A NOVEL SYSTEM FOR IMPROVING URBAN TRANSPORTATION

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With the conventional "stop-go" type of traffic the overall speeds achievable in urban dimensions are discouragingly low. Because the limitation in the attainable maximum overall speeds is due to physiological reasons, namely, to the limited ability of people to endure the discomfort of acceleration and deceleration, it cannot be eliminated by the application of technological improvements. A novel "semiconventional" transportation system is suggested, by which the overall speeds achievable with conventional systems can be doubled. The concept of "at-speed" passenger transfer is used. With the aid of mobile people-platforms carried on board, any passenger can be transported nonstop from any station to any other station of the transit line without the need for additional trackage. The traffic remains unfragmented and the rules of travel are simple. The system has to operate automatically. The applicable control systems, some technical solutions, and the question of passenger safety are briefly discussed. Under a particular set of conditions, it is possible to build a cable-operated version of the system, which offers the additional advantages of very simple operation and very high degree of safety.

• URBAN development experts are greatly concerned about the problems posed by the transportation of people in certain rapidly growing urban areas. The unrivaled popularity of the private automobile is undoubtedly the main source of the difficulties. In this free society, however, any new system designed to improve urban transportation must offer not only superior performance but also some additional advantages by which people can be enticed away from the convenience of using their private cars.

SHORTCOMINGS OF CONVENTIONAL TRANSPORTATION SYSTEMS

Unfortunately, it seems unlikely that the pressing problems of urban transportation can be solved by the use of conventional rapid transit facilities. Some recent developments, such as computerized controls, will undoubtedly improve some safety aspects of the operation. The plain truth is, however, that an upper limit exists beyond which the overall speed of conventional transportation cannot be increased, and this limit is discouragingly low under normal urban conditions.

The thick curve shown in Figure 1 is a typical speed-time curve for an underground train at 1-mile station-to-station distances. The time allowed for the boarding and disembarking of the passengers was taken as 25 sec, and the initial acceleration and braking deceleration as 0.000833 mile/sec^2 (3 mph/sec), which is probably close to the maximum value permissible from the point of view of tolerable passenger discomforts. With the given speed-time curve the overall speed of transportation is only 30 mph.

It is obvious that under the given conditions the overall speed of transportation cannot be higher than it would be if the train kept accelerating at the maximum permissible rate up to the point when the braking retardation begins (also at the maximum permissible rate), as shown by the thin speed-time curve in Figure 1. The overall speed in

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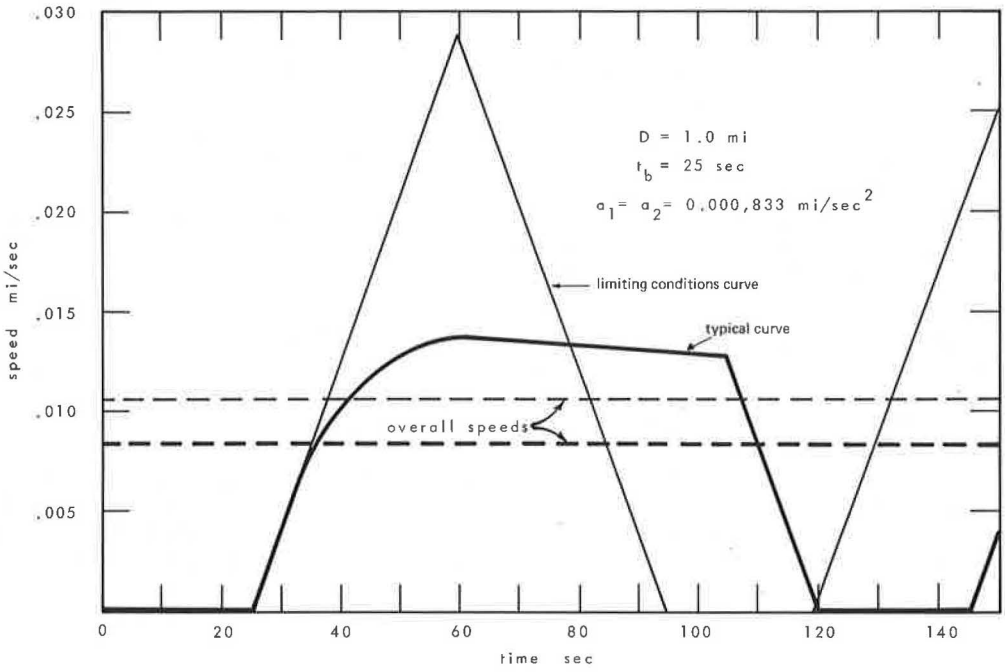

Figure 1. Speed-time curves for conventional system.

this limiting case is 38.2 mph, only 27 percent higher than in the previous realistic case. Yet to achieve even this modest gain the available power has to be increased by at least a factor of 4.

