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Trends in the Development of Urban Passenger Transport Systems and Vehicles

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Abstract
Basic technology of the automobile is now stable, but there are innovations in its "fitting" in urban environment and its improved relationship with pedestrians and human activities in general. Technology of transit systems has had many innovations in the last 2-3 decades. There has been a general trend to provide partially or fully separated rights-of-way for transit. Buses and trolleybuses have been given special lanes or roadways in many cities. Separation of rail vehicles from other traffic has led to creation of light rail transit, a new mode that provides much better service than streetcars, trolleybuses and buses, but requires significantly lower investment than metros. Because of the great diversity of services it can offer, light rail transit is now being built in many cities around the world. Metro (rapid transit) systems have been built intensively in the last 30 years: their number increased from 17 in 1950 to over 60 today. There are now attempts to develop small-scale automated metro systems, on rails or rubber tires, which require lower investments than metros and thus enable also medium size cities to upgrade their transit services.

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TRENDS IN THE DEVELOPMENT OF URBAN PASSENGER TRANSPORT SYSTEMS AND VEHICLES

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ABSTRACT Basic technology of the automobile is now stable, but there are innovations in its "fitting" in urban environment and its improved relationship with pedestrians and human activities in general. Technology of transit systems has had many innovations in the last 2-3 decades. There has been a general trend to provide partially or fully separated rights-of-way for transit. Buses and trolleybuses have been given special lanes or roadways in many cities. Separation of rail vehicles from other traffic has led to creation of light rail transit, a new mode that provides much better service than streetcars, trolleybuses and buses, but requires significantly lower investment than metros. Because of the great diversity of services it can offer, light rail transit is now being built in many cities around the world. Metro (rapid transit) systems have been built intensively in the last 30 years: their number increased from 17 in 1950 to over 60 today. There are now attempts to develop small-scale automated metro systems, on rails or rubber tires, which require lower investments than metros and thus enable also medium size cities to upgrade their transit services.

1. INTRODUCTION
Transportation technology has always had a major impact on the form, density and environment of cities. For example, during the period between the invention of railways (1825) and introduction of electric transit (1890s) the rapid urbanization and growth of cities led to extreme concentrations of population, development of slums and extremely unhealthy urban environments. Transit allowed considerable dispersal of population and led to substantial separation of residential from industrial and other activities, resulting in improved living conditions and urban character.

The wide use of the private automobile in cities, which started in the United States during the 1920-30s, in Europe in the 1950-60s, and later in most other countries, caused another major "revolution" in urban development. The automobile increased personal mobility tremendously and facilitated ubiquitous travel, causing an even faster spatial spreading of cities.

However, together with numerous benefits, the automobile has brought some serious problems. Congestion automobiles cause on urban streets had negative effects on public transport, pedestrians and urban environment in general. The roles of the automobile and different public transportation modes and their mutual relationships represent the most complex problem in urban transportation today.

This paper will present a brief review of urban transportation modes and discuss current trends in the development of their systems and vehicles.

2. PRIVATE AUTOMOBILE AND ITS ROLE IN CITIES*
The role given to the private automobile in the city and its relationship to public transport on one, and pedestrians on the other side, have a strong influence on the entire character of the city. Cities which gave automobile the dominant role have grown with very low densities, developed life styles based on the automobile and lost much of the human character in their social activities. Cities following the other extreme - not providing any major facilities for automobile traffic - have suffered from extreme congestion, poor efficiency in functioning of various activities and congested, unhealthy urban environment.

Although the optimal role of the automobile in a city depends greatly on each city's size, topography, economy and other factors, it is generally true that in medium and large cities a coordinated system of private and public transportation (auto and transit, respectively) leads to far better efficiency, social activities and physical environment than either one of the two extremes, each favoring one mode only.

Houston, Los Angeles and Caracas are good examples of cities which for a long time pursued policies of total reliance on private automobile only. Although they built hundreds of kilometers of freeways and huge parking garages, they now suffer from serious congestion, unreliable travel conditions and severe limits to their growth.

