one quadrant of an actual middle-sized metropolis. The citywide network appears as an imperfect grid, warped to the features and available rights-of-way of the real city. One-way routes are prevalent in this network outside of downtown. The suburban extensions form a loose network composed generally of two-way routes along highways. Primarily these facilities would serve places like shopping centers, large plants, and older towns (where modest networks may be provided). Stub-end express routes, like the airport extension, would also have a two-way regular mainline for access and for reserve capacity.

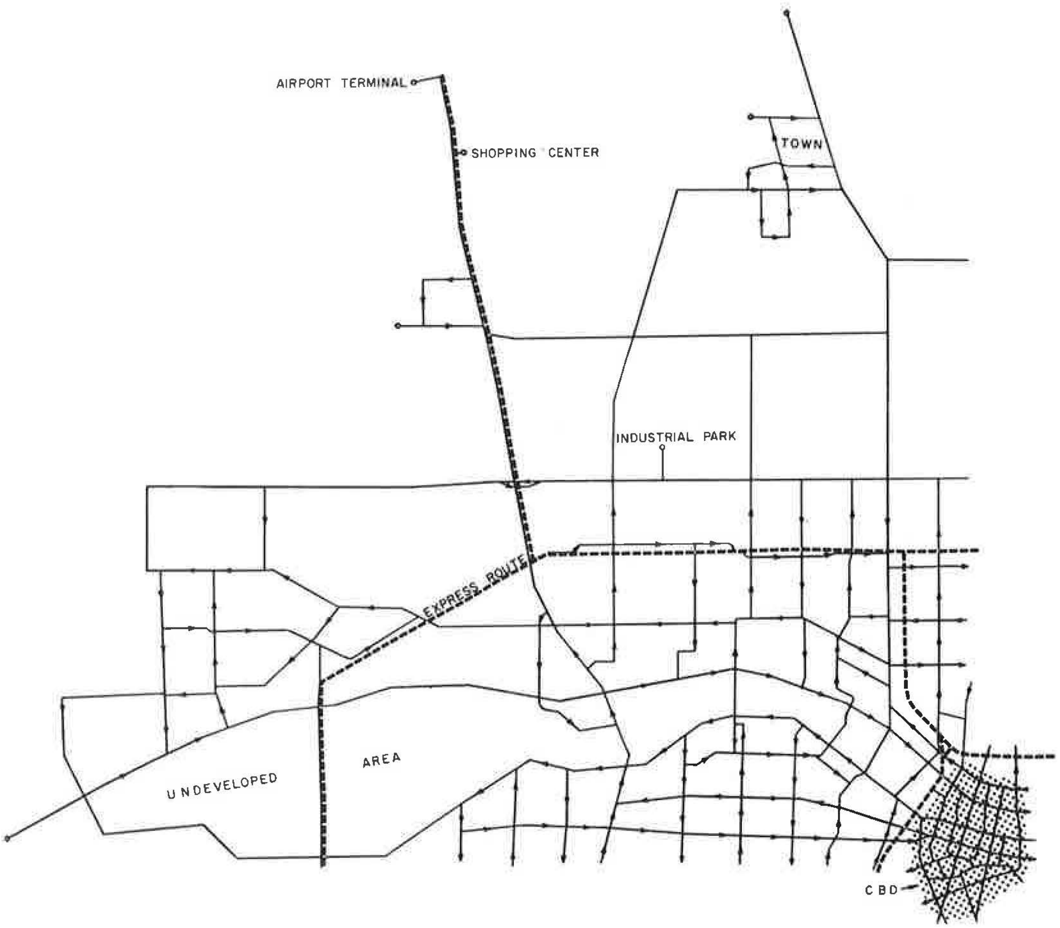


Figure 6. Concept of SCAT metropolitan route network (one quadrant only).

FACILITIES

The notion of unattended conveyances operating among vehicular traffic in the streets is rejected here, out of deference to the capriciousness of street users—whether driving or afoot. SCAT cars must use off-road trafficways. To emphasize that these SCAT facilities have to be discussed as tangible structures, they will be termed "tramways" (after tram, in the sense of a beam).

The scale of the tramway is set by the size of SCAT cars, which would be as tall as a schoolchild and as wide as a stout adult. As a transport facility, the tramway is modest in its scale. Essentially, though, the SCAT tramway is also an urban utility line, and it would rank among the largest of such lines. The width of subsurface tramways (tunnels) would be further enlarged by walkway space alongside the car-clearance envelope. Although above-street tramways would occupy less space, quite evidently the SCAT tramway in general would not be fitted into most metropolitan settings as readily as utility lines are.

Like any transport facility, the SCAT tramway would occupy a right-of-way. Certain categories of right-of-way would be suitable only for tramways built at particular levels, as suggested in Table 1. Whether an express (x) or a regular (r) tramway would fit a given right-of-way and level depends on network and aesthetic factors. The "easement" right-of-way concept is applicable in settings composed of detached houses.