The limiting overall speed can be calculated by the following equation:

$$(v_o)_{lim} = \frac{D}{t_b + \sqrt{[2D/(a_1 + a_2)]}\left[\sqrt{(a_1/a_2)} + \sqrt{(a_2/a_1)}\right]} \tag{1}$$

where

$(v_o)_{lim}$ = limiting overall speed achievable with a conventional system, miles/sec;
D = distance between stations, miles;
t_b = time of boarding and alighting, sec;
a_1 = permissible acceleration, miles/sec^2; and
a_2 = permissible deceleration, miles/sec^2.

The following values were calculated by Eq. 1 for t_b = 25 sec and $a_1 = a_2 = 0.000833$ mile/sec^2:

D (miles)	v (mph)
0.5	24.3
0.75	31.8
1.0	38.2
1.25	43.9
1.5	49.2
1.75	54.0
2.0	58.6

Whether the value 0.000833 mile/sec^2 actually represents the upper limit of tolerable passenger discomforts may be questioned by some physiologists. Nevertheless, it is believed that realistic comparisons can be made with the consistent use of this value.

Two important conclusions can be drawn from the data given in this table.

1. With the conventional stop-and-go type of systems, it is impossible to achieve overall speeds comparable with the average speed of freeway traffic unless the station-to-station distances are selected at several miles; and
2. The speed barrier is based on physiological constraints and cannot be exceeded by the application of technological improvements such as by the use of more powerful motors or computerization of the operation.

Because of these difficulties, the Stanford Research Institute (1, 2) recommended the conventional mode of operation only for extended area travel, preferably for station-to-station distances greater than 4 miles. For travel at major activity centers and in local areas the reports visualized the use of more continuous types of transportation facilities such as low-speed conveyors and man-controlled or automatic point-to-point transportation systems.

There are, however, considerable difficulties in providing point-to-point public transportation systems. Relatively few people can be expected to contemplate identical trips. For example, 45 different nonstop trips are conceivable in each direction along a line comprising 10 stations. Thus the time gained by completing the trip nonstop may be overshadowed by the time lost due to long waiting periods at the stations. In addition, a complete fragmentation of the traffic—similar to present automobile traffic—would result.

A SEMICONVENTIONAL SYSTEM

By using the system to be described here, the limiting overall speeds achievable in urban dimensions, even by the most modern transportation facilities, can be doubled. This system has been devised to solve the fundamental problem of urban passenger transportation: how to make large numbers of nonstop trips possible without the complete fragmentation of the traffic and without adding substantially to the cost of transportation.

The system utilizes the principle of at-speed passenger transfer between vehicles temporarily joined together. Generically similar systems have been suggested earlier by Fogel (3), M.I.T. (4, 5), and Larson (6). The M.I.T. system was specifically developed for providing nonstop passenger transfer between intercity and intracity trains. The other two systems are easily adaptable to both long-distance conditions and urban conditions. They both require some additional trackage, the relative length of which increases with a decrease in the distance between the stations, and thus may not be ideal under certain typical urban conditions.

The basic concept of the present system was suggested by Brown (7) almost 70 years ago. With his system the at-speed transfer of passengers could be achieved without the need for extra trackage. Because the utilization of his idea required a much more thorough knowledge of automation than was available at the turn of the century, it is not surprising that his suggestion received hardly any attention. Much later, Barry (8) described some automatic control equipment applicable to Brown's system.

By using the semiconventional system, the nonstop transportation of passengers takes place along a single track by the repeated application of the following operations:

1. The overtaking of a transport unit that carries passengers boarded recently at a station along the transportation line by a second unit that runs behind nonstop through this station;
2. The temporary joining of the two units;
3. The automatic advancing of the through-passengers from the second unit into the first and the transferring of the passengers to be discharged at the next station from the first unit into the second; and
4. The leaving behind of the second unit with the passengers to be discharged at the next station and the nonstop running of the first unit through this station.

