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Abstract

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TRANSIT TECHNOLOGY TODAY

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FROM THE BEGINNINGS OF TRANSIT TO THE PRESENT

Rapid growth of cities in the 19th century created a great need for improved urban transportation services. Numerous inventors tried to develop technology that would provide faster, cheaper and more reliable transportation than the horse-drawn omnibuses and streetcars which had been introduced in all large cities between 1820 and 1850. Then, several major breakthroughs occurred. Hallidie invented cable cars in San Francisco in 1873 and introduced the first successful mechanical transit system; German inventors Otto (gasoline motor) and Diesel (diesel motor) built power units which several decades later allowed development of motor buses; but the most dramatic revolution occurred due to a series of inventions in electric traction technology. Siemens in Germany and Sprague in the United States had leading roles in developing practical, economical and safe electric streetcar (tram) and rapid transit systems which rapidly replaced all horse-drawn vehicles by about 1900.

Buses and trolleybuses were fully developed considerably later, during the 1920s and 1930s. Thus at the time of World War II the technology of urban transit systems was well developed; it consisted of buses, trolleybuses, streetcars, rapid transit (metro) and commuter rail systems.

Yet, it would be very wrong to believe that the basic transit technology was established by 1940 and few major improvements have taken place since. Actually, modern buses on streets, light rail and metro vehicles travelling quietly on prestressed concrete structures today have little resemblance with the heavy, noisy buses and rail vehicles of 40 years ago.

Numerous innovations from this period can be grouped into three categories:

- Improvements of physical components (vehicles, motors, tunnel construction, etc.);
- Operational innovations of transit systems such as separate bus lanes, transit priority at signalized intersections, computer control of rapid transit systems, self-service fare collection, better communications, etc.;
- New transit systems, i.e., transit systems consisting of unconventional vehicles, stations, types of operations, and other elements; monorails, automated guided transit and dual mode vehicles are some of the examples.

Transit technology today encompasses a large variety of components, systems and modes which provide transit planners and designers with virtually a continuous range from conventional buses on streets to fully computer-controlled high capacity rapid transit systems. Thus there is today a much richer choice for selecting transit systems than ever before; at the same time, the task of selecting modes and their components has become much more complex.

The purpose of this presentation is to review modern transit technology, concepts and modes, and to clarify the most important problems facing transit planners and designers. The focus of this presentation will be on medium capacity transit systems.

THREE 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. There are three right-of-way categories: streets with mixed traffic (C), longitudinal circulation with some crossings at grade (B) and fully controlled rights-of-way (A), and they have a major impact 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, operates on right-of-way B, includes semirapid bus and light rail transit; it has medium capacity and overall performance.

And,

- Rapid transit, which has exclusively right-of-way A and includes rail and rubber-tired rapid transit, 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 substantially 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 65 cities with rapid transit. However, many rapid transit systems were becoming larger in scale (larger cars, longer trains, greater spacings between stations, etc.), while buses degraded to very slow services on 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 this problem which took place since 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 15 years there have been many inventions and innovations in providing this medium-capacity class of transit modes. They can be classified into three major categories:

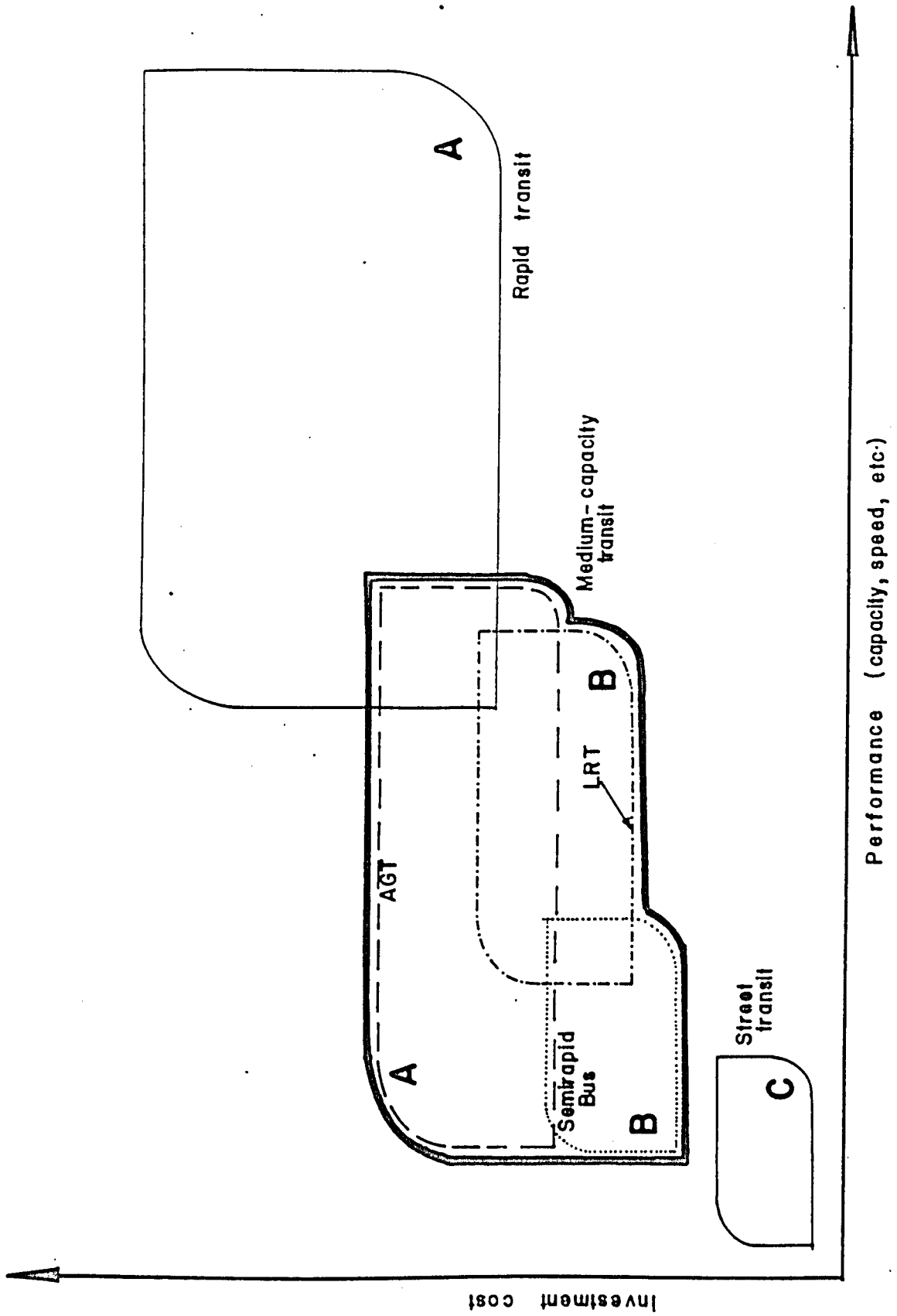


Figure 1. Investment cost/performance characteristics of different generic classes of transit modes

1. Semirapid bus (SRB), i.e. bus systems improved through provision of special lanes, busways, preferential treatments at intersections, new types of vehicles, and recently, invention of a guided bus which can operate both on streets and on special guideway sections (O-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 new LRT systems. These vary from rather low-performance systems similar to streetcars, to medium capacity/moderate investment cost systems, and even to some LRT systems which are very similar to rapid transit 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 are presently operated on short-haul lines, primarily in airports, but only a few AGT systems have been applied to regular urban transit lines: AGT systems in Morgantown, Kobe, Osaka and Lille are the only ones which fall in this category and which have been in operation for some time.

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 did create 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. The

result was that there were a number of errors in early development of AGT systems. It may be useful to give several examples of incorrect concepts which had a negative impact on the development of AGT systems.

- 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.

- Small-capacity vehicles were used 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.

- Overemphasis of short headways occurred. Enormous efforts have been placed in research of operations with headways of several seconds; however, there are no realistic definitions of transit systems which would need such headways. Actually, experienced transit operators try to avoid operations with less than 2 or 1.5 minutes.

- The concept of "personal rapid transit" (PRT) was proposed as "transit of the future". Although the concept is physically and economically infeasible, it has caused confusion and delays in planning transit in several cities.

These errors in AGT development increased already strong skepticism of transit operators toward AGT systems. Another difficulty in the development of AGT has been that in most cases they should be coordinated with and supplementary to high capacity rail transit systems; however, most operators of large transit systems have had so many problems in modernizing and expanding their basic rail systems, that little attention and funding could be given to the introduction of new modes.

In recent years AGT systems have attracted increasing attention. Among numerous new AGT systems invented since about 1960, several have been developed into fully operational systems and their deployment has begun to expand from airports, amusement parks and other controlled areas to regular transit lines. However, since all 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.

MEDIUM CAPACITY TRANSIT MODE CONCEPTS

The basic need which medium-capacity transit is aimed to satisfy is provision of considerably higher level of service than street transit can offer, but at a lower investment cost than full size rapid transit requires. How can this goal be achieved?

The first and most important step in providing higher level of service is to separate transit vehicles from other traffic, i.e. to provide a separated right-of-way at least on critical sections of lines. Once a significant portion of right-of-way is separated, guided modes represent the logical and optimal solution. Their disadvantage of not being able to mix with traffic becomes irrelevant, while they offer numerous benefits, such as ability to couple cars into trains with lower operating costs, higher capacity and safety ability to use electric traction with all its benefits increased reliability of service, image, passenger attraction; etc.

There are two basic ways in which cost of guided transit can be kept lower than for full-size rapid transit:

1. Provide right-of-way B, i.e. have a mostly separated right-of-way, but with on-street stations and grade crossings where their negative impact on transit line operation is minimal. This solution represents light rail transit.

2. Provide right-of-way A, but reduce the size of vehicles and trains, consequently allowing smaller stations and, in some cases, lower geometric standards of alignment than for rapid transit. This solution, resulting in AGT systems, actually represents a form of small scale rapid transit.

Both of these methods have a variety of solutions and their appropriateness depends often on local conditions. Let us analyze both concepts, focusing then in more detail on AGT modes and their numerous variations, which are subjects of discussions and testing in several cities.

Partially Separated Right-of-Way. The only transit technology which can be utilized on right-of-way category B and provide the benefits of large vehicles which can be coupled in trains, electric traction, durability, economy and others, is conventional rail, since only that technology allows crossings and even mixing with highway traffic. Rubber-tired guided transit systems do not allow any crossing at grade. The ability of conventional rail to be applied on any right-of-way category allows a great diversity of LRT applications; while this mode generally utilizes right-of-way B, it can also use right-of-way categories A or C on different sections of the same line. Depending on local conditions, LRT can have different vehicle types, train lengths, operating speeds, stations (a simple island in a street or an underground station similar to rapid transit), driving on visibility or with signals, etc. Through various innovations in these concepts since 1960, productivity of LRT has been greatly increased. While on typical streetcar systems there were about 60 spaces per

crew member, in a modern LRT systems such as in Frankfurt or Calgary, one person operates a train of about 600 spaces at a speed two or three times higher than the old streetcars. Thus labor productivity is 20-30 times greater.