TABLE 1

SUITABLE TRAMWAY LEVELS

Level	Right-of-Way				
	Street	Freeway	Railroad	Easement	Private
Elevated	r x	x	x r		
Surface		x			x r
Subsurface	r	x		r	

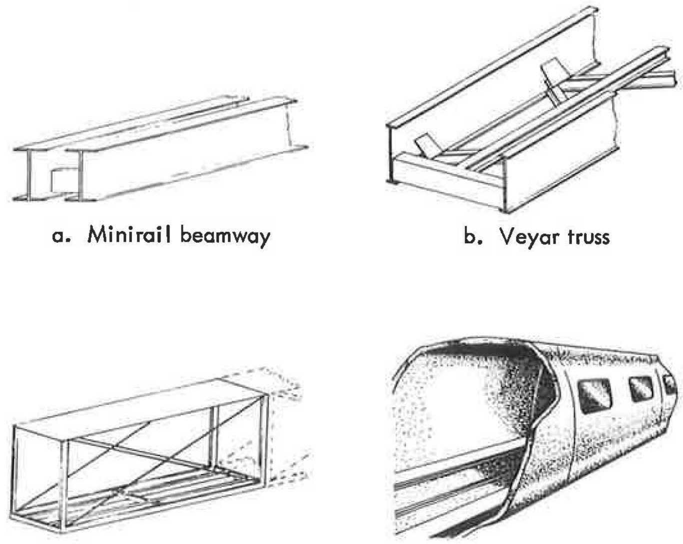
x = express, r = regular.

There, tramways might be tunneled in easements located either between houses or along backyard lot lines, and would cross streets just beneath the pavement. Despite the construction economy of surface tramways (merely trackage protected by adequate enclosures), there are few rights-of-way where a long barrier to surface movement is acceptable.

Among the above possibilities, only the right-of-way of streets is believed to be practical for most of the routes of a citywide SCAT network. Streets are nearly ubiquitous and their rights-of-way already have a public status for transport purposes. Accordingly the rest of this section on facilities presupposes their being located within the right-of-way of thoroughfares—chiefly arterial streets—above or beneath the surface.

Several types of tramway spans are shown in Figure 7. Figures 8 and 9 show sectional views of elevated and subsurface tramways in relation to a street. (Details of an actual installation could differ widely from those sketched, of course.) The interval between supporting columns or bents would range upward from 20 feet.

The structural design of tramways would be a more straightforward engineering task than finding a place for them in the public right-of-way. One complication is that existing features along the street would have a kind of seniority over the planned tramway, forcing on it most of the compromise of fitting in among them. Unlike a gas main,



a. Minirail beamway

b. Veyar truss

c. Roofed through truss

d. Teletrans tube

Figure 7. Types of SCAT spans (not to scale).

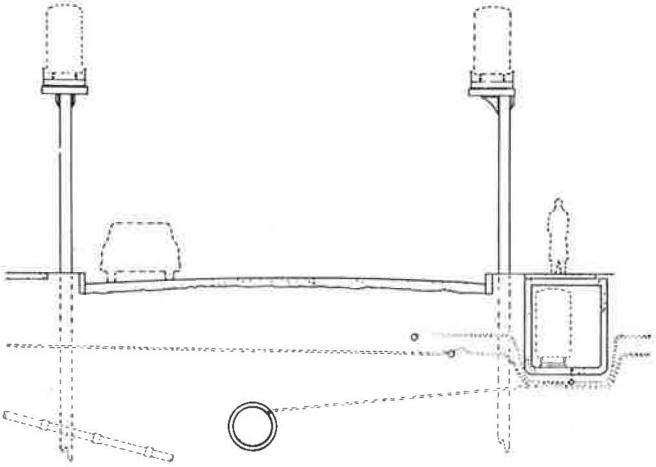


Figure 8. Street cross section with elevated tramways and subsurface tramway under sidewalk.

moreover, a tramway could not be offset abruptly around obstacles but would have to be deviated gradually to avert them. For elevated facilities in particular, trees are a further planning difficulty. Much citywide route mileage would follow arterials that are more or less residential, making the preservation of trees extremely desirable.

One may anticipate a substantial divergence in the methods of producing elevated and subsurface tramways. The designers of an above-street tramway, for all the trees