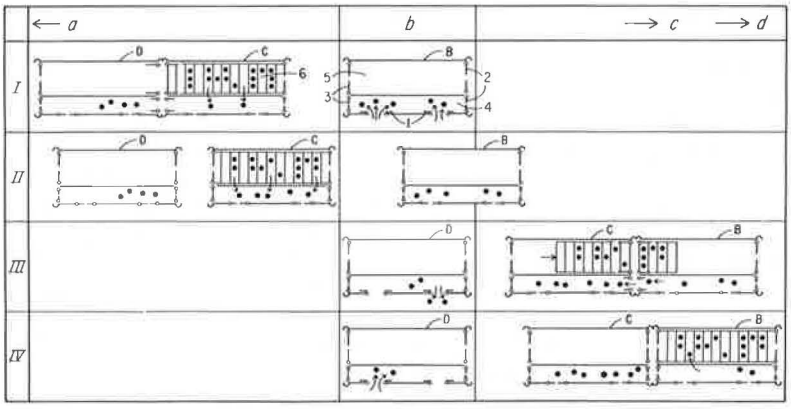

Figure 2. Operation of semiconventional system.

Figure 2 shows phases I through IV of the operation, involving vehicles B, C, and D, in the vicinity of a station b. All vehicles are of identical design. They have side doors (door 1) on the side of boarding and end doors at the front and rear (doors 2 and 3) respectively. The interior of each vehicle is divided into two areas. Area 4 is a strip area adjoining the side doors. This area is for interim stay and one- and two-station travelers; therefore, it is not furnished with seats. Area 5 will be referred to here as the "operational" area. It is accessible from the strip area only when covered by a mobile "people-platform," which in phase I is located over the operational area of vehicle C and is shown as a lined area. There may be seats provided on this platform. Because the average travel time with the use of this system is, in urban dimensions, usually less than 10 min, it is believed that a few seats should be provided for disabled persons only.

In phase I, vehicle B stands still in station b, and its side doors are open allowing passengers to board. (The passengers are shown as dots. Their movements and the movement of the people-platform are indicated by arrows.) Those passengers who wish to travel farther than station c can stay anywhere along the strip area, but the one-station travelers must remain in the vicinity of the rear-end door.

A combined unit, consisting of vehicles C and D, are approaching from the direction of station a. Before reaching station b, unit C-D will separate into its components, as shown in phase II. Vehicle D slows down and later stops in station b, while vehicle C continues its travel at its cruising speed through the station.

Meanwhile the process of boarding in station b has ended. The side doors of vehicle B have closed and the vehicle has left the station. It is now accelerating. The time of its departure is programmed, and its speed is controlled in such a way that, by the time vehicle B attains its cruising speed, it is overtaken by vehicle C. The two vehicles join and for a while continue their travels as a temporarily combined unit.

In phase III, unit B-C is shown a few seconds after the joining of the vehicles. Their adjacent end doors are open and the people-platform, with passengers on it, is in the process of advancing from vehicle C to vehicle B. During this time two of the recently boarded passengers of vehicle B, who want to alight at station c, walk over to the strip area of vehicle C.

Vehicle D is already standing still in station b, and its side doors are open allowing passengers to alight. In phase IV the discharge is completed and new passengers are boarding. Phase IV also shows the last moments of the existence of combined unit B-C. The advance of the people-platform has been completed and the adjoining end doors of the two vehicles are already closed. The passengers who wanted to alight at station c are by now all in the strip area of vehicle C. Those passengers of vehicle B who intend to disembark at station d remain standing in the strip area. All others start to move onto the people-platform. In a moment unit B-C will separate into its components.

Vehicle C will stop at station c, while Vehicle B will run through the station for a rendezvous with vehicle A (not shown).

The speed-time curves for the four vehicles are shown in Figure 3. When the time allowed for embarkation and disembarkation expires, vehicle B (the speed-time curve of which is shown in thicker line) leaves station b. As mentioned, its time of departure and speed during the period of acceleration are programmed in such a way that, at the time when vehicle B attains its cruising speed, it becomes overtaken by vehicle C, which has been approaching from the direction of station a. The two units join, and in this temporarily combined unit the people-platform advances. (The period of advance is shown in Figure 3.) After the completion of the platform movement, unit B-C divides into its original constituents. Vehicle B, with the through-passengers (and the people-platform) on board, continues its travel at the cruising speed and passes nonstop through station c to join with vehicle A, while vehicle C, with the passengers to be discharged on board, slows down and stops at station c.

The initial acceleration and the deceleration of 0.000833 mile/sec^2 were also selected here so that comparison can be made with the conventional system. The cruising speed (i.e., the overall traveling speed over a large number of stations) is 73.4 mph, which compares with an overall speed of 30 mph under similar conditions with the use of the conventional system (Fig. 1).