* Excellent analyses of issues discussed here can be found in (1, 2 and 3).
Examples of cities which have not made adequate adjustments to accommodate vehicular traffic, either automobile or transit, can be found in Great Britain, Italy, Japan and a number of other countries.

The most advanced urban transportation systems exist in cities which have followed policies of coordinated developments of roads and transit systems. Munich, Brussels, Stockholm, Toronto and Rotterdam have achieved outstanding successes in coordinating private and public transport, selectively favoring each one according to its efficiency in providing a specific service.

2.1 Automobile/Pedestrian Relationship

Interestingly, the cities which have advanced farthest in coordinating transport modes have also tended to be ahead of other cities in coordinating transportation with urban design and land uses. Moreover, they have also been leading in increasing compatibility between the automobile and pedestrian traffic.

The problem of making automobile more compatible with pedestrians, with human-oriented areas in cities and with entire urban environment is very complex. As vehicular traffic intensified, the problem has become more acute. With increased awareness about the quality of urban environment since the mid-1960s, it has attracted increasing attention, and the progress toward its solution in recent years has been very significant.

The distinct trend in "fitting the automobile in urban environment" has been along two lines. First, separation of major automobile traffic into high-capacity facilities (arterial roads and freeways), and major pedestrian flows into pedestrian areas, plazas, streets or entire auto-restricted zones. These measures eliminate the most serious conflicts which cause majority of accidents, delays and other problems. Second, improved traffic engineering measures and new design patterns for neighborhoods (Woonerf concept is a particularly interesting innovation) lead to a greater tolerance and safer relationship between pedestrian and motorized traffic.

Examples of these developments are particularly numerous in West European cities: urban freeway and pedestrian plazas in Rotterdam, circumferential roads and "traffic cells" in Bremen and Göteborg, traffic/pedestrian pattern in the central area of Munich, etc.

2.2 Relevant Technological Features

Most of the basic operational and design features of the automobile have been stabilized in recent years. No major changes in size, dynamic performance or general shape of automobiles appear likely to occur in the foreseeable future. Yet, there is still a place for a number of technological improvement which will have a bearing on the performance of automobile in cities. Such desirable and possible further improvements may occur in the following features:

- Design for greater passenger safety;
- Motor modification for increased fuel economy;
- Better control of air pollution;
- Signals for communications among drivers in addition to the present ones, consisting only of horn, blinkers and brake lights.
- Development of computerized "navigation" systems for auto drivers.

Actually, the first three features - increased safety, fuel economy and air pollution control - have already been advanced considerably in recent years, but their progress is likely to continue. Signals for communications among drivers have been neglected in spite of their primitive status; there have been virtually no innovations in them since the 1950s. Driver navigation systems, recently demonstrated as prototypes, appear to have considerable potential.

Interestingly, fully automatic guidance and driving of vehicles on freeways was considered around 1960 to be a very likely innovation in the foreseeable future; however, closer examination of such a system uncovered many serious obstacles. Technical and operational problems of equiping all vehicles with automatic controls, checking mechanical/electrical components of vehicles entering freeway, handling of defects and legal responsibility in cases of any accidents are some of the problems of this system which are not easy to solve. Consequently, it is not likely that automatic guidance and control of automobiles on freeways will be introduced in the foreseeable future. Since automatic guidance on streets is not possible either, navigation systems assisting driver orientation appears to be the most promising improvement for vehicle travel in urban areas.

3. PUBLIC TRANSPORT (TRANSIT) MODES

Up to the mid-1950s transit systems consisted basically of four modes: bus, trolleybus, tramway (streetcar) and metro (rapid transit). These modes were defined and recognized by the public through their technological characteristics, such as types of wheels (rubber tires or steel wheels), guidance (steered or guided), propulsion (diesel or electric), etc.