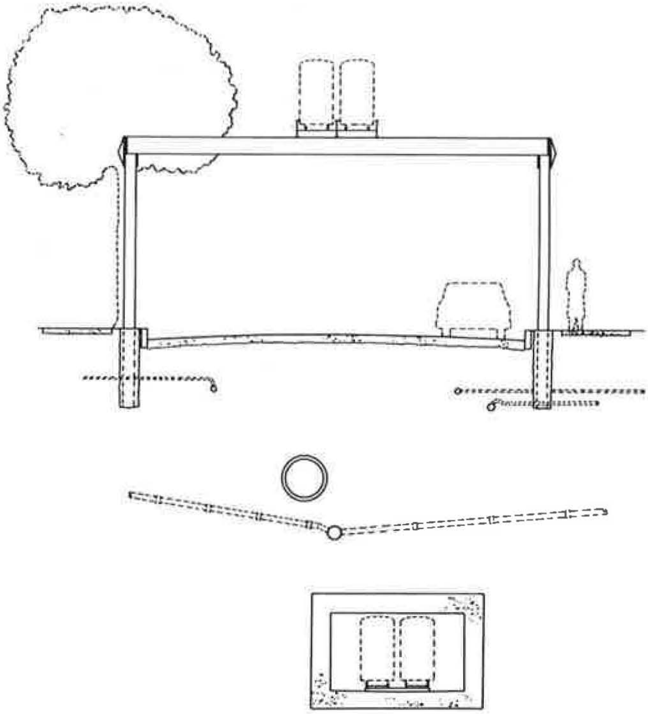


Figure 9. Street cross section with elevated tramways on "bent" support and subsurface tramway.

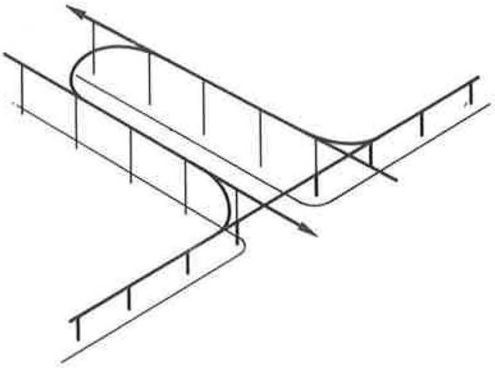


Figure 10. Portion of elevated two-way CBD junction.

and wires and luminaires encountered, would at least be coping with known and visible obstacles. By contrast the subsurface tramway would typically have to be fitted in among a clutter of mains and drains, sewers and conduits—mapped with varying inexactness, if mapped at all. Once the exact tramway alignments had been defined, elevated spans or tunnel sections complete with track might be fabricated in a mechanized or even semi-automated shop. Completion of an elevated tramway would require little field work beyond setting the supports and erecting the spans. Installing tunnel sections to exact alignment in the ground would entail much field labor, however, with work constantly subject to much higher risk of disruption from breaking a utility line. Considering the difference in labor inputs, the elevated tramway would seem likely to have a lower unit cost. Further development of remotely controlled tunneling methods might eventually permit building tramways beneath all the utility lines (as in Fig. 9) at reasonable cost, for the tunnels proper. Nonetheless, these deep tramways might incur substantial costs on items such as drainage and stations.

At either level, junctions are difficult elements in a SCAT installation. Their junctures demand a prescribed amount of space for transitions to and from the mainlines and a curve whose sweep is dictated by speed and the dynamics of a smooth ride. Because each juncture (or turnback) may add visual bulk if above the street or may entail utility relocations if beneath it, simple junctions are preferable to those having two-way routes (Fig. 5). Simple one-way junctions are also preferred because their mainlines need not cross over each other but may intersect at the same level.

It is this kind of simplified junction (Fig. 3) that fixes the basic citywide network as a grid of one-way routes, alternating in direction. Accustomed to bidirectional travel networks, the public would find these one-way SCAT routes somewhat inconvenient, yet this fault seems more acceptable than the alternative of serious junction problems. Two-way routes need not be entirely excluded from the citywide network, however, if it is elevated. Their side-by-side mainlines might be appropriate along major arterial streets whose width and abutting development can accommodate the bulkier junctions. In the CBD, the SCAT routing situation is quite different, owing to the large volume of travel at the beginning and close of the work day. Analysis suggests that a closely spaced grid of two-way routes is needed. These routes could take the form of single elevated tramways directionally paired along opposite sides of a street, and overcrossing as shown in Figure 10, with compact inclined junctures appropriate to the reduced operating speed. A subsurface network on this pattern is judged to be impractical.

Assuming that downtown SCAT facilities must be elevated, how do elevated and subsurface systems generally compare otherwise? Operationally a subsurface SCAT system should be more weatherproof; indeed, unenclosed elevated facilities are exposed to snow and fog, and may involve special measures if cars are to have enough traction to run in the face of a gale. On the other hand, in case of a blockage or other emergency, the elevated facilities are potentially more accessible for being cleared, and their exposure to public surveillance should lessen policing requirements. Because road vehicles may be 12 to 14 feet tall, the typical elevated station cannot have its platform lower, which poses the problem of service for persons unable to climb stairs to that height. By contrast the platform of a shallow subsurface station could be but half that distance from the surface—a climb of only a dozen steps. From an aesthetic standpoint, a subsurface installation has the merit of being out of sight except for its stations. There is another aspect of aesthetics, however: how many riders would prefer the view inside a tunnel to that from an elevated tramway? Moreover the very visibility of the elevated system makes it far more intelligible to patrons in the relationship of its routes to one another and to their surroundings. Considering all of the comparative features of the alternative levels, neither appears to be clearly the better.