It is clear from data shown in Figure 3 that the time required for the advance of the people-platform is one of the main factors that limits the achievable cruising speed. If we assume that the first third of the travel of platform takes place at constant acceleration, the second third at constant velocity, and the final third at constant deceleration, and that the acceleration and deceleration are of equal value, the time of advance of the platform can be written as

$$t_p = 2.5\sqrt{2L/3a_p} \tag{2}$$

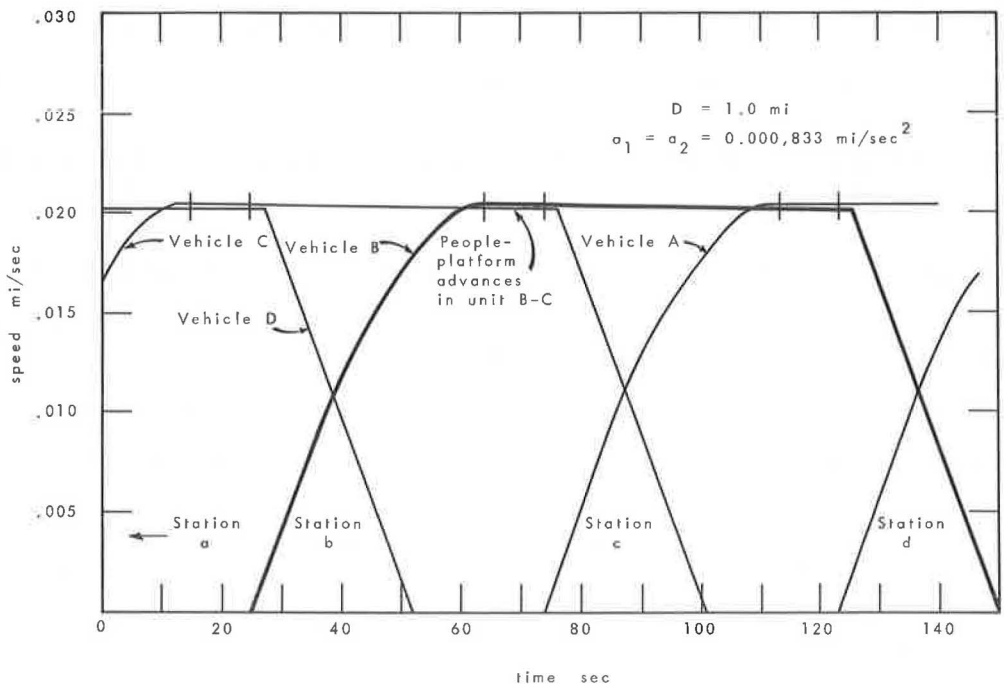

Figure 3. Typical speed-time curves for semiconventional system.

by virtue of the fact that the total travel of the platform is equal to the vehicle length. In this equation t_p = time of advance of platform, sec; L = length of vehicles, miles; and a_p = acceleration and deceleration of people-platform, miles/sec^2.

The following expressions can be further utilized in estimating the achievable cruising speed: The distance run by the first vehicle during its period of acceleration (by the end of which the cruising speed is reached) can be taken roughly as

$$s_1 = v^2/a_1 \tag{3}$$

i.e., as twice the distance that the vehicle would run if the initial acceleration (taken as the maximum permissible acceleration) could be maintained throughout the entire period. The distance covered by the second vehicle during its period of deceleration (with the deceleration taken as constant and equal to the maximum permissible deceleration) can be written as

$$s_2 = v^2/2a_2 \tag{4}$$

Finally, the distance run by the two-vehicle unit at the cruising speed is

$$s_c = v(t_p + t_m) \tag{5}$$

In Eqs. 3, 4, and 5

s_1 = distance covered by the first vehicle during the period of acceleration, miles;
s_2 = distance covered by the second vehicle during the period of deceleration, miles;
s_c = distance covered by the two-vehicle unit at the cruising speed, miles;
v = cruising speed, miles/sec; and
t_m = time required for miscellaneous operations, such as the joining and separation of vehicles and the opening and closing of the end doors.

Because the sum of s_1, s_2, and s_c must be equal to the station-to-station distance, D, an equation is obtained from which the cruising speed can be expressed. The result is

$$v = \frac{\sqrt{\left[2.5\sqrt{(2nL/3a_p)} + t_m\right]^2 - 4D\left[(1/a_1) + (1/2a_2)\right]} - \left[2.5\sqrt{(2nL/3a_p)} + t_m\right]}{(2/a_1) + (1/a_2)} \tag{6}$$

In this equation nL has been used instead of L to allow for the possibility that each transport unit may be made up of n number of vehicles.