Conflicts which LRT has with other traffic at some crossings or other locations sometimes have no significant negative impacts on operations; in such cases LRT represents an extremely economical and efficient transit mode. However, if right-of-way B has many crossings which would either prevent reliable operations or require high investments in full separation of long sections of lines, then construction of a fully separated right-of-way, category A, becomes necessary. Then an AGT (rail or rubber-tired) or rapid transit would represent the logical choice.

Fully Separated Right-of-Way. 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 not only for completely separated and controlled guideway, but also for each station, maintenance yards, and other facilities. Second, physically and geometrically, right-of-way A tends to provide conditions for higher speed of operation, but 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 which are commonly designated as transit system performance.

While very large and dense 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 only 10,000 to 20,000 persons per hour? That is the goal in the development of medium capacity systems. Adaptations of all major components to these reduced performance requirements will now be reviewed one by one.

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, 2-axle vehicles;
- + Guideway and switching of rubber-tired vehicles may be either cheaper and simpler, or more complicated and expensive than for rail vehicles, depending on specific technology of the former;
- 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 experiences from the last 20 years 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 14 m, rail is usually superior.

There are several important innovations in rail technology, such as steerable axles and linear induction motor, applied in the ALRT system. Steerable axles insure 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 achieved on transit systems if two conditions exist: right-of-way must be fully separated (A) and guided technology must be used. Automation is not related to guidance technology: it can be used on rail, rubber tired, magnetically suspended or any other guidance technology; nor is automation related to vehicle sizes, except that for high capacity systems such as rapid transit it is somewhat less important than for medium and small capacity systems. Rapid

transit is entirely economically feasible without automation, 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 rather 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 full automation not only involves higher investment costs, but it also requires a much more sophisticated technology in construction, operation and maintenance of the transit system. Thus automation 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, the case for automation is not strong; however, it is still 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 and in some test uses; 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, or weight of empty cars as related to their floor areas. The 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-Bahn, the system which utilizes magnetic suspension, thus avoiding many elements of support and suspension, such as wheels and springs. The 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.

Table 1. Vehicle characteristics for selected AGT systems.

Code	System - city	Manufacturer - country	Length L [m]	Width W [m]	Gross area A _g [m ²]	Capacity ^a seats/total	Tare wgt W _t [kg]	Gross wgt W _g [kg] ^b	Power P [kW]	W _t /A _g [kg/m ²]	W _g /n _{axl} [kg]	P/W _t [kW/t]
A	Airtrans- Dallas/F.W.	LTV/Vought - USA	6.48	2.24	14.52	16/40	5,350	8,150	56	368	4,075	10.47
B	ALRT - Vancouver	UTDC - Canada	12.70	2.50	31.75	40/100	13,600	20,600	(LIM) ^c	428	5,150	(LIM) ^c
C	KCV - Kobe	Kawasaki - Japan	8.00	2.39	19.12	20/62	10,500	14,840	90	549	7,420	8.57
D	M-Bahn	Siemens - Germany	11.80	2.30	27.14	?/70	7,800	12,700	(LIM) ^c	287	n.a.	(LIM) ^c
E	Morgantown	Alden/Boeing - USA	4.73	1.83	8.66	8/21	3,900	5,370	45	450	2,685	11.54
F	New Tram - Osaka	Niigata/LTV - Japan	8.00	2.29	18.32	20/62	10,000	14,340	90	546	7,170	9.00
G	Skybus - Miami	Westinghouse Elec. - USA	9.30	2.59	24.09	28/70	8,600	13,500	90	357	6,750	10.47
H	VAL - Lille	Matra - France	12.50	2.06	25.75	34/86	15,800	22,100	120	614	11,050	7.59

^a Assumed area per standee: 0.20 m². 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.