In summary, SCAT facilities typically would be located within street rights-of-way; the appearance of elevated facilities is a major concern, as are subsurface construction difficulties; and network design is influenced by the desirability of geometrically simple junctions. Based on what is currently known about small car automatic transit systems, the elevated level is believed for economic reasons likely to prevail in any metropolitan installations that may be built.

CAPACITY

The capacity of SCAT is first established here for mainline operation, and then for network traffic; station and junction capacities are not discussed. Attention focuses on conditions during periods of peak demand when capacity would be most needed. In the context of this treatment, mainline traffic is regarded as a steadily moving stream whose composition is ever changing as cars enter or leave at stations and junctions along the way.

The question of how much traffic a SCAT facility ought to be able to handle raises some issues that would be met in system design work and the development of SCAT technology. For example, every interruption in the mainline track, like switches, presents a finite (though very small) risk of serious failure. That possibility should give pause to proposals for a tightly packed traffic stream. The whole question of the economics of control sophistication has great importance from a system standpoint. Should controls be relatively simple, requiring liberal gaps between moving cars and yielding a somewhat jerky or "stiff" performance? Or should controls have the complexity (and cost) needed to handle higher traffic volumes more adroitly while providing a smoother ride? Befitting this preliminary survey, SCAT performance specifications are inclined to be conservative.

Mainline Capacity

The defining of mainline capacity begins from a regard for safety: How abrupt a halt may be imposed on a dozing or inattentive rider? The stopping distance for an emergency halt fixes the (minimum) "safe-gap" allowable between successive cars. A quite arbitrary critierion for emergency halting has been set as:

> In effect, on perception of an emergency the car instantly begins to halt at a braking rate that increases uniformly from 0 to 0.4 G (or 8.8 mphps) in 1.0 sec, remaining at 0.4 G until the car has halted.

Here are the approximate safe-gaps and halting times at the three proposed standard operating speeds:

	Downtown	Regular	Express
Mainline speed (mph)	11	27	45
Mainline speed (fps)	16	40	66
Safe-gap (ft)	18	79	200
Halting time (sec)	1.8	3.6	5.6

Mainline capacity, in the sense used here, specifies a practical ability to move persons. Cars are considered to be 7 feet long and to seat only one rider (although tandem seating could be accommodated). If the cars operate singly (no trains), a maximum volume of riders may be calculated for these assumed conditions. Seventy-five percent of this maximum is taken to be the capacity. It allows for spaces in the traffic stream to admit cars whose riders wished to enter from stations or other routes, and also for

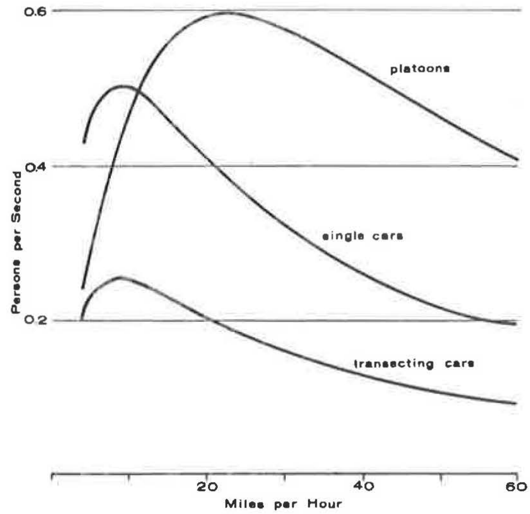


Figure 11. Mainline capacity relative to speed and operating method.

an occasional empty car diluting the flow of riders even in peak-direction traffic. The single cars curve in Figure 11 shows capacity attaining a peak value of 0.5 persons per second at a mainline speed of 9 mph.

If a SCAT junction is to have two mainlines that intersect, their capacities must be based on the ability of their traffic streams to cut across or transect each other safely. This requires that the gaps between successive cars be lengthened greatly—to two safe-gaps plus a car length, according to a reasonable criterion (Fig. 12). Application of this criterion to single-car traffic results in the low capacity per mainline shown in Figure 11 by the transecting cars curve.

Mainline capacity through an intersection may be improved by aggregating the traffic into groups or platoons (Fig. 12) so that the necessarily lengthened gap is shared by several cars. Although in a platoon, the individual cars (as well as 2-car and 3-car trains, if desired) would still have complete independence of routing and station choice, just as in single-car traffic. The controls would handle every platoon as though equal in length to the permitted maximum of 6 cars. Even in peak traffic, however, most platoons would have to consist of fewer cars in order that trains and cars might enter traffic promptly by joining almost any platoon. Based on a limit of 3.6 riders per platoon, the capacity of a mainline that could safely intersect others is given by the appropriate curve in Figure 11.