With the extensive replacement of tramways and trolleybuses in many countries during the 1950s and 1960s, the choice of transit modes was increasingly polarized to only two extremes: buses operating on streets and metros. The former require very low investment, but they offer the lowest quality of transit service in many respects: reliability, image, riding comfort and other characteristics of buses are inferior to those of electrically powered vehicles. Metros offer by far the highest level of service of all transit modes, but they require very high investment. Between the two modes a large "gap" developed: there were no modern transit modes which would provide an "intermediate" level of service at a moderate investment cost. Yet, that was exactly what was missing in most medium-size cities in Europe and North America,
as well as in many large cities in developing countries. These cities needed transit systems which can offer higher capacity and better performance than buses, but which would require considerably lower investment than metros.

With the increasing need for diversity in urban transportation and numerous inventions in vehicle technology, electric traction and electronic control, the last 30 years have seen numerous and highly significant developments in transit technology. Moreover, new concepts in right-of-way type, system control and operations, intermodal coordination and other aspects have been invented and implemented.

3.1 Definition of Modes

As a result of extensive theoretical analyses of urban transportation systems, a new definition of transit modes has been developed (4). It allows a systematic classification of the present numerous systems into a "family of urban transportation modes".

Transit modes are defined on the basis of three characteristics:

- Right-of-way (R/W) category, which may be of three types: C - urban streets with mixed traffic; B - R/W longitudinally physically separated from other traffic, but with crossings at grade (typical for this category are curbed street medians for rail transit); and A - fully controlled R/W without any access by other traffic or pedestrians, such as metros have.

- Technology of vehicles and ways, mainly defined by four elements: support, guidance, propulsion and control.

- Type of service, such as local, accelerated or express, regular or commuter, etc.

Thus, in addition to the previously popular classification based on technology (e.g. bus and trolleybus differ in propulsion only), characteristics of R/W and operation are used for mode definition. Actually, various analyses of transit modes clearly show that R/W category is the basic characteristic determining the performance/cost features of each mode. For example, upgrading R/W on a tramway line from category C to B permits so many changes in vehicles and operations, that the upgraded system becomes a mode more similar to metro than to classical tramway. To indicate its features which distinguish it from both the metro and the tramway, this mode has been given the name light rail transit - LRT (German: Stadtassert, French: Métro léger). Or, to introduce fully automatic operation, the system must have R/W category A. Since exclusive R/W (A) involves high investment, all automated systems will belong to high-performance/high-investment modes.

Grouping of transit modes by their R/W category therefore gives their most logical classification.

3.2 Family of Transit Modes

The diagram in Figure 1 shows transit modes plotted by their performance and investment costs and grouped by their R/W categories. The performance can usually be expressed by such elements as speed, capacity, reliability, or by productive capacity - the product of line capacity and operating speed. Investment cost is computed per kilometer of line length.

The diagram shows that street transit modes (R/W category C) have distinctly the lowest performance, but they also require very low investment costs. Rapid transit, including metro and regional rail, is the highest-performance/highest-investment cost category because of its R/W category A. Intermediate systems, utilizing

Figure 1 Family of transit modes classified by R/W category
R/W category B, represent transition between the two "extreme" groups. Most of the recent inventions have taken place in this area: semi-rapid buses, i.e. buses with substantial line sections on busways or separated bus lanes. They have been developed since 1970; LRT has also been recognized as a distinct mode in the last couple of decades; finally, automated guided transit (AGT) systems, although with R/W category A, belong by most features in this group of "intermediate modes".

As a result of these developments, there is today, unlike several decades ago, a virtually continuous family of transit modes which allows every city to select the system which is optimal for its specific conditions.

A brief review of development trends in all major transit modes - their recent and likely future developments - will now be presented.

4. HIGHWAY TRANSIT MODES

Transit systems which utilize highway (road) vehicles can be classified into two major modes: buses and trolleybuses. In a broad sense, paratransit modes, such as taxis, jitneys, vans, etc. belong in this category, but they are distinguished from buses mostly by ownership and organizational characteristics, rather than by technology. Consequently, although paratransit has an important role in many cities of developing countries, it will not be discussed here.