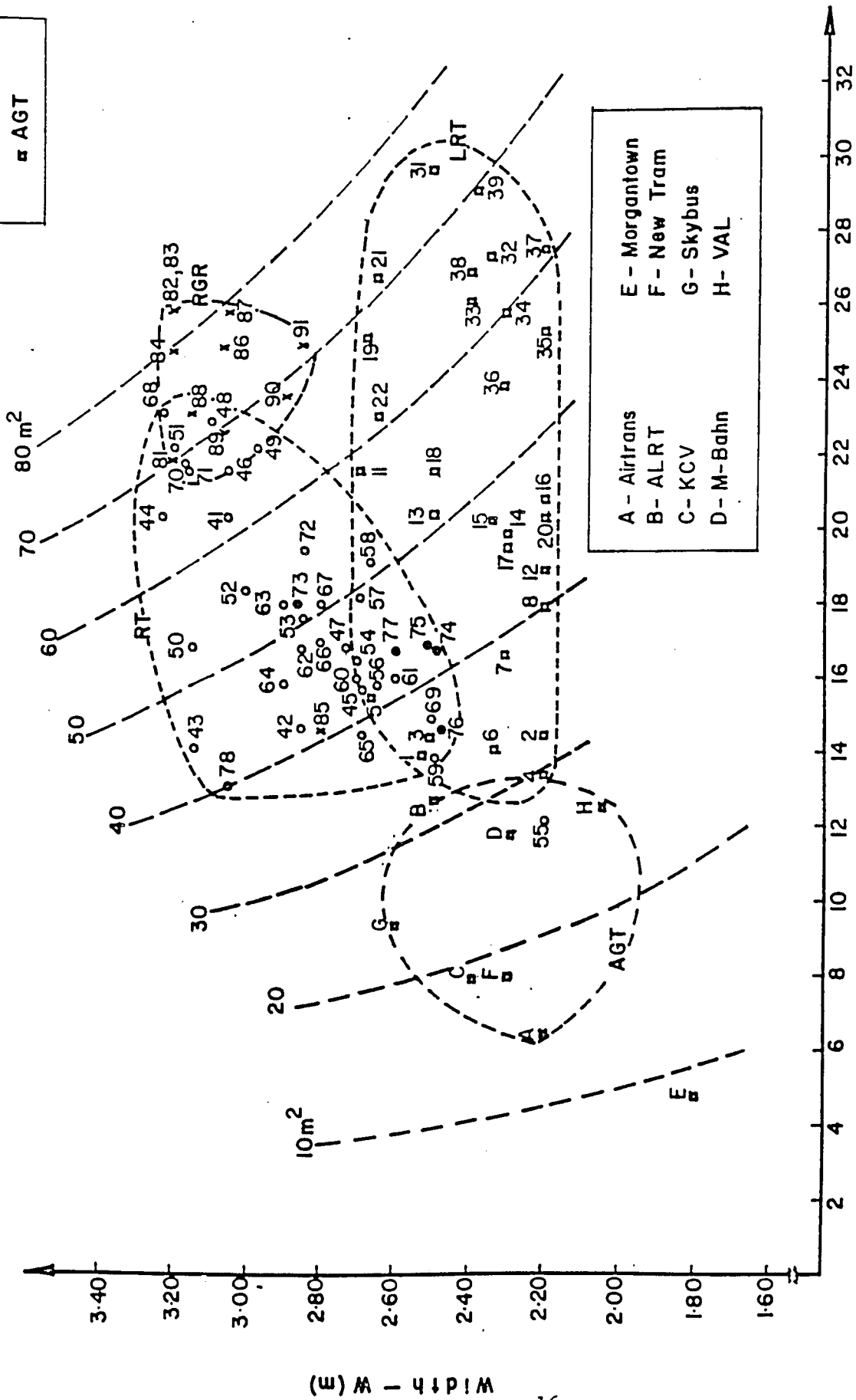
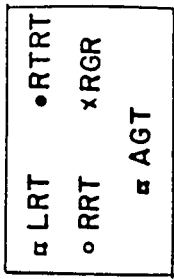


