12-1992

The Role of Automated Guided Transit Systems in Urban Transportation

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The Role of Automated Guided Transit Systems in Urban Transportation

Abstract
New transportation systems have always attracted attention of both transportation experts and general public: the first railway in England, first automobile and streetcar in Germany, first airplane in the United States - all of these inventions attracted excitement, curiosity, enthusiasm - and skepticism.

With time, many inventions fulfilled or exceeded expectations: they have been developed into major transportation systems which influence our lives and shape our cities. However, an even greater number of inventions never developed into viable systems; incorrectly conceived, they never matured into operating systems.

For the last 20-30 years there have been many inventions of automated transit systems. They attracted attention by their new vehicle and guideway designs, operating concepts, and new image. Among the numerous inventions there were many promising concepts, as well as misguided proposals.

Parallel with these developments, understanding of urban transportation and analytical methodology for its evaluation have advanced greatly. A particularly important development has been system approach to urban transportation which allows evaluation of entire systems, including all their physical and operational components, rather than only mechanics and body of vehicles. This theory now allows us to evaluate different systems and define their optimal role in urban transportation.

The main subject of this presentation is Automated Guided Transit; let us first define this mode of urban transportation.

Disciplines
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International Symposium & Exhibiton
on Automated Guided Transit

December 1 - 2, 1992
Seoul, Korea.
The Role of Automated Guided Transit Systems in Urban Transportation

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(Professor, Univ. of Pennsylvania, U.S.A)
THE ROLE OF AUTOMATED GUIDED TRANSIT SYSTEMS
IN URBAN TRANSPORTATION

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1. Innovations in Urban Transportation

New transportation systems have always attracted attention of both transportation experts and general public: the first railway in England, first automobile and streetcar in Germany, first airplane in the United States - all of these inventions attracted excitement, curiosity, enthusiasm - and skepticism.

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The main subject of this presentation is Automated Guided Transit; let us first define this mode of urban transportation.

Automated Guided Transit (AGT) encompasses transit systems operating on exclusive guideways without drivers. There are a great number of these systems, sometimes also designated as "People Movers", "Automated People Movers (APM)", "Cabintaxi", "Downtown People Movers (DPM)" and others. To evaluate these systems and define their role in cities, it is necessary to make a brief review of all urban transportation modes.

2. The Family of Urban Transportation Modes

In a small town, ideal mode of transport for most trips is a
small, privately owned vehicle operated by individuals on public streets. The vehicle has capacity for a few persons (4-6) and its owner operates it whenever and wherever he/she wants.

As the town grows into a large city, it becomes logical to make the following changes in the vehicles, roads and operations:

- Increasingly shift travel from private to public systems;
- Use larger vehicles;
- Introduce technology of guided vehicles, use trains;
- Provide separate ways, protected from other vehicles.

Thus, after this evolution, the systems best serving the largest volume of trips in large cities are public transportation modes, guided on separate rights-of-way (rapid transit or metro), supplemented by steered vehicles, operating on streets (buses).

Public transport systems themselves represent a family of modes which vary in their physical and operational characteristics. A review of these modes follows here.

3. Generic Classes of Transit Modes

Transit modes are defined by three basic characteristics: **right-of-way category, technology and type of operation**. The most important of these three is the right-of-way category, which may be of three types: streets with mixed traffic (category C), longitudinal circulation with some crossings at grade (B) and fully controlled rights-of-way (A). These categories have major impacts on transit system technology and type of operation. At the same time investment costs, as well as operating costs of a transit system largely depend on its right-of-way category. Thus all transit systems can be classified into three generic classes on the basis of their right-of-way category:

- **Street transit** includes buses, trolleybuses and streetcars operating on right-of-way C; its performance (speed, capacity, reliability, safety, etc.) depends on street conditions.

- **Semirapid transit**, operating on right-of-way B, includes semirapid bus and light rail transit; it has medium capacity and overall performance. And,

- **Rapid transit**, which has exclusive right-of-way and includes rail rapid transit or metro, and some other modes. It is characterized by very high performance.