Another important aspect of the system is the maximum passenger throughput, which is limited by the fact that the movement of each unit is programmed. Therefore, to avoid interference and to allow sufficient times for boarding and alighting, there must be a minimum time left between the departure of two subsequent units from the same station. From an examination of the conditions the following equation can be derived:

$$T \approx t_b + t_1 + t_c + t_2 - (D/v) \tag{7}$$

where

T = minimum time-spacing between two units departing from the same station, sec;
t_1 = period of acceleration, sec;
t_2 = period of deceleration, sec; and
t_c = time of run between two stations by a combined unit at the cruising speed, sec.

By expressing these variables in terms of some already introduced variables one obtains

$$T \approx t_b + (v/2)\left[(1.4/a_1) + (1/a_2)\right] \tag{8}$$

Consequently

$$V \approx (3{,}600\ nC)/\left\{t_b + (v/2)\left[(1.4/a_1) + (1/a_2)\right]\right\} \tag{9}$$

where

V = maximum achievable throughput, passengers/hr, and
C = passenger capacity of one vehicle.

Equations 6 and 9 are only approximately valid. The exact expressions for v and V depend on the actual speed-time program during the period of acceleration.

In the design of the system it is usually necessary to check whether the throughput of the system is sufficient both for one-station and for multistation travels. The first can be expressed as some fraction of the capacity of the strip area, and the second is determined by the capacity of the people-platform. Of course, such a sophisticated calculation can be performed only if a reasonably good estimate of the passenger flow model is available.

Figure 4 shows some calculations based on Eq. 1 concerning the limiting speed for conventional systems and on Eqs. 6 and 9 concerning the cruising speed and maximum throughput for the described semiconventional system. The following numerical values have been used: $a_1 = a_2 = a_p = 0.000833$ mile/sec^2; $t_b = 25$ sec; $t_m \approx 0$; L = 0.009470 mile; n = 1 to 5; D = 0.5 to 1.5 miles; and C = 250 passengers.

The multistation transportation speeds that can be achieved with the present semiconventional system are, in urban dimensions, twice as high as the limiting overall speeds that can be attained with the conventional system and are comparable to or higher than the average speed of freeway traffic. This finding clearly indicates that the described system is potentially capable of competing with automobile transportation in popularity.

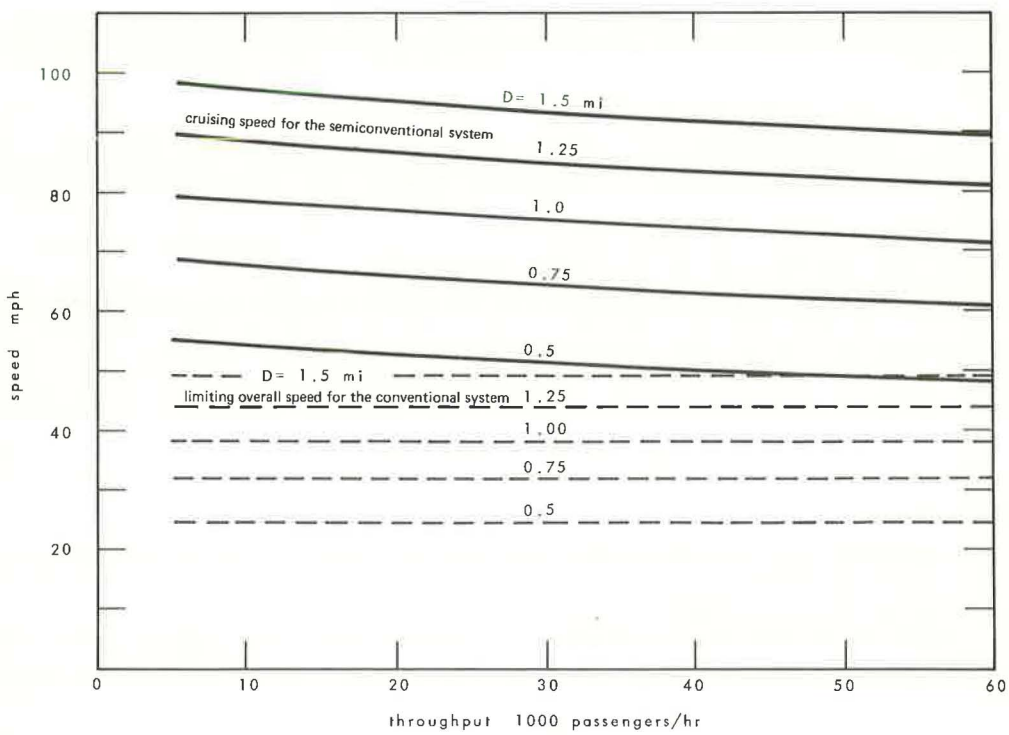

Figure 4. Comparison of performances of semiconventional system and conventional system.