Figure 2. Dimensions of rail transit and AGT vehicles

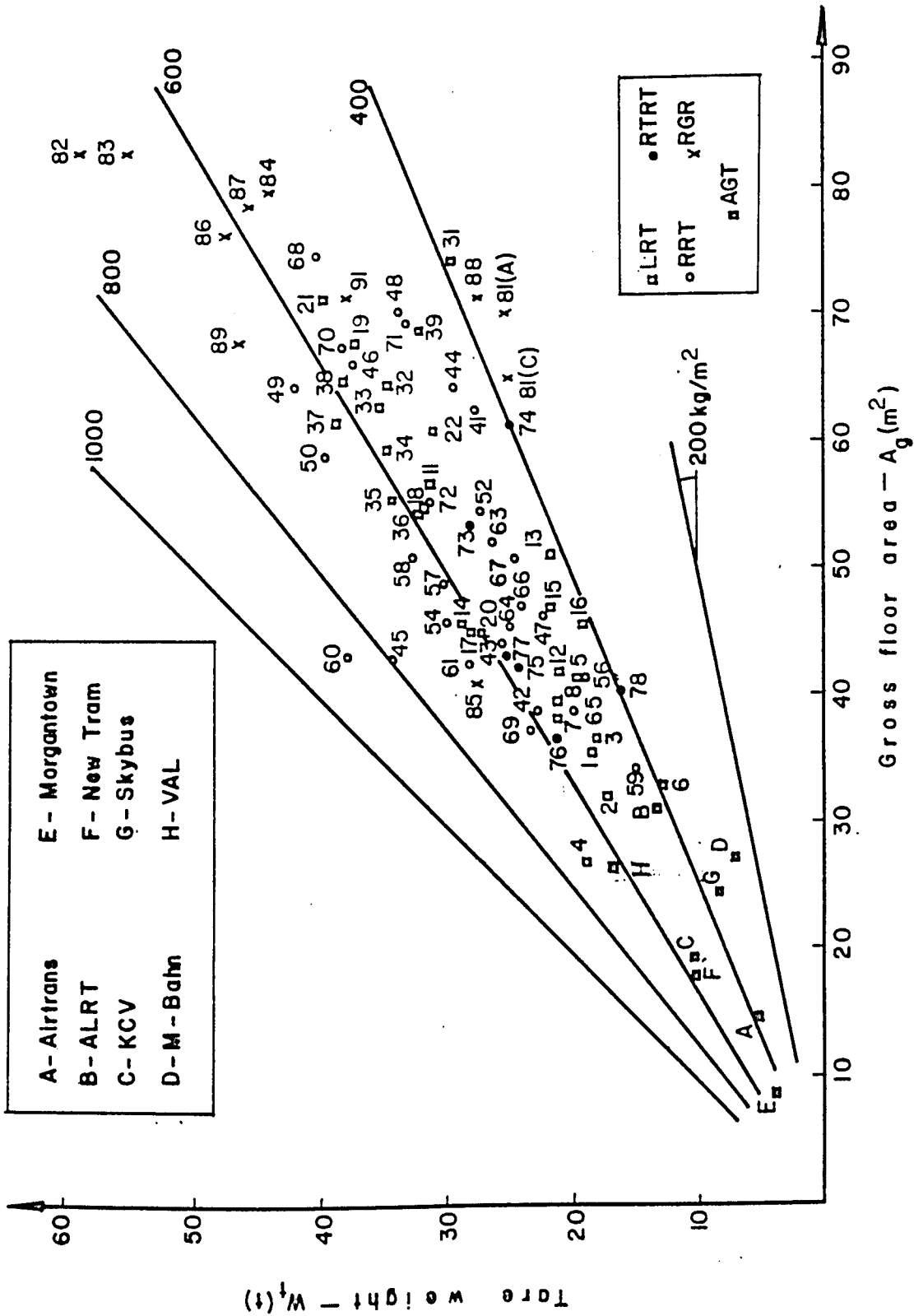


Figure 3. Tare (empty) weight vs. gross floor area of rail transit and AGT vehicles

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 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 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 very little 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 achieve economy and higher 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

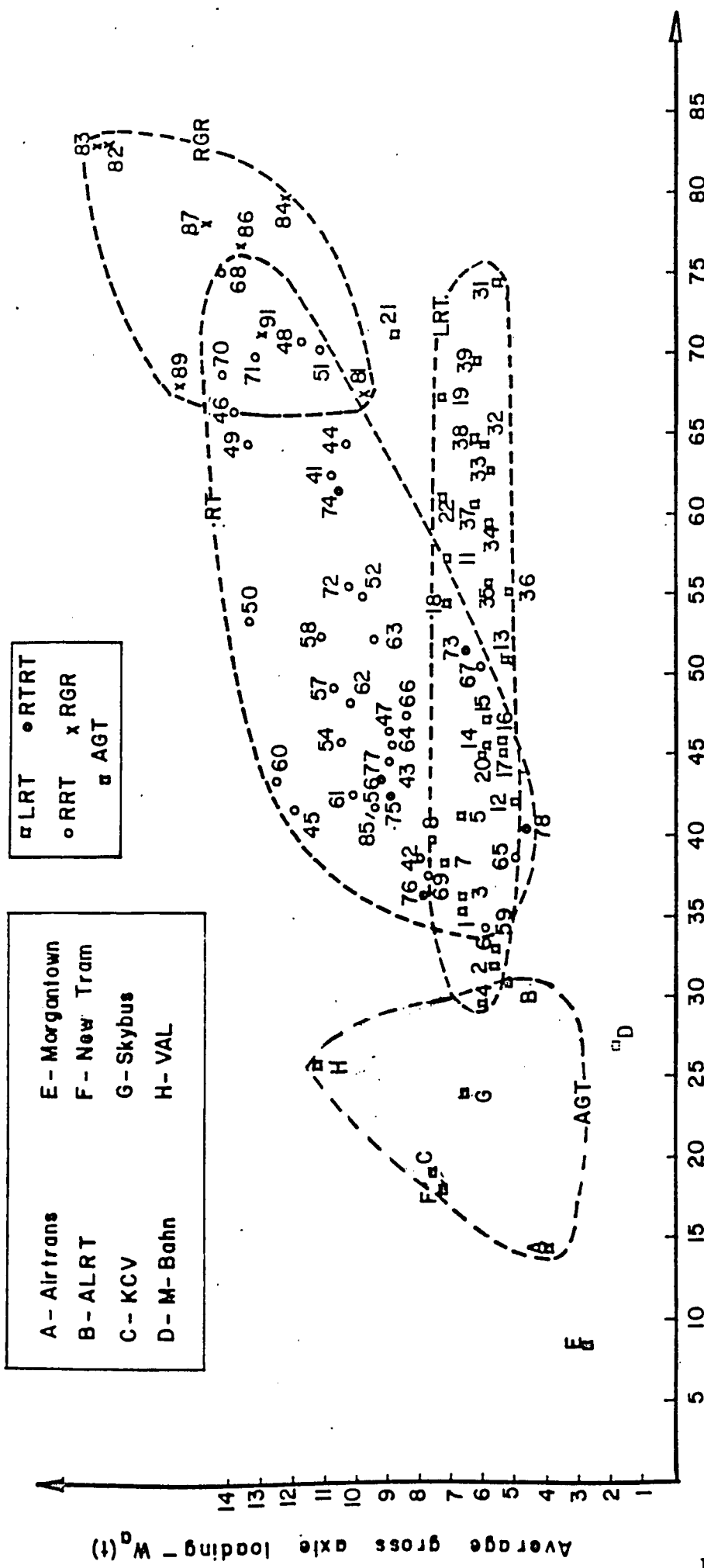


Figure 4. Average gross axle loading vs. gross floor area for rail transit and AGT vehicles