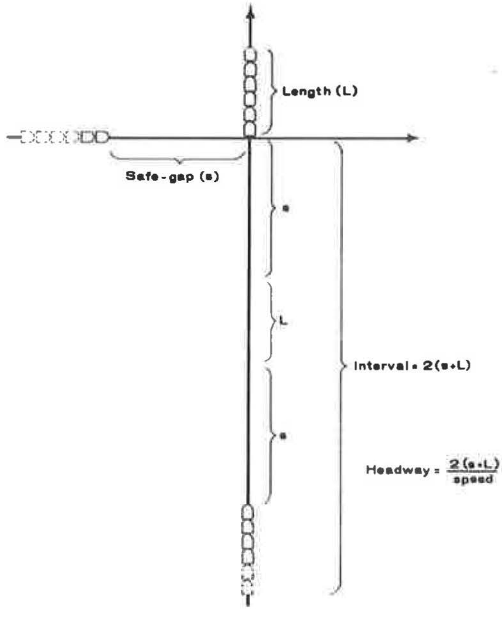


Figure 12. Transecting criterion.

The platoon method of operation obviously calls for sophisticated controls. It would not be restricted to either dense or transecting traffic, of course. The lengthened gaps between platoons would provide considerable slack in the traffic stream. This slack could be drawn upon by cars for slowing on the mainline prior to turning from it, aiding the compactness of junctions and stations.

Network Capacity

With mainline capacity established, the adequacy of a citywide SCAT network under peak traffic may now be examined. There are two approaches to doing so. Assume in either case that SCAT carries half of the person trips. The network may be thought of as a grid of alternate one-way routes. They consist of intersecting mainlines having a capacity of 0.58 persons per second or 2,100 persons per hour.

The first approach determines the widest spacing of routes just adequate for an idealized, essentially homogeneous urban region. The network is a regular grid of square cells. Trips commence uniformly in space and time, and travel along one-way trafficways. On these facilities the average volume V may be shown to be:

$$V = \frac{LT}{w} \text{ (trips/unit time)}$$

where
L = average trip length on network,
T = tripmaking per unit time, and
w = total length of trafficways.

Tripmaking is related to area and population density and to the people's trip-commencing rate, while the grid size determines trafficway length:

$$T = ADC \qquad w = 2\frac{A}{S}$$

where
A = area of region,
D = population density,
C = trip-commencing rate per person per unit of time, and
S = length of side of grid cell.

Then the required grid spacing or cell size, S = 2V/LDC, if the trafficway capacity is set equal to average volume V.

To determine route spacing requires a knowledge of the trip-commencing rate. Metropolitan transport surveys have generally found that the peak-hour trip-commencing rate for transit and auto travel is in the range of 45 to 55 person trips per second per million population. The expression for S, evaluated with a SCAT trip-commencing rate of 25, density of 10,000 persons per square mile, and average trip of 4 miles (allowing for network circuity), indicates a grid spacing of some 1.2 miles.

That spacing assumes ideal homogeneity. Suppose, however, that 40 percent of the total traffic went along crosstown routes while 60 percent were radially oriented toward downtown, with a 60:40 directional split. Then the radial routes would have to be spaced 0.8 mile apart at the assumed population density. Appreciably higher densities are not usually found over large areas in middle-sized cities. Therefore, a SCAT network based solely on coverage policy—with cells ⅜ to ½-mile square—should have adequate capacity outside of the CBD.

The other approach to checking network capacity is based on the observed vehicular volumes (ADT) on arterial streets. Imagine a grid of two-way arterial streets, overlaid with a similar grid of one-way SCAT routes. For analytic purposes the total daily vehicular volume on each of the arterials would be essentially unchanged whether they were all two-way streets, or alternately one-way facilities in the manner of the SCAT routes. (To illustrate, the combined northbound traffic of a pair of two-way arterials may be placed on one of them, while the other arterial then carries all the southbound traffic.)

To compare the person-capacity of the arterial streets and the SCAT facilities, first assume that each arterial has a two-way ADT of 10,000 vehicles, with 11 percent of the daily volume in the peak hour, directionally split 60:40. Further, assume a peak automobile occupancy rate of 1.33 persons (exclusive of trucks and buses) and assume that the resulting peak-direction flow of persons is increased 25 percent by transit riders. Then two adjacent arterials have a combined volume of 2,200 persons per hour in the peak direction. If 50 percent of that volume is assigned to the single equivalent SCAT mainline, slightly more than half of its capacity is used. Apparently, then, a one-way SCAT route network, coinciding with a two-way arterial street system whose vehicular volumes had generally not exceeded 19,000 ADT, should be capable of serving about half of the peak-period travelers.

Downtown, the SCAT network consists of reduced-speed mainlines rated at a capacity of 0.49 persons per second (1,760 persons per hour). If it were to carry half of the peak-period person travel—including all of the present-day street transit travel, assumed to be one-third of the current travel there—a one-way SCAT network could suffice only if vehicular volumes on the corresponding streets had not been greater than roughly 11,000 ADT. Thus, it appears that although the downtown SCAT network would be finely meshed (with cells containing only a few city blocks), much of the network in and near the CBD would have to consist of two-way routes.