4.1 Buses

Operated in all cities with transit services, buses are now the most ubiquitous mode of transit. The vehicles are rather simple, rugged and economical to operate; however, they still have some deficiencies: most buses produce considerable noise and exhaust fumes, which are particularly objectionable in urban streets; moreover, their riding comfort and spaciousness are often limited and substantially inferior to those of modern rail vehicles.

Numerous attempts have been made in recent years to alleviate the noise and exhaust problems through introduction of improved propulsion systems. Propane gas, turbine, steam, electric (with battery) and several other systems have been tested, but none of them could match the performance and economy of the diesel motor.

Articulated buses, perfected in the late 1950s, are now used extensively in many countries. Due to their steered third axle, they have the same turning profile as standard buses. Articulated bus with traction via the third axle, developed in the late 1970s, offers somewhat greater vehicle stability at high speeds, but it has a greater weight and requires a wider turning path because the third axle wheels are rigid. This limits maneuverability of the articulated bus with rear-mounted motor.

The most significant innovation in bus systems has been the introduction of lanes or roadways for bus use only. When buses have substantial sections of lines with this R/W category B, they have higher speed, reliability and stronger image than regular bus services. As explained in the preceding section, these systems represent semi-rapid bus mode. Substantial independence from street traffic gives semi-rapid buses greater ability to attract passengers than regular buses.

Much attention has recently been given to the O-Bahn, buses designed with small guidance wheels which can be extended by the driver to operate these vehicles on a special roadway with vertical guidance surfaces. Driver continues to drive the bus on the guideway; he only does not have to steer it. This guidance of buses results in increased riding comfort and safety; however, it eliminates ability of buses to overtake each other and increases considerably investment costs of bus lines. Thus the advantages of O-Bahn over the standard semi-rapid bus are quite marginal and in most cases they do not outweigh its disadvantages - lower capacity and higher cost. It is therefore not likely that the O-Bahn will find many applications (5).

Major efforts have been directed in a number of European countries and United States to the development of a bimodal articulated bus/trolleybus, with diesel and electric propulsion. These vehicles are intended to operate as trolleybuses on major route sections in central cities, and then continue as buses on suburban, non-electrified route sections. This feature would make bimodal trolleybus more attractive than bus for operation on center city streets, transit malls or in tunnels. Whether these advantages will outweigh the greater complexity and higher cost of the bimodal vehicle remains to be seen, but the concept has some very promising features and it has attracted a strong interest in professional circles.

4.2 Trolleybuses

Trolleybuses were massively replaced by buses until mid-1970s. Lower purchase cost of buses often outweighed longer life, higher riding comfort and other non-monetary advantages of trolleybuses. As population attitudes toward the quality of urban environment, including noise and air pollution, changed during the 1970s, this trend changed: trolleybuses regained their popularity, their replacement ceased, new vehicles were ordered and in some cities their networks have been extended. This development occurred simultaneously in many cities around the world, from Belgrade and Grenoble to Sao Paolo and San Francisco. These improvements of trolleybuses have generally found very positive acceptance by the riders and populations of these cities.

Technological progress in trolleybus construction has continued in the meantime. Increased efficiency of traction motor, chopper control and automatic placement of trolley poles on the wires by remote control from the driver's seat have been some of the significant innovations.
As the concern for quality of urban environment continues to be strong, it is presently expected that trolleybuses will be increasingly used. Their role will tend to be particularly important in cities which have hilly terrain, those which place high value on the quality of their environment, and in countries which favor use of electricity over oil.

5. RAIL TRANSIT MODES

Rail modes, which utilize the oldest technology of modern transit, have had numerous innovations in their systems and components in the last 2-3 decades. Modern rail transit is much more diverse and has a greater role in cities than in 1950s.