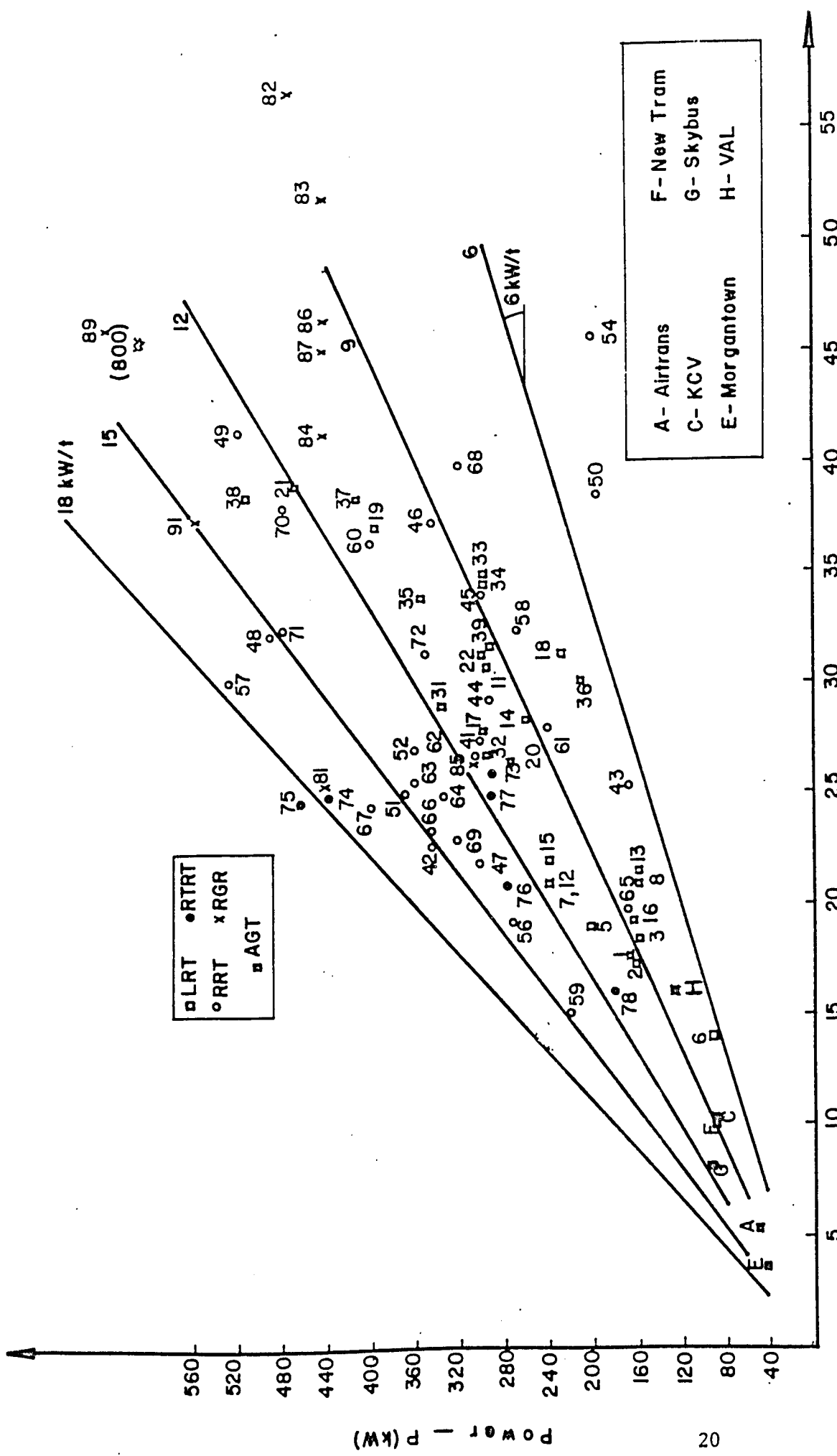


Figure 5. Power - to - weight ratio of rail transit and AGT vehicles

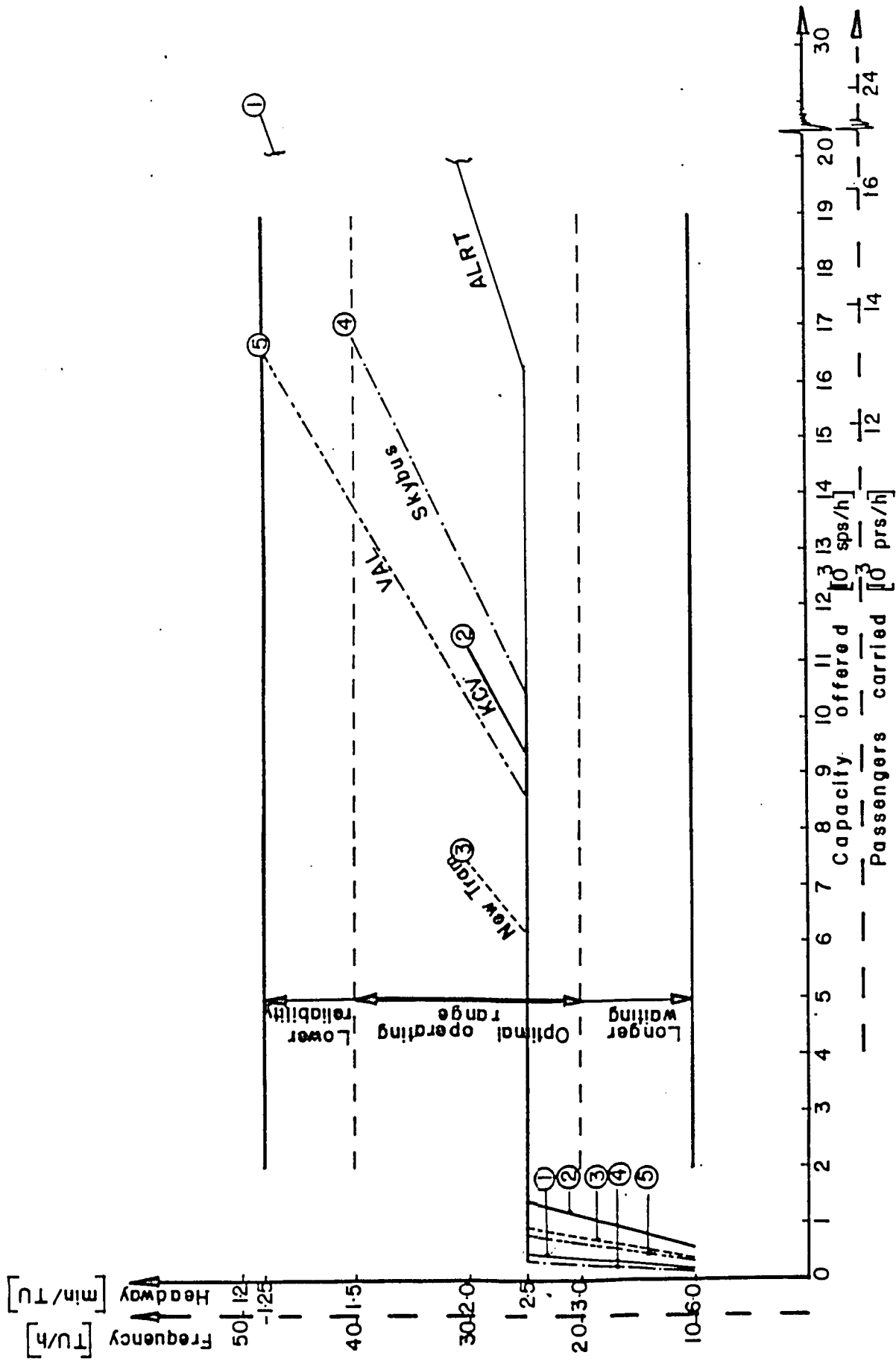


Figure 6. Transit unit sizes, service frequencies and line capacities of AGT systems

Table 2. Data for service/capacity computations of different AGT systems

System - city	Types of service	Headway (min/TU)	Frequency (TU/h)	Cars/TU	Car capacity (prs/car)	Offered capacity (sps/h)
1. ALRT - Vancouver	Min	2.5	24	1	20	480
	Max	1.25	48	6	100	28,800
2. KCV - Kobe	Min	2.5	24	6	10	1,440
	Max	2.0	30	6	62	11,160
3. New Tram - Osaka	Min	2.5	24	4	10	960
	Max	2.0	30	4	62	7,440
4. Skybus - Miami	Min	2.5	24	1	14	336
	Max	1.5	40	6	70	16,800
5. VAL - Lille	Min	2.5	24	2	17	816
	Max	1.25	48	4	86	16,512

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 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 from 10 to 24 transit units 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.

Investment and Operating Costs. Every transit system must be evaluated as a "package" of its performance and costs. A serious problem with AGT modes is that many of their installations were financed as research and developments by governments or private industry and their realistic investment costs for actual applications in cities are therefore somewhat uncertain. In addition, there is a limited experience with operating and maintenance costs, which are the permanent ones for the life of the project, and their values may vary considerably with local conditions, such as specific designs, component reliability, availability of technically competent personnel, etc. Estimation of costs is therefore a major and very serious task for any city which plans to introduce an AGT system in actual commercial operation.

EVALUATION AND SELECTION OF TRANSIT MODE AND TECHNOLOGY

Selection of a high performance transit system is an extremely important task in every city, since it is often the largest public project the city has ever undertaken and that decision will influence not only efficiency of transit service in the future, but probably the functioning and environment of the entire city for many years to come. However, this important decision is extremely complex. How can all the numerous factors, such as vehicle comfort, frequency of service, costs, fitting of the line into streets, on aerial structures or in tunnels be analyzed in a systematic way? While there is no simple and exact procedure for comparative analysis of modes, since it varies somewhat from one city to another, some general principles and sequence of steps can be specified.

Mode Selection. Generally speaking, the transit system should be selected which satisfies two basic requirements:

- a. It is technologically and operationally sound; and