With the rapidly increasing use of private automobiles in cities, particularly in the period between mid-1950s and mid-1970s,
traffic congestion on urban streets led to deterioration of street transit services. It became clear that to provide attractive and efficient transit services, transit vehicles must be partially or completely separated from other traffic. Thus the wide use of private automobiles actually increased the need for high-performance transit.

As a consequence, the number of cities in the world which have rapid transit began to grow rapidly. In 1950 there were 17 such cities; today there are 85 cities with rapid transit. However, many rapid transit systems were becoming larger in scale (larger cars, longer trains, greater spacing between stations, etc.), while buses degraded to very slow services on congested city streets. These trends created a "polarization" of transit systems: many cities began to use only low investment/low performance buses and high investment/high performance rapid transit. The differences in performance, level of service, and costs between these two groups, as can be seen on the schematic diagram in Figure 1, is very large.

With the growing emphasis on urban environment, social and economic vitality of cities, and increasing attention of national governments to these problems, which took place since the late 1960s, it became obvious that the large "gap" between these two transit mode classes must be filled. There are many cities which need much better transit services than buses on streets can offer, and yet cannot afford the very high investment which rapid transit requires. Actually, majority of medium-sized cities, as well as certain corridors in large cities, fall in this category.

During the past couple of decades there have been many inventions in providing this medium-capacity class of transit modes. They can be classified into three major categories:

1. **Semirapid bus (SRB),** i.e. bus systems improved through provision of special lanes, busways, preferential treatments at intersections, new types of vehicles, and invention of a guided bus which can operate both on streets and on special guideway sections (0-Bahn).

2. **Light rail transit (LRT),** developed in several West European countries which had a consistent policy of transit improvements, has been recognized as an excellent solution for medium-performance systems. Since mid-1970s an increasing number of cities has built new LRT systems. These vary from the systems similar to streetcars, to medium capacity/moderate investment cost systems, and even to some LRT systems which are very similar to metros in their performance and investment costs.

3. **Automated guided transit (AGT) systems,** which have been produced by various manufacturers and with many different technical and operational features. A number of AGT systems
Figure 1: Investment cost/performance characteristics of different generic classes of transit modes
were built for short-haul lines, primarily in airports and amusement parks. In the last 10 years, several AGT systems have been applied to regular urban transit lines, as will be discussed later.

It is interesting to note that while the developments of semirapid bus and LRT were initiated and carried out by transit planners and operators, the AGT systems were developed by industries which have been largely outside of transit operators' and manufacturers' circles. This created some problems. Inventors and developers of AGT often sought little advice from the transit operators; they tended to underestimate the complexities of transit operations and believed that they could handle the development of transit systems by themselves. Their development was therefore slowed down, so that only in 1980s the first use of AGT systems for transit applications occurred.

4. Conceptual and Design Features of AGT Systems

AGT systems incorporated many interesting, innovative features, but also a number of errors in their conceptual design. It is useful to present a brief review of AGT features and evaluate their validity.

* **Fully automated operation**, often considered unrealistic, has been proven feasible and very beneficial. A distinct success.

* **Frequent service without high operating cost**, possible because 2-3 crewless trains can be operated at the same cost as one long train. A major advantage.

* **Great flexibility in service adjustments to changes**. This is a distinct feature of automated operation. Very useful.

* **On-demand operation**, similar to elevators, was planned for. However, except for periods with very low demand (during the night), fixed and regular schedules always result in higher capacity, reliability and simpler operations. Very seldom possible to apply.

* **Small-capacity vehicles** were often designed, with most passengers standing. While this type of vehicle may be appropriate for short shuttle lines (airports, amusement parks), it cannot offer capacity and comfort required for regular transit lines. Infeasible for any medium or heavily used line.

* **Overemphasis on short headways**. Enormous efforts have been placed in research of operations with headways of several seconds; however, there are no realistic operating conditions under which transit systems would need such headways. Actually, experienced transit operators try to avoid
operations with less than 2 or 1.5 minute headways. Usually unnecessary and undesirable.

* The concept of "personal rapid transit" (PRT) was proposed as "transit of the future": small vehicles used by individuals only; actually, an expensive version of the private automobile. Although the concept is physically and economically infeasible, it has caused confusion and delays in planning transit in several cities. It has never been built. A confused, unrealistic concept.