It is obvious from data shown in Figure 2 that the number of vehicles needed for the operation of this semiconventional system is larger than that for a conventional system. The rolling stock requirement is roughly three times as high as in the case of stop-and-go type of traffic and even higher for lower throughput levels if the system is designed for a passenger throughput close to the maximum achievable value (Eq. 9). Clearly, the need for a greater number of vehicles is the price that has to be paid for faster transportation. It is well known, however, that modern rapid transit facilities have at least 80 percent of their investment in immobile assets, such as acquisition, track, structures, stations, and power supply facilities, so that the extra costs associated with the larger number of vehicles do not alter the overall expenditures significantly. (In general, more than 100 transit vehicles can be purchased for the price of a 1-mile section of a subway line.)

Control

It is clear that the smooth and safe operation of the suggested transportation system is inconceivable without automatic controls. An extremely simple control system can be devised in that particular case if the following two conditions are met:

1. The transportation line can be made a closed curve without sharp curvatures (half of the curve may take care of the reverse traffic or the reverse traffic can be carried on a parallel loop), and
2. The stations can be spaced at equal distances.

Under these conditions the system can be operated from $(k + 2)$ cables or chains ($k = 1, 2, 3, \ldots$) with every $(k + 2)$th vehicle firmly attached to the same cable at kD distances. The movements of the cables can be effected from $(k + 2)$ sets of stationary motors, brakes, and control equipment programmed to yield the prescribed periodic movements, differing only in phase for the various cables.

Fortunately, the least expensive solution is one that gives maximum passenger throughput. In this case three cables are needed, and every third vehicle is attached to the same cable at distances equal to the station spacing.

With careful planning of the transit lines the preceding two conditions can always be met. Figure 5 shows an example of the arrangement of the transit lines in a metropolitan area in such a way as to fulfill those conditions. In this example the rapid transit system consists of seven closed loops. Three of these (loops 1, 2, and 3) are simple loops (i.e., each loop takes care of the traffic in both directions). Loops 4-5 and 6-7 are double loops (i.e., the reverse traffic is carried by a separate closed loop). Mileages and speeds are as follows:

Loop	D (miles)	v (mph)
1	0.5	53
2	0.5	53
3	0.625	60
4-5	0.75	67
6-7	1.5	96

Because of the great advantages offered, such schemes would deserve consideration at every new planning, even if they would require the installation of a few stations that are not fully used. These "extra" stations would not affect the speed of transportation. Because people tend to go where transportation is, it is very likely that these extra stations would quickly attract housing development in the area. (In Toronto, two-thirds of all new construction over a 5-year period was along the route of the Yonge Street subway.)

If the preceding schemes are not feasible, or if the task is to modernize an already existing rapid transit system, each transport unit must be propelled and controlled individually. Although the problem of automatic vehicle control is regarded as a controversial topic, there is nothing basically new about the techniques used. The automatic control of the proposed system creates few problems that have not already been