5.1 Tramways and Light Rail Transit

With increasing automobile traffic, operation of trams and trolleybuses in urban streets became unreliable and slow. Many cities therefore replaced them by buses and trolleybuses; during the 1960s and 1970s trams had practically disappeared from all cities in Great Britain, France, Denmark, and several other countries. A number of cities, however, wanted to preserve the higher capacity, better riding comfort and other features which buses cannot match; through traffic engineering measures they improved operation of trams and retained them. Examples of such systems are found in Zürich, Munich, Zagreb and many East European countries.

The most significant development of rail transit, however, took place in those West European cities which decided to upgrade trams through their separation from other traffic. Constructing tunnels, viaducts, street medians and other types of track alignments, these systems were gradually provided with separate tracks at high speeds and high safety (through signalization). These innovations were gradual but very significant and they eventually resulted in creation of the light rail transit.

There is today practically a continuum of rail systems from typical old-fashioned trams to modern LRT. Many systems have "overlapping" features, such as operation of single 4-axle cars with on-board fare collection on lines with R/W category B or A; alternatively, there are LRT systems with trains of 2-3 articulated cars and self-service fare collection still operating on substantial sections of R/W category C. This situation often causes confusion of concepts and terms: trams and LRT's are often confused with each other. Yet, a typical LRT system, such as is found in Calgary, Hannover or Newcastle, compared to a typical old-fashioned tramway, has 2-3 times higher operating speed, 2-3 times greater train capacity, 10-20 times greater productivity of its operating personnel, much higher reliability, etc.

The transition from trams to LRT represents an excellent example of the impact innovations in technology and operations of transport systems can have on their performance, economics and thus their role in urban transportation. Figure 2 illustrates how the introduction of articulated vehicles, longer trains and self-
service fare collection resulted in increased train capacity and decreased operating personnel requirements; the result of these changes has been that an operating person (driver or conductor) on a tramway in 1960 served about 60 passengers; on a modern LRT train today, he serves 540 passengers. Taking into account approximately doubling of operating speed during the same period, labor productivity has increased by a factor of about 20.

As the success of modern LRT systems in West European cities, such as Kiel-Bonn, Frankfurt, Göteborg and Rotterdam, became widely recognized, many cities in Canada, USA, France and other countries began to build new LRT systems. Even "supercities" with extensive metros, such as London and Paris, have begun to build LRT lines in their suburban areas.

Another "wave" of LRT construction has begun to occur in cities of developing countries. With their rapidly growing populations they desperately need modes with much higher capacity than buses can provide, but they have very limited financial resources. As the most appropriate mode to satisfy such conditions, LRT has been built or is under construction in Manila, Tunis, Buenos Aires, Kuala Lumpur and several other cities.

All indications are that LRT, as the most successful medium-capacity mode, will continue to be built in the coming years in many cities in Europe, North America as well as in developing countries (6).

5.2 Metro (Rapid Transit) Systems

The basic function of metro systems has remained the same since their invention in the 19th century: they represent the highest-performance transit mode which provides high-capacity, high-speed transport independent of street conditions. Yet, modern metro systems like those in Munich, San Francisco and Tokyo are distinctly different from their predecessors, the Paris Metro, New York Subway or Hamburg U-Bahn from 1950s. Similar to the automobile, bus and LRT, technological progress of metro systems has continued to the present time.

The differences exist in vehicle design and performance, train control and operation, station design as well as in concepts of coordination of metros with other modes of urban transport and with land development in station areas.

Modern metro vehicles offer such high level of riding comfort, temperature control and absence of noise, that few further improvements are possible or necessary. Larger vehicles (18-22 m long, 2.90-3.20 m wide), chopper control of motors and increasing use of power regeneration result in smooth ride and high energy efficiency.

In some cases great complexity of modern vehicles has resulted in several serious problems: increased cost of vehicles, decreased reliability and increased weight, which partially defeats the benefits of energy efficiency achieved by chopper control and regeneration. However, similar to buses and LRT vehicles, this has usually been the problem with vehicles which were designed with excessive complexity but without sufficient testing and appropriate maintenance procedure.