* Lower investment cost than rapid transit. Correct, although the difference is not always sufficiently great to make AGT clearly superior to conventional modes. Usually true and very useful.

* Light, unobtrusive structures, environmentally friendly. In many cases true, in some not (Morgantown). Often correct.

* Attractive and popular due to novelty and image. Correct.

* Separate planning and financing from transit systems. Although in many cases practical, this separation makes integration of transit systems in a city difficult. Usually undesirable, may create problems.

* Proprietary technology. This feature limits competition and may result in problems for the operating agency. Requires caution.

The fact that most of the presently operating AGT systems have been sponsored, partially or fully, by governments as special developmental projects, it is necessary to examine these systems very carefully prior to their adoption for regular, technically and economically sound public transit systems. Many new technological and operational features, which include some very promising innovations on rail and rubber-tired guided systems, also deserve a careful consideration.

5. Operational Characteristics of AGT Systems

By their cost and performance characteristics AGT systems fall "between" LRT and rapid transit systems. They actually represent a small scale rapid transit mode. To clarify the relationships among these modes, their basic physical and operational features will be described here.

Fully Separated Right-of-Way (Category A). The distinction between modes with right-of-way categories B and A is a major one, since it affects a number of basic system characteristics. First of all, the cost of providing fully separated right-of-way is much higher because the space must be found for a completely separated
guideway, as well as for each station, for maintenance yards, and other facilities. Second, physically and geometrically, right-of-way A tends to provide conditions for higher speed of operation. On the negative side, it prevents the guideway from entering streets, shopping and governmental areas, malls, parks, etc. Third, full automation, i.e. operation of trains without drivers, becomes physically feasible. Fourth, any type of guidance and power supply are possible, since there are no contacts with other vehicles or pedestrians. Fifth, train length becomes limited only by station size, rather than by conditions along the line. As a result of all these changes, right-of-way category A provides conditions for transit service with very high capacity, speed, reliability, safety and other features, commonly designated as transit system performance.

While very large cities, such as Tokyo, New York, Moscow and Hong Kong, utilize these elements to their maximum and transport up to 60,000 persons/hour on a single track, the question for many medium-sized cities is how can the system be simplified and its costs decreased when it should be built to carry on 5,000 to 20,000 persons per hour? That is the goal in the development of medium capacity systems. Their basic features are analyzed here.

Guidance Technology. There is little doubt that conventional rail technology remains by far the most appropriate guidance technology for full size rapid transit systems. However, most of the AGT systems have been designed with rubber tired support and guidance. What are the relative characteristics of these two technologies?

The main advantages(+) and disadvantages(−) of rubber tires over rail are:

+ Better adhesion under dry weather conditions, permitting full utilization of maximum acceleration and braking rates which passenger comfort allows;
+ Better grade climbing ability;
+ Lower noise in curves;
+ Involves simpler vehicle construction of small vehicles;
± Guideway and switching of rubber-tired vehicles is usually more complicated and expensive than for rail vehicles;
− Higher energy consumption;
− Higher heat production, which is particularly a problem in tunnels and in warm climates;
- Greater sensitivity to wet, snow and ice conditions;
- Inability of guideways to cross each other;
- Vehicle size is restricted by the carrying ability of tires to about 25 m² of floor area for 2-axle vehicles and 45 m² for 4-axle vehicles.

Designs and operating experience have disproved some initial expectations. For example, rubber-tired guided vehicles do not produce less noise than rail vehicles (assuming the same vehicle size and speed); rail vehicles are not heavier per unit area than rubber-tired vehicles; but, on the other hand, neither is it true that rubber tires do not last long and must often be replaced. The simpler construction and suspension of rubber-tired vehicles makes this technology better suited for small vehicles, approximately up to 10m in length; for large vehicles, longer than 12m, rail is usually superior.

There are several important innovations in rail technology, such as steerable axles and linear induction motor, applied in the ARRT (Vancouver) system. Steerable axles ensure quiet travel even in curves. Linear induction motor eliminates all adhesion problems, because it takes over all acceleration/braking forces, so that wheels serve only for vehicle support and guidance.