The portion of a metropolitan SCAT network shown in Figure 6 is based upon an actual middle-sized city whose arterial vehicular volumes are known. According to the ADT-based criteria presented above, SCAT facilities outside the CBD appear adequate. Similarly the rather irregular SCAT network within downtown offers enough mainline capacity, but its ability to handle peak turning and station loads was not examined. Downtown cordon count data for the city in question suggest that SCAT capacity into and out of the CBD should, in the aggregate, be sufficient.

ECONOMICS AND SERVICE

No attempt has been made to estimate the economics of a SCAT system having the attributes discussed. Nonetheless, the partial metropolitan network mapped in Figure 7 does allow a rough check, in terms of the limiting cost and investment at which this SCAT installation could break even financially. With this same network some indication can also be obtained of the comparative service afforded by SCAT and by autos.

For this comparison, trips were traced along mapped streets and SCAT facilities to simulate travel via each mode system between the same origin-destination pairs. Ten such pairs were used, their straight-line lengths aggregating some 30 miles and having a length distribution like that of reported person trips. Trip end locations were essentially random with respect to transport facilities, while reflecting actual travel patterns (with a single trip end in the CBD). No trip used an express facility. Travel time for the alternative systems was synthesized according to these parameters:

Automobile	SCAT
Average running speed: 9 to 28 mph (varying by distance from CBD)	Mainline speed: 27 mph (11 mph in CBD)
Terminal delay: 120 to 20 sec (decreasing farther from CBD)	Penalties: 70 sec for both stations, plus 10 sec per turn
	Walking: 4.6 ft/sec (3.14 mph)

Although approximate, the test indicated that the SCAT system would compare favorably with autos in travel time. On the average (door-to-door), the trip by auto saved not quite five minutes over the average 19-min SCAT trip. (One of the factors slowing SCAT was routing indirectness, its network/direct travel ratio being 1.38 compared with 1.21 for the auto trips; the other factor was walking, which cost an average of 3½ minutes per trip end, but which amounted to 14 minutes on one of the SCAT trips.) Survey data for the actual metropolis show that the average bus trip there reportedly takes somewhat longer than half an hour altogether.

For the economic investigation, the facilities in Figure 6 were expanded to represent a full metropolitan installation roughly 12 miles in diameter. This indicated a system equivalent to some 525 miles of one-way mainline, with 1,000 stations and 540 junctions. The unit cost of an average station and junction, respectively, may be taken as equal to 0.1 and 0.2 mile of single-direction tramway; total expense of system service (including inspection and renewal of fleet and controllers, plus power and general maintenance) is considered to be 3.33 times the carrying charges on the facilities alone, based on cost estimates for a particular system (3, p. 126 and 128). The annual amortization and operating expense of the system is therefore equivalent to the price of about 180 miles of one-way tramway.

TABLE 2

BREAK-EVEN UNIT COSTS

Fare per Person Mile ($)	SCAT Usage of Total Travel (%)	Unit Cost of Tramway per Mile of One-Way Mainline ($)
0.04	20	55,000
0.04	50	137,000
0.06	33	137,000
0.10	20	137,000
0.10	50	340,000

Within that portion of the actual metropolis supposedly served by the test SCAT installation, known person-trip interchanges via all transport modes between all districts are estimated to generate about 3 million straight-line person miles of travel on a work day, or some 3.4 million network miles on an AADT basis. If this travel is arbitrarily split among autos and SCAT (superseding buses) and the system revenue is calculated for several rates of fare, the break-even unit costs of tramway are as given in Table 2 for several combinations of SCAT usage and fare.

SCAT service would differ so much from taking a bus (or driving in city traffic, for that matter) that usage can only be guessed. Besides the superior speed of the new mode, several other factors may be weighed. Currently in the middle-sized metropolis the usage of public transit rarely exceeds 10 percent, riders often pay more than $0.10 per mile on the bus, and auto-driver trips to "serve passenger" are as numerous as transit trips. It seems reasonable, then, to guess that mainlines should not exceed a unit cost in the range of $100,000 to $150,000 per one-way mile if a metropolitan SCAT installation is to pay for itself entirely from fares. On a self-liquidating basis the installation in question must not exceed a total investment of roughly $100 to $150 million, or about $300 per capita for the 450,000 population in the service territory.

These sums are not cost estimates. They are more nearly guesses of the cost limits above which financial self-sufficiency would be unlikely for a particular metropolitan SCAT installation.

DUAL-MODE TRANSPORT

In a small car automatic transit installation having the proposed citywide coverage, walking is presumably the chief linkage between the system and its patrons' ultimate trip ends. This linkage is quite appropriate to downtown, where SCAT service would compare favorably with use of an auto both in general convenience and in steps walked. In city settings outside of the CBD, the nonresidential trip ends are mainly at work places, public buildings, and stores—typically located on arterial streets and, therefore, apt to be reasonably near a SCAT station.