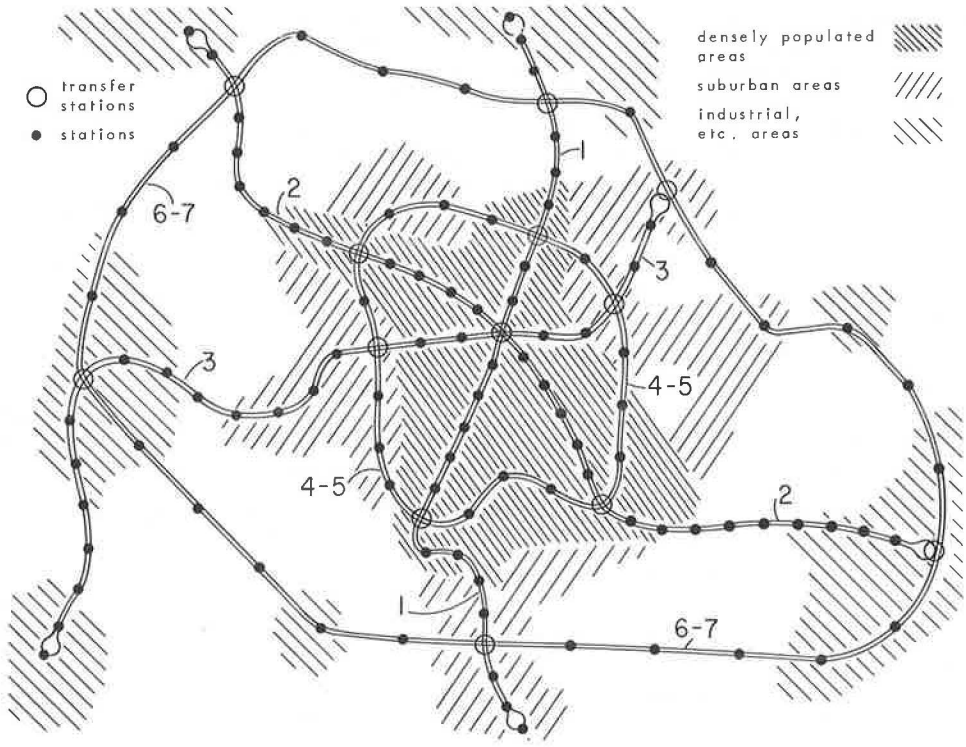

Figure 5. Arrangement of transit lines for cable operation.

studied by the companies participating in the design of the control system for the San Francisco Bay Area Rapid Transit District (9) or by M.I.T. in connection with Project METRAN (10).

Only the main features of the control system will be discussed here. For details the reader may refer to the previously mentioned reports or to handbooks dealing with modern information feedback control methods (11, 12, 13).

Two kinds of control systems are conceivable. One may be termed "on-board" control, the other "centralized" (or computerized) control. As its name implies, with the on-board control system each individual transport unit is equipped with facilities for (a) gathering information on its own velocity, the distance between itself and the unit ahead, and the velocity difference between itself and the unit ahead; (b) comparing this information with the information prescribed for the given situation; and (c) taking corrective actions (acceleration or braking) to minimize the difference between the two sets of information.

With a centralized control system each transport unit carries equipment only for (a) determining its own position and velocity and (b) taking corrective actions. The information concerning the position and velocity of each unit is continuously transmitted to a central computer that makes the decisions concerning the corrective measures. The computer commands are then transmitted back to the individual units for execution.

For networks consisting of simple loops with no branching, the on-board control system would probably prove more advantageous. On the other hand, for a complex network containing many nodal points, especially when the variable routing of the transport units is a requirement, the use of the centralized control system is unavoidable. By using the centralized control system it is also possible to increase the cruising speed along those sections of the line where the stations are located at longer distances, which increases further the overall speed of transportation.

People-Platform, Doors

The use of the mobile people-platform offers two advantages. First, it greatly simplifies the rules of travel because only the newly boarded passengers and those who wish to alight have to act. The through-passengers who are standing or seated on the platform are automatically transferred forward from one vehicle to another and thus continue their travels as long as they stay on the platform. Second, the people-platform makes it possible for the transfer of the passengers always to take place in a prescribed time. This factor is extremely important in a completely automated process.

Some problems may arise in the design of the platform because of the fact that it must be capable of absorbing certain length changes that occur when it is advancing between two units while the vehicles are running along a curved section of the track. A possible solution is shown in Figure 6. The main components of the assembly shown are a rubber sheet reinforced with obliquely placed steel wires, a substructure consisting of rib-like elements, and a flexible spine, possibly also made from rubber, reinforced longitudinally. When the platform moves, the spine is guided along the centerline of the vehicles by a multitude of rollers. The lower section of the spine is formed into a flexible rack with metal pegs. The pegs mesh with the teeth of pinions driven by driving mechanisms fastened to the operational areas of the vehicles.

Figure 7 shows the interior of two joined vehicles at a time when the platform advances. For simplicity, only three through-passengers and a one-station traveler are shown. The latter walks along the strip area in a direction opposite to the platform movement.

All doors are automatically operated, and the side doors are sliding doors. In order to ensure that the opening and closing of the doors is accomplished in minimum time and to keep the whole cross-sectional area of the vehicles unobstructed while these doors are open, the use of sectional "fold-up" or "roll-up" doors are recommended for end doors.

Safety Aspects

Some railway people may receive the idea of the described transportation system with mixed feelings. People think that safe operation along a single track is inconceivable without maintaining a certain minimum headway between the trains or vehicles.