**Fully Automated Operation.** Operation of trains without drivers can be performed only on guided system with fully controlled right-of-way. Automation is not related to guidance technology: it can be used on vehicles with any type of guidance technology; nor is automation related to vehicle size, except that for high-capacity systems, such as rapid transit, it is less important than for medium and small capacity systems. Rapid transit is entirely economically feasible with manual operation, while systems operating small transit units may be uneconomical without automation (transit unit or TU is a set of cars travelling together - a single vehicle or train).

The dominant benefit from automated operation is that with the elimination of the drivers operating costs of a large number of short trains (TUs) are the same as those of operating smaller number of longer TUs. This makes it economically feasible to provide high frequency of service also during hours of moderate and low demand for travel. It also allows easy adjustment of service to any changes of demands: trains can be added, withdrawn, lengthened or shortened very easily.

Other benefits of full automation, such as optimal driving regime, easier control of operation of all trains, possibilities of adjustment to schedule, etc. are much less significant.
It must be borne in mind that fully automated systems need considerably more preparation and higher quality personnel for operation and maintenance than manually operated systems.

Consequently, the case for automation is particularly strong in cities with requirements for high level of service, need for medium capacity transit system, high labor wages and availability of high technology. In the cities with the primary need to transport large masses of people safely and efficiently, with moderate labor wages, cooperative labor unions and little experience in advanced train control, automation should not be used; however, it may be advisable to provide for its possible introduction in the future when some of these conditions change.

**AGT Vehicle Design.** To examine physical and dynamic characteristics of AGT vehicles developed in recent years, four diagrams showing dimensions, weights and power of various rail transit modes from the book *Urban Public Transportation Systems and Technology* have been used to add the AGT vehicles and compare them among themselves and with rail vehicles. The selected AGT vehicles are those which are either in operation on some transit lines, or in advanced development; they are listed with their basic physical characteristics in Table 1.

Figure 2, showing length and width of guided vehicles, indicates that AGT vehicles are substantially shorter, but not much narrower than LRT vehicles, with the exceptions of the VAL system and the Morgantown system, which has an extremely small vehicle. All AGT vehicles are characterized by smaller floor area than conventional rail vehicles. Figure 3 shows specific weight per square meter of floor area. An interesting observation from this diagram is that although AGT vehicles are smaller, they are not distinctly lighter per unit of area than conventional rail vehicles, with the exception of the M-Bann. This system utilizes magnetic suspension, thus avoiding many elements of support and suspension, such as wheels and springs. The Westinghouse Skybus has similar specific weights to the lightest of all conventional rail vehicles plotted.

The significant conclusion from this diagram is that there is no major gain in using small rubber-tired vehicles in terms of energy consumption; in other words, if the demand is such that the system requires either one large or two small vehicles, vehicle types will have very similar specific weight (and therefore similar energy consumption if the guidance technology is the same); the large vehicle will, however, offer better passenger accommodation and greater riding comfort.

To test the claim that AGT requires lighter guideways because of their lighter weight, AGT vehicles have been plotted on the diagram of maximum weight per axle (with fully loaded cars) as related to vehicle floor area (Figure 4). This diagram shows that
Table 1. Vehicle characteristics for selected AGT systems.