The residential linkage has particular importance, because transport studies consistently show that some 80 percent of all person trips begin or end at home. The citywide grid of SCAT routes, which frame cells 3/8 to 1/2 mile on a side in residential portions of the city, seeks to place service within an acceptable walk of most homes. Yet the walking linkage does have disadvantages, including the possibility of the tripmaker's being exposed to a downpour, walking on icy sidewalks, or being afoot after dark. Such disadvantages might be ameliorated by substituting vehicles for walking—for example, by a low-fare taxicab linkage incorporated with SCAT service. Unorthodox systems for vehicular linkage are also conceivable (battery-electric scooters stored at SCAT stations; driverless "golf carts" circulating continuously on minor streets) but are deemed not advantageous.

The most prominent approach to resolving the residential linkage problem appears to be the dual-mode idea. It may be exemplified by the generic "Urbmobile" concept advanced by Cornell Aeronautical Laboratory, Inc. (4). Dual-mode Urbmobiles could be driven on streets and highways, and could also operate on special trafficways at high speeds under driverless automatic control. Conceived as a kind of "drive-yourself rapid transit" combination, the system gives promise of door-to-door linkage plus the advantages of rail travel for long commuting trips.

Urbmobile may, on first impression, seem to be small car automatic transit having additionally the desired feature of excellent linkage. In comparison with the proposed SCAT ideas, however, Urbmobile is really so different that it constitutes quite another concept. The difference inheres in the Urbmobile itself, which by its size and performance is no less than a small automobile. It follows that the tramway for such conveyances must be so large as to raise serious doubt about the general feasibility of elevated Urbmobile facilities over arterial streets. In most situations, therefore, Urbmobile route planning would be confined to much the same right-of-way and construction practices that govern the planning of rapid transit lines. The Urbmobile route network is thus visualized as a relatively sparse one, perhaps comparable (or even congruent) with the metropolitan freeway network. Urbmobiles should serve the suburban commuter admirably, unless his work place is too far off-route to reach on foot and his driving linkage is vexed by parking or traffic troubles. Yet the system is unable, because its limited facilities so often must be augmented by driving, to promise extensive improvement in transport service for the one-third of the driving-age population not licensed to drive.

If Urbmobiles as such are of seemingly meager utility to many members of the existing transit market, nonetheless the dual-mode idea does warrant examination as a supplement to small car automatic transit. Any dual-mode conveyance adapted to SCAT facilities must be comparable in size with SCAT cars; that is, it could hardly be larger than a motorcycle encased in a slender shell. Such a conveyance, used both on streets and the SCAT trafficways, may be termed a "sub-Urbmobile." Its engineering—with the aim of compactness, low cost, and great reliability—must unite car switching and control functions with the vehicular requirements of steering, suspension, and independent motive power. The dual-mode version would surely weigh and cost more than a regular SCAT car. Maintenance expenses of sub-Urbmobiles would be compounded by their inherent complexity, reduced availability for servicing, and exposure to road abuses.

The incorporating of sub-Urbmobiles into a metropolitan SCAT system involves several requirements. The first is that sub-Urbmobiles must be completely compatible with the SCAT cars and facilities. Numerous ramps would have to be added for interchange between tramway and street. On the facilities, a sub-Urbmobile would function as a car. For example, instead of having to be parked, it could be left by the rider at any station to rejoin the fleet of anonymous cars (this assumes that the conveyances would not be individually owned). Sub-Urbmobiles could be driven from the SCAT facilities only by qualified patrons possessing a license in the form of a key or card specially designed so as to preclude unauthorized use. Were a station to lack a sub-Urbmobile, one could be called-in by any qualified patron. The converting of a sub-Urbmobile into a road vehicle would have it display the patron's license number in front and in back, both to facilitate his finding it when parked and to aid enforcement of traffic and parking regulations.

Several subsidiary considerations may be noted. If residential linkage is the chief purpose of sub-Urbmobiles, most of them, like family autos, would remain parked at homes overnight to be ready for linkage service in the morning. Many of these tiny vehicles could be blanketed-in by an overnight snow not affecting the SCAT car fleet. Of more significance, however, is the unavailability overnight of these dispersed sub-Urbmobiles for the routine testing and servicing given each of the SCAT cars in the fleet every few nights. Accordingly, the sub-Urbmobiles may be expected to cause more than their share of blockages on SCAT facilities. Finally, there is an obvious need for supervision of the sub-Urbmobilies. Their movements through any ramp would be reported automatically to a recording center to establish patrons' accountability both for possession of the conveyances and for their off-system mileage and time.

The major uncertainty about sub-Urbmobiles stems from the risk associated with their diminutive size, which poses a serious liability question for the agency furnishing them. There is no reason to suppose that driving a small and vulnerable sub-Urbmobile in present-day traffic would demand any less skill, judgment, and responsibility than would driving an auto. Therefore, a regular driver's license would probably be a requisite to qualify for a sub-Urbmobile user card. It follows that the citywide network would still be needed if SCAT is to give adequate coverage for persons requiring transit service. Also, the redundant capacity of this relatively close-meshed network would help to alleviate the more frequent blockages due to the use of sub-Urbmobiles on SCAT mainlines.