The fears of the increased possibility of rear-end collision with the suggested transportation system are, of course, unfounded. In fact, the normal vehicle control equipment is capable of taking care of most emergency situations. With the use of additional control features, it is possible to design the system to any specified degree of safety.

At first sight one may think that during the period preceding the joining of two vehicles there is an increased danger of collision if, for some reason, the front vehicle

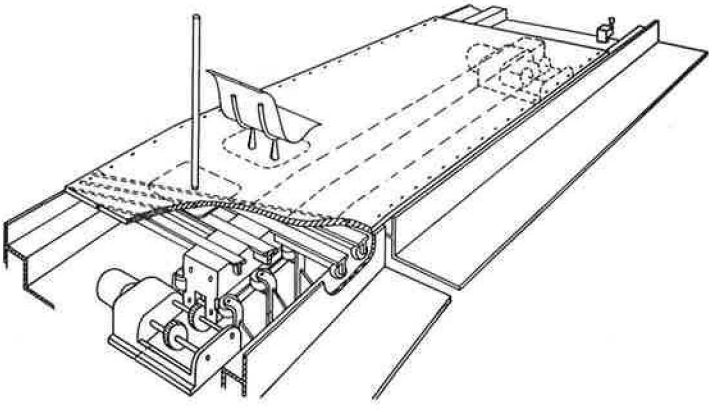

Figure 6. Possible design of people-platform.

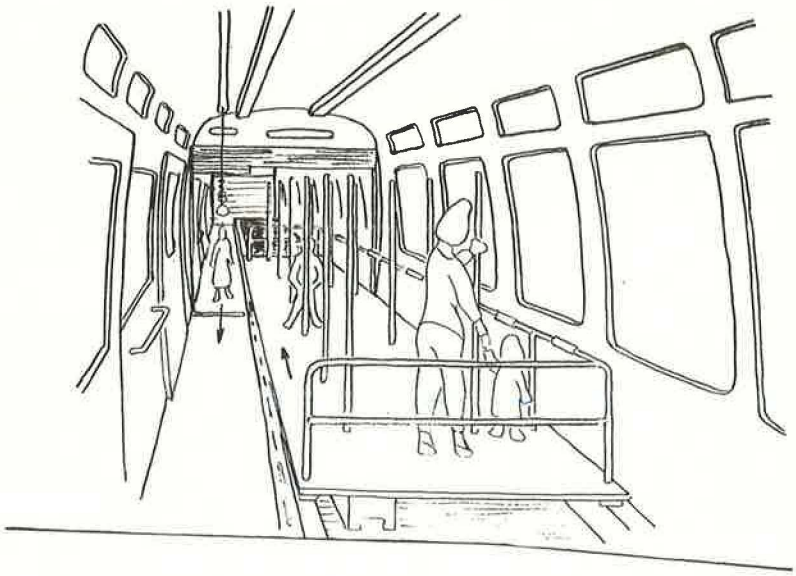

Figure 7. Interior view of two joined vehicles while people-platform advances.

is forced to stop suddenly. However, the following facts should be remembered:

1. Because of the automatic operation the system must have exclusive right-of-way, and interference in its operation by people or foreign vehicles is most unlikely;
2. Short of some rare disaster (for example, tunnel collapse) the front vehicle cannot stop instantly but will slow down at a deceleration that is not likely to be higher than 0.000833 mile/sec^2, the value regarded in this paper as representing the limit of permissible discomforts;
3. With the use of an on-board control system, the vehicle running behind continuously obtains information on the distance and velocity difference between itself and the vehicle ahead, compares this information with the theoretically correct information, and takes immediate corrective measures; and
4. With the use of centralized control system, the position and velocity of all vehicles in the transport system are continuously checked by the computer.

In case of any irregularity the appropriate corrective action comes immediately. Thus, if the distance between the two vehicles begins to drop unexpectedly, the vehicle running behind will at once apply its brakes in an effort to maintain the theoretically correct distance.

There is a relatively narrow range of distances between two vehicles during the joining period at which, in case of emergency, the vehicle running behind may be forced to slow down at decelerations within the discomfort zone in order to prevent rear-end collision. To achieve such decelerations the use of rubber-tired wheels may be necessary.

Naturally, if the previously described cable-operated version of the transportation system is used, there is practically no possibility for collision.

SUMMARY

A transportation system has been described by which the overall speeds achievable with modern rapid transit facilities in urban dimensions can be doubled. With this system any passenger can be transported nonstop from any station to any other station along the transit line without the need for additional trackage. The initial costs of this system are only slightly higher than those of a comparable conventional system.

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