<table>
<thead>
<tr>
<th>Code</th>
<th>System - city</th>
<th>Manufacturer - country</th>
<th>Length L [m]</th>
<th>Width W [m]</th>
<th>Gross area $A_g [m^2]$</th>
<th>Capacity seats/total</th>
<th>Tare wgt $W_t [kg]$</th>
<th>Gross wgt $W_g [kg]^b$</th>
<th>Power $P [kW]$</th>
<th>$W_t/A_g [kg/m^2]$</th>
<th>$W_g / n_{ax} [kg]$</th>
<th>$P/W_t [KW/t]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Airtrans - Dallas/F.W.</td>
<td>LTV/Vought - USA</td>
<td>6.48</td>
<td>2.24</td>
<td>14.52</td>
<td>16/40</td>
<td>5,350</td>
<td>8,150</td>
<td>56</td>
<td>368</td>
<td>4,075</td>
<td>10.47</td>
</tr>
<tr>
<td>B</td>
<td>AIRT - Vancouver</td>
<td>UTDC - Canada</td>
<td>12.70</td>
<td>2.50</td>
<td>31.75</td>
<td>40/100</td>
<td>13,600</td>
<td>20,600</td>
<td>(LIM)$^c$</td>
<td>428</td>
<td>5,150</td>
<td>(LIM)$^c$</td>
</tr>
<tr>
<td>C</td>
<td>KCV - Kobe</td>
<td>Kawasaki - Japan</td>
<td>8.00</td>
<td>2.39</td>
<td>19.12</td>
<td>20/62</td>
<td>10,500</td>
<td>14,840</td>
<td>90</td>
<td>549</td>
<td>7,420</td>
<td>8.57</td>
</tr>
<tr>
<td>D</td>
<td>M-Bahn</td>
<td>Siemens - Germany</td>
<td>11.80</td>
<td>2.30</td>
<td>27.14</td>
<td>?/70</td>
<td>7,800</td>
<td>12,700</td>
<td>(LIM)$^c$</td>
<td>287</td>
<td>n.a.</td>
<td>(LIM)$^c$</td>
</tr>
<tr>
<td>E</td>
<td>Morgantown</td>
<td>Alden/Boeing - USA</td>
<td>4.73</td>
<td>1.83</td>
<td>8.66</td>
<td>8/21</td>
<td>3,900</td>
<td>5,370</td>
<td>45</td>
<td>450</td>
<td>2,685</td>
<td>11.54</td>
</tr>
<tr>
<td>F</td>
<td>New Tram - Osaka</td>
<td>Niigata/LTV - Japan</td>
<td>8.00</td>
<td>2.29</td>
<td>18.32</td>
<td>20/62</td>
<td>10,000</td>
<td>14,340</td>
<td>90</td>
<td>546</td>
<td>7,170</td>
<td>9.00</td>
</tr>
<tr>
<td>G</td>
<td>Skybus - Miami</td>
<td>Westinghouse Elec. - USA</td>
<td>9.30</td>
<td>2.59</td>
<td>24.09</td>
<td>28/70</td>
<td>8,600</td>
<td>13,500</td>
<td>90</td>
<td>357</td>
<td>6,750</td>
<td>10.47</td>
</tr>
<tr>
<td>H</td>
<td>VAL - Lille</td>
<td>Matra - France</td>
<td>12.50</td>
<td>2.06</td>
<td>25.75</td>
<td>34/86</td>
<td>13,850</td>
<td>19,870</td>
<td>240</td>
<td>538</td>
<td>9,935</td>
<td>17.33</td>
</tr>
</tbody>
</table>

$^a$ Assumed area per standee: 0.20 m$^2$. Capacity may vary due to different seating arrangements.

$^b$ Assumed weight per person: 70 kg.

$^c$ Propulsion by linear induction motor (LIM) which has different power characteristics than conventional electric motors.
Figure 3: Tare (empty) weight vs. gross floor area of rail transit and AGT vehicles
Figure 4: Average gross axle loading vs. gross floor area for rail transit and AGT vehicles.
some of the AGT systems, such as the Airtrans, M-Bahn and ALRT, have lower loads per axle than any conventional modes (the Morgantown system is even lighter, but that system is very exceptional in many ways). The other four systems are not at all lighter, and actually the VAL system is heavier per axle than any of the LRT vehicles in the diagram. Thus a few AGT technologies may have lighter structures, but most of them will require the same structures as conventional rail systems.

Finally, Figure 5 presents a diagram of power against empty weight of vehicles, indicating their dynamic characteristics (primarily the ability to accelerate). This diagram shows that the AGT modes have generally the same ratios of power-to-weight as all other rail modes.

Transit Unit Size, Service Frequency and Capacity. Since there is still limited experience in operating AGT systems on heavily travelled regular transit lines, particular attention must be given to the capacity which these systems can provide. Actually the vehicle size and the ability to couple vehicles into trains determine two important features:

- Physical ability to offer the critical (peak hour) transporting capacity;
- Ability to utilize smaller TUs to economically provide high frequency during periods of low passenger volumes.