The prospects for the citywide use of sub-Urbmobiles appear to be poor, owing to their frailty relative to other street vehicles. Yet the very vulnerability of the sub-Urbmobiles points to a possible role for them where the SCAT system is weakest: in linking suburban homes with SCAT facilities confined generally to a few highways. In the suburban setting the usual clear distinction between road types should afford good opportunity for enforcing a strict prohibition on the use of sub-Urbmobiles beyond the comparative safety of subdivision streets. With this prohibition, backed by measures to assure traffic safety in subdivisions, their streets should be usable by sub-Urbmobiles with minimal risk. Such conditions could permit a policy of authorizing even responsible youngsters to drive the conveyances on local streets between home and the SCAT ramps at the subdivision entrances. Those would be the only mode-changing ramps in an installation, so long as prevailing traffic hazards were considered to bar the street use of sub-Urbmobiles elsewhere.

CONCLUSION

This paper has discussed an advanced transit concept based on a myriad of driverless cars able to range widely over their own exclusive facilities. Small car automatic transit, or SCAT, seems especially applicable to the middle-sized metropolis. The SCAT facilities (perhaps only modest beamways over the street) would form a network coinciding generally with the more traveled thoroughfares: most downtown streets, many of the arterials in the rest of the city, and suburban highways. The desirable qualities of small car automatic transit service as it is conceived here derive from the extensiveness of the network, combined with automation assuring safe push-button transport at all times.

The new mode should be beneficial both to people as tripmakers and to the urban environment more generally. In the middle-sized metropolis, SCAT would represent a vast improvement for virtually all users of present-day transit, for some persons now involved in pool-riding arrangements, and for the few individuals to whom driving or parking is a daily burden. To the extent that SCAT reduced dependence on automobiles, it would contribute to abating the environmental pollution and hazards due to vehicular traffic (and easing the competition for driving and parking space). System safety would have to be manifestly excellent, of course, if the constructing of a full SCAT installation were ever to be undertaken.

In the course of time, small car automatic transit might become an ecological imperative. Under present conditions, however, it may be regarded merely as a worthwhile alternative to the automobile, but not as its replacement. For the proposed mode system does not, to be sure, quite measure up to one's own auto. SCAT patrons would experience the inconvenience of numerous one-way routes, the lack of facilities for taking rides out in the less developed countryside, and difficulty in moving items like a carton of groceries so readily carried in an auto. A major fault of the system as proposed would be its inability (with rare exceptions) to convey anyone to or from his own door, with the corollary of time-consuming walking on many trips.

Door-to-door transport might be offered by modifying the SCAT system to accommodate dual-mode conveyances which would run driverless on its facilities, but could also be driven on roads. The attractiveness of this improved linking of homes with the network would, it turns out, be attended by considerable expense and complexity, aggravated by the critical vulnerability of such tiny conveyances while operating in street traffic. By limiting their road use strictly to local streets within residential subdivisions, possibly even persons too young to operate autos might be authorized to drive the little vehicles locally from home to the SCAT facility nearby. If an extensive SCAT network were combined in this way with dual-mode conveyances for suburban residential linkage, the majority of persons could have access to virtually all the important places in the metropolis without possessing an auto or regular driver's license. An arrangement like this may be the closest approach possible to a mobility breakthrough without putting everyone behind the controls of an automobile regardless of competence.

Should small car automatic transit (even without conveyances) eventually become feasible, it would be a factor in metropolitan planning. Though the applicability of existing modal-split models to forecasting the patronage of this innovation is questionable, there is little doubt that a SCAT network in proximity to 100,000 homes would have more effect on traffic conditions than any rapid transit line, however fast. Thus a metropolis thwarted now in the quest for rapid transit actually may be retaining an option to gain much more transport service later for a comparable investment. It also follows that a reappraisal of highway planning may be warranted with respect to the central portions of the metropolis, which so often present the most severe difficulties to transport planners and engineers.

The CBD would surely be affected by a metropolitan SCAT installation. It would improve the efficiency of the center by greatly facilitating local circulation there. This feature, however, would permit new development to spread beyond the walking limit that has tended to preserve a compact downtown core; financially marginal parking facilities would become liable to conversion to more productive use. At the suburban fringe, small car automatic transit could give an impetus to the cluster pattern of development, which appears singularly compatible with the new mode both economically and aesthetically.

Before SCAT could become a salient factor in the metropolis, formidable problems must be mastered. Design of the car-and-track subsystem presents difficult engineering questions. Network operation at even the proposed capacities and speeds demands the perfecting of extremely reliable controls. The importance of achieving the lowest possible unit costs for completed facilities cannot be overstated. If problems of a technical nature can be solved, difficulties of a broader nature such as vandalism must also be faced. In all likelihood, the acceptability of elevated facilities must be established by thorough legal research and the temporary installing of full-scale tramway models along streets. Finally, if the development and promotion of small car automatic transit should become a serious venture, care must be taken to preserve operational compatibility among installations that, by growth, might eventually interchange traffic.

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