- b. Has a performance/cost "package" at least equal to that of any other mode.

The first condition, a, is satisfied by all conventional modes: buses, LRT and rapid transit, as well as by several monorails and other systems which have been in operation for long periods of time. In recent years several new modes have been added to this list: tests and actual operations have proved that the O-Bahn, Skybus, VAL, KCV and several other systems meet this requirement also.

The second requirement, i.e. determination which mode is the best, requires a careful and systematic comparative analysis, which can be divided in two parts.

First, the general mode characteristics should be determined through an analysis of a sequence of steps. Starting from street transit (i.e. regular bus), the following steps should be examined.

i. Is provision of right-of-way category B justified?

This question is answered positively whenever the goal is to create transit which is competitive with private automobile, or when buses on streets cannot carry passenger loads. Both of these conditions are satisfied in most large cities. The benefits from right-of-way B easily justify the required investment.

In most cases when right-of-way B is justified, guided system (i.e. LRT) is the optimal technology.

ii. Is provision of right-of-way A justified?

To answer this question, a very preliminary design should be used to compare the planned line with the two right-of-way categories, B and A, as alternatives. As already discussed, modes with right-of-way A provide a better service and often lower operating costs, but require a substantially higher investment. Thus the question is whether the difference in performance justifies the additional capital expenditure. Or a different question should be asked: if a fixed amount of investment funds is available, should, for example, a 20 km long network with right-of-way B be built, or a 12 km long network with right-of-way A? The decision depends on the relative importance of higher performance vs. larger area coverage by the network. If right-of-way A is selected, the next question follows.

iii. Is fully automated operation necessary and justified?

The benefits of lower cost of operations during off-peak hours, easy control of schedule, optimal driving regime, etc., should be evaluated against the considerably greater investment and system complexity, higher requirements for skilled personnel, etc.

If this question is answered positively, then various automated guided systems, which have passed the technical feasibility test, such as conventional but automated light rail rapid transit, ALRT (with linear induction motor, etc.) KCV, New Tram, Skybus and VAL must be compared.