The diagram in Figure 6 presents relationships of these factors: TU sizes (minimum and maximum), frequencies of service, desirable range of frequencies (or headways) of service and line capacity. Five AGT systems, listed with their data in Table 2, are plotted on the diagram for illustration of these relationships. The five systems are merely examples for illustration of the type of analysis and they are not intended to be considered as superior to others, nor are the values adopted here absolutely fixed: some of the systems could be constructed to somewhat different specifications. The diagram does show, however, distinct differences among their basic characteristics.

The relationship between frequency of service on the ordinate of the diagram (headway or interval between TUs, being the inverse of the frequency, is also plotted), and line capacity, plotted on the abscissa, is shown. Every TU capacity gives a straight line on this diagram, with smaller slope for greater TU capacity.

With respect to the frequency of service, it is obvious that to provide good service, higher frequency is required; in the case of AGT, it may be considered that service should have at least a frequency of 10 TU/h, or 6-min. headways. It is desirable to shorten these headways, but only to a certain level: once headways of 3, 2.5 or 2 min. are reached, passengers do not care for any
Figure 5: Power-to-weight ratio of rail transit and AGT vehicles
Figure 6: Transit unit sizes, service frequencies and line capacities of AGT systems.
<table>
<thead>
<tr>
<th>System - city</th>
<th>Types of service</th>
<th>Frequency (TU/h)</th>
<th>Car capacity (prs/car)</th>
<th>Offered capacity (spc/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. ALERT - Vancouver</td>
<td>Min: 2.5</td>
<td>Max: 1.25</td>
<td>24</td>
<td>480</td>
</tr>
<tr>
<td>2. KCV - Kobe</td>
<td>Min: 2.5</td>
<td>Max: 2.0</td>
<td>48</td>
<td>28,800</td>
</tr>
<tr>
<td>3. New Tram - Osaka</td>
<td>Min: 2.0</td>
<td>Max: 3.0</td>
<td>30</td>
<td>1,440</td>
</tr>
<tr>
<td>4. Skybus - Miami</td>
<td>Min: 2.5</td>
<td>Max: 1.25</td>
<td>30</td>
<td>11,160</td>
</tr>
<tr>
<td>5. VAL - Lille</td>
<td>Min: 1.5</td>
<td>Max: 2.5</td>
<td>24</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>Max: 40</td>
<td></td>
<td>48</td>
<td>7,440</td>
</tr>
<tr>
<td></td>
<td>Max: 336</td>
<td></td>
<td>62</td>
<td>16,800</td>
</tr>
<tr>
<td></td>
<td>Max: 816</td>
<td></td>
<td>62</td>
<td>16,512</td>
</tr>
</tbody>
</table>

Table 2. Data for service/capacity computations of different AGT systems.
further shortening of headways; on the other hand, if the headways are shortened further, reliability of operations decreases rather rapidly; therefore, from the operational point of view, headways shorter than 2 or 2.5 min. should be used only when this is absolutely necessary to provide higher capacity. Thus, these two requirements define the range of headways between 6 and 2.5 min. (or frequencies form 10 to 24 TUs per hour) as most desirable for AGT operations.

The diagram assumes that for very low passenger volume minimum size TUs are used and an average occupancy of only half of offered seats is planned for; as the volume increases, service frequency increases, until it reaches 24 TU/h; after that point the same frequency is maintained, while utilization of vehicles increases and, in the cases of systems which can change TU size, such as the Skybus, ALRT and VAL, additional cars are gradually coupled to the trains. When the occupancy of 100% and maximum TU size are reached, further increase in capacity must be provided by increasing the frequency, i.e. the headways must be shortened to their minimum operationally feasible values, which vary for these modes from 1.25 to 2.00 minutes.

An additional factor is important to consider. These offered capacities can never be fully utilized because of the fluctuations of passengers volumes during the peak hours, difficulty in filling up every car to its maximum, etc. Therefore unless absolutely "jammed" conditions are expected and major delays to passengers are acceptable, not more than about 80% of the offered spaces can be actually utilized. To show these values, a different scale of utilized capacities is plotted on the abscissa. Projected passenger volumes for the planned line should be considered on the basis of this utilized capacity and the ability of AGT systems should be examined with respect to those values.