Transit agencies with extensive experience and highly competent technical personnel, such as those in Hamburg, Tokyo and Toronto, have succeeded to take full advantage of the latest technological advances without the above mentioned problems. Thus, Tokyo Rapid Transit Authority developed, after extensive testing, rolling stock which utilizes light-weight aluminum body construction, chopper control and regeneration and thus achieves 38% lower energy consumption than the preceding rolling stock.

Rubber-tired metro systems have been built in six cities and they operate satisfactorily. Interestingly, all these systems were designed by French engineers and companies. In all other cities which evaluated this technology the conclusion has been that their advantages of better adhesion and lower noise in curves are outweighed by their greater cost, complexity and energy consumption compared to conventional rail technology. Recently Montreal decided to use conventional rails on a new line to avoid expensive tunnel construction which rubber-tired trains need in climates with snow and ice.

Other innovations in metro systems include moving block signals, automatic train operation and on-line computer control of train movements. Full automation of train operations is now physically entirely feasible, but conservative attitudes have delayed introduction of fully automated metro trains (without drivers) up to now. The first such operation is being planned for a new metro line in Lyon.

Prestressed concrete aerial structures have led to much better acceptance of aerial R/W alignments. New station design concepts and, particularly sophisticated intermodal transfer stations which facilitate transfers among metro, LRT, buses and private automobiles, have greatly contributed to the creation of integrated multimodal systems. This type of station has been built since 1960s in a number of West European, North American and Japanese cities. By far the greatest obstacle to construction of metros is their very high investment cost. Yet, urban congestion and growing needs for high-performance, reliable and comfortable transit systems have led to the period of most intensive construction of metros in history during the last 30 years: in 1950 only 17 cities in the world had metros. Their number has increased to over 60 today.

5.3 Regional Rail

Former "suburban" or "commuter railways" are becoming increasingly members of the "family of transit modes". As cities spatially grow, regional railways assume the role of the basic transit carrier serving the region. In response to this demand for better regional services, many cities have connected previously separate radial networks into diametrical ones.
offering better area coverage, distribution and connectivity. Such network integrations have been achieved in Munich, Oslo, Paris, Philadelphia and several other cities.

Modern regional rail systems are rather similar to metros: their electric trains operate with regular headways and offer easy transfers to/from other modes at many stations. Longer station spacings, higher speed, longer lines and, usually, operation by railway agency still distinguishes them from conventional metros.

6. NEW GUIDED SYSTEMS

Extensive research and development has been done in the last 20 years in many countries to develop automated guided transit (AGT) systems, but for a long time the only results of these efforts were several small automated shuttle lines in airports, amusement parks and other major activity centers.

Since 1980, however, AGT systems with rubber-tire technology have been built as regular transit lines in several cities: Kobe, Osaka, Lille and Miami are the best known ones. At the same time major development efforts have also focused on AGT systems utilizing rail technology. The first lines with rail AGT technology have been recently opened in Toronto and Vancouver. They have 12 m long, 2.50 m wide rail vehicles, with linear induction motors and steerable axles, operating automatically on R/W category A. Similar concept is also in advanced stages of development in Belgium.

The intention in building AGT systems is to provide a "mini-metro"-transit mode which is smaller (and therefore cheaper) than metro, but which still offers high level of service. If successful, these systems will allow cities with moderate resources (usually medium size) to have high-performance transit systems. Their success depends mostly on how much cheaper they can be than full-size metro.

As medium-capacity systems, AGT has a potential role similar to that of LRT. However, competition of the two modes is not direct, since under similar conditions AGT systems require substantially higher investments than LRT because of their R/W category A and very complex control subsystems (7). Major significance of the AGT mode will be to add another member to the "family of transit modes".

This review of trends in urban transport systems shows that technological and operational innovations of the last 2-3 decades have greatly increased choices which cities have in improving their passenger transportation.

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