System Selection. The comparative analysis and selection of specific system technology should include many different factors, classified in three categories by the interested groups:

- Passengers, representing the most important group, require fast, reliable, safe, comfortable and attractive service at a reasonable fare.

- Transit operator, responsible for provision of service required by passengers, must have a system which can offer specified operating speed, capacity, frequency, reliability and safety at an acceptable level of investment and operating costs.

- Society, including the government, entire city and communities to be served by the planned system, consider mostly such factors as investment costs of the project, overall level of service which it will provide (increased mobility in the city) and the system's impacts. The last item, impacts, include a variety of items from aesthetics and noise to stimulation of desired urban patterns; thus, there are both positive and negative impacts, immediate and long-range ones.

Comparative evaluation of candidate systems should consist of analyses of all these aspects in terms of costs, various other units (such as person-hours, service frequencies, percent of seated passengers, etc.) and a number of qualitative factors, such as vehicle comfort, image of the system or ease of train operations at junction points. The system which has the best "package" of performance elements and costs should be the optimal choice.

The Decision in Taipei. The outlined sequence of major decision steps in transit mode and system selections should be followed in Taipei's current transit planning. The main trade-off in the decisions about basic mode is between higher performance (right-of-way A vs. B, automated vs. manual, etc.) and more extensive network. This assumes that the total investment is limited, which is always the case.

Evaluation of alternative guided systems will be simplified by the fact that most of them have a number of very similar characteristics; all are electrically powered and have similar dynamic characteristics, therefore similar travel speeds; their aesthetics are also similar because car exteriors need not differ much among different systems; environmental impacts are nearly the same because of similar guideways, very low noise levels, etc.

The major items that may bring decisive differences are:

1. System capacities. While aesthetics, comfort and even speed are desirable but not quantitatively imperative features, the planned system must provide required capacity. It is a great mistake if a system is built at a great expense and then cannot perform as expected because it is under-designed. Mexico offers an example of such a problem: soon after its Metro opened, it was loaded to capacity and today some of its lines are simply inadequate. Its cars with only 42 m² of gross floor area (as compared to the Hong Kong cars with 74 m²) are too small for the city of that size.

Similarly, Paris would build today its Metro lines for much longer than 5-car trains which it planned in 1900.

This does not mean that every city should have cars like Hong Kong or San Francisco; for Taipei a considerably lower capacity will suffice. But in determining the design capacity, one must bear in mind that facts that regular transit lines must provide greater comfort than short shuttle lines; that the trend is toward increasing comfort, therefore more seating; that some portion of capacity cannot be utilized for operational reasons, etc. In other words, there is a substantial difference between offered and utilized capacity.

2. Operational Characteristics. Simple, tested operational procedures are necessary in order that the transit system can provide reliable, efficient and economical service. This factor includes such aspects as the need for flexibility of track layouts, convenience of automatic operations, ability to expand systems capacity, mechanical and electrical complexity, etc.

3. Total Costs. As always, total system costs, including investment and operations, represent a very important, often dominant factor in system selection.

CONCLUDING REMARKS

Taipei is emerging as one of the far-sighted cities planning transportation systems for the future. In considering development of a medium capacity transit system it faces the difficult decision how to utilize some innovations which modern transit technology offers, but without serious risks which technological innovations often present.

While keeping an open mind for innovations, Taipei's transportation planners must also utilize extensive experiences from transit planning and operations which many other cities offer.

It is hoped that this Symposium and continuing professional cooperation will make a significant contribution in the difficult but promising task facing Taipei: how to ensure good mobility of its population as well as a prosperous, attractive environment for many decades to come.

BIBLIOGRAPHY

1. Bundesminister für Verkehr, Forschung Stadtverkehr, Sonderheft 12; Kirschbaum Verlag, 1976; Bonn-Bad Godesberg, F.R. Germany.
2. Calverley, H.B., "Developments for medium-capacity urban public transport"; Proc. IEE, Vol. 126, No. 11R, pp. 1097-1125; November 1979, IEE Review, England.
3. Chung, C.C., Preliminary Data Base for Existing Automated Guideway Transit Systems; TSC report to UMTA/U.S. DOT, Dec. 1977; Washington, D.C., USA.
4. Ferbeck, Daniel and Henri Frey, "Die automatische U-Bahn in Lille"; Der Nahverkehr, pp. 62-75; 0/82. Alba Buchverlag, Düsseldorf, F.R. Germany.
5. Krettek, Otmar, Rollen Schweben Gleiten; Alba Buchverlag, 1975; Düsseldorf, F.R. Germany.
6. Müller, Siegfried, "Die H-Bahn"; Nahverkehrsforschung '79, pp.166-209; BMFT, Bonn, F.R. Germany.
7. "Osaka and Kobe pioneer automated people movers"; Railway Gazette International, April 1980, pp. 288-290; London, England.
8. TCO-Traction Cem-Oerlikon, "Lille's Val Metro a new concept in fully automated transit system"; Techniques CEM Nr. 115, Paris, France.
9. Vuchic, Vukan R., "Place of Light Rail in the Family of Transit Modes"; TRB Special Report 161, "Light Rail Transit", pp. 62-76, 1975. Washington, D.C., USA.
10. Vuchic, Vukan R., "Rapid transit automation and the last crew member" - Railway Gazette International, October 1973, pp. 382-385; London, England.
11. Vuchic, Vukan R., Urban Public Transportation Systems and Technology; Prentice Hall, 1981; Englewood Cliffs, NJ, USA.