6. Applications of AGT Systems

There are presently two general types of AGT applications with rather different roles.

I. Internal circulation in airports, office complexes, amusement parks, etc. These systems play an important role in the functioning of various activity centers, which may be amusement or transportation function, depending on the specific case (Disney World has both types).

Being designed and financed together with the development they serve, these AGT systems are of different nature and little significance for cities and public transportation services in them.

II. Transit systems applications of AGT have been introduced mostly in the last 10-12 years. In general, these systems have been very successful and the main problem that prevents their
faster introduction is that their investment cost is still quite high. For example, comparisons in several French cities show that AGT systems require about 3 times higher investment than LRT systems. Given this relationship, many cities logically opt for a larger network of somewhat lower performance systems, rather than a major investment in only a single line. However, in several cities, such as Lille and Vancouver, AGT serves so heavily traveled lines, that no other mode except full scale metro could meet the demand. The investments in AGT in these cases has obviously been the optimal choice.

Major, most significant AGT systems in urban transit applications are the following ones.

- Portliner in Kobe, New Tram in Osaka and several other AGT systems in Japan serve either as feeders to rail transit (Kobe), or as self-standing major lines (Yokohama). They perform these roles very well. One questionable feature is that these systems have fixed trains of 4 or 6 cars for all conditions, thus failing to use the advantage of automated systems to adjust capacity to demand by changing TU lengths. Also, use of 2-axle 8-meter long vehicles provides comfort inferior to that of larger vehicles.

A realistic comparison of these systems with rail technology cannot be made in Japan, because of a policy aberation in financing. The funds of the Department of Construction are available for guided transit systems if they use rubber tires, but they cannot be used for rail systems!

It is interesting that while several of these systems in Japan are automated, others, of the same basic technology, are operated manually.

- VAL in Lille, France, has been very well used and popular. Developed after extensive testing, the VAL system has excellent performance. Its "tight" vehicle design poses some limitations in handling heavy passenger loads; the same manufacturer has subsequently developed larger vehicles, better adapted for urban transit service conditions.

- ALRT in Vancouver, Canada, has shown that AGT systems can utilize conventional rail technology (the fact that it uses linear induction motors is irrelevant to the basic vehicle technology). Together with VAL, the Vancouver ALRT is one of the AGT systems which clearly demonstrates how the positive features of automation can be used for frequent, efficient and economical transit service and attract very large numbers of passengers.

- Docklands system in London has one crew member, but that person serves passengers and collect fares, because driving is fully automated. This system illustrates that a conventional LRT system can be easily converted into AGT if it has an exclusive
right-of-way. Its passenger loads are far above expectations.

- Downtown People Movers in Miami and Detroit were very imaginatively designed and they perform very well. With two different technologies (rubber tires in Miami and rail in Detroit), these systems have basically the same role of downtown circulation. The Detroit system has lower ridership because the city does not have any high performance rail transit.

- Lyon Metro has become the world's first standard metro to be operated as an AGT system.

Monorails have been built in several cities, mostly in Japan, but they are not AGT systems: they represent rapid transit with different (unconventional) support and guidance. Some of them, like the one in Sydney, could be operated automatically, i.e., it can be converted into an AGT.

7. The Emerging Definition of AGT Systems

Since 1980, AGT systems have entered the family of regular urban transit systems, rather than only shuttles and local distributors. The "profile" of AGT systems is emerging with the following basic features.

Rubber-tire or steel-wheel vehicles operate in transit units with 100-400 space capacities, at minimum headways of 1.5-2.5 min., exceptionally 1 min. Schedules are fixed. Line capacities are in the range of 8,000 to 20,000 persons/hour, sometimes lower or higher than this range. Their feasibility depends on their investment costs: there are systems which require such low investment, that they may be justified for volumes of 3,000-5,000 persons/hour.

The roles of AGT can be several. First, medium-capacity, high quality major transit lines (Vancouver, Lille). Second, feeders to metro systems (Kobe, Miami, partly Docklands). And third, shuttle and loop lines or circulators within airports and various major activity centers.

It is likely that AGT systems will continue to play a somewhat limited, but increasing role, usually "between" LRT and metro systems.