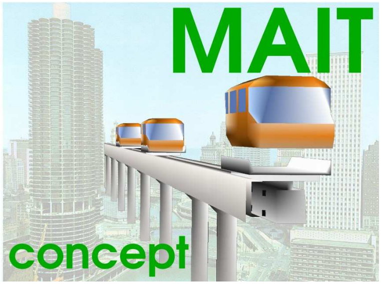
Modular Automated Individual Transport



the concept*

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Abstract

Modular Automated Individual Transport (MAIT) is an innovative ground transportation concept for passenger and light freight that combines the flexibility of the automobile with the advantages of public transport. Applying state of the art computer and control technology, MAIT offers a highly efficient, safer, and environmentally friendly alternative to existing transportation systems. MAIT provides fully automated, 24h, on-demand, non-stop transportation for passengers or freight within *small, public or privately owned vehicles*.

MAIT *is user-friendly*, a trip with MAIT is as easy as the use of an elevator and because no passenger-system interaction is required during the trip MAIT can be used by almost every member of the society.

MAIT *is environmental friendly* because it allows the use of electrical motors. Furthermore, MAIT 's computer system optimizes traffic flow, avoiding polluting and time-consuming congestion. Computers organize also the *reuse of empty vehicles* which leads to a significant reduction of parking space.

MAIT is physically and logistically divided into *three* modular groups: (1) the *cabins*, in which the passengers or freight reside during a trip, (2) *carriers*, which move the cabin on a particular track and (3) the *track* which can be either a guideway (elevated, groundlevel or underground), an ordinary road, or designed with whatever technology is suitable to meet any specific transit need. The idea is that passengers or freight remain in

the same cabin from departure to destination, while the cabin is automatically changing carriers during the trip. Fortunately, track supporting this "container" system can be integrated well within a city's architecture while providing for local transportation needs. Road carriers, which are a low-cost implementation of MAIT in low traffic-density areas (i.e., residential suburbs), can roll cabins slowly and quietly on ordinary roads along induction loops. For longer distances or intercity connections, the cabin gets switched to a high speed and high capacity carrier system, which runs on elevated guideways. In this way a complete MAIT network offers individual, non-stop, *door-to-door transport*.

In addition, MAIT can provide automated home-delivery service. Previously ordered goods are posted by freight-cabins to special "automated parcel boxes" installed beside the track. Similarly, MAIT can optimize manufacturing processes, providing better just-in-time delivery between remote production lines or even directly between distant machine tools.

This illustrative document gives a brief introduction to MAIT and highlights its advantages. It is demonstrated that MAIT is economically attractive for system users and operators. It is further shown, how the flexibility of MAIT allows a smooth transient phase from the present car, road and rail transport to a fully connected MAIT network. It can be guaranteed that during the transient phase, people can freely choose between using their private car or MAIT . In a final stage, MAIT can use a large part of present transport infrastructure like parking space, bus-lanes, tram-lanes and railways.

Therefore, MAIT is seen as an appropriate solution to society's most urgent problems, such as traffic congestion, urban air and noise pollution, land use, limited natural energy resources, medical costs, and an aging society. MAIT can also increase the overall efficiency of industrial production because it perfectly supports the trends in modern manufacturing like flexible and decentralized production, out sourcing, modular sourcing, and down sizing.

Contents

1 What is Modular Automated Individual Transport ?

Modular Automated Individual Transport (MAIT) is a system that provides *individual transportation without a human driver*. Due to its *modular concept*, this system can be adapted to meet a *wider range of transportation needs* than has ever been possible before.

1.1 General characteristics

The core of the MAIT concept is its *integration of various types of individual automated transportation systems* by means of its *modularization* at a minimum of additional costs (see Section 3.2). MAIT can therefore provide the following fundamental features:

- *Fully automated vehicles* capable of operation without human drivers.
- *Small vehicles* available for exclusive use by an individual or a small group, (at maximum 4 adults and two children), traveling together by choice.
- *Small guideways* that can be located elevated, ground-level or underground.
- *Direct origin to destination service*, without a necessity to transfer or stop at intervening stations.
- *On demand service and available 24 hours a day*, eliminating fixed timetables.
- *Door-to-door service*: the modular structure allows cost effective transportation solutions in high *and* low traffic density areas (see Section 1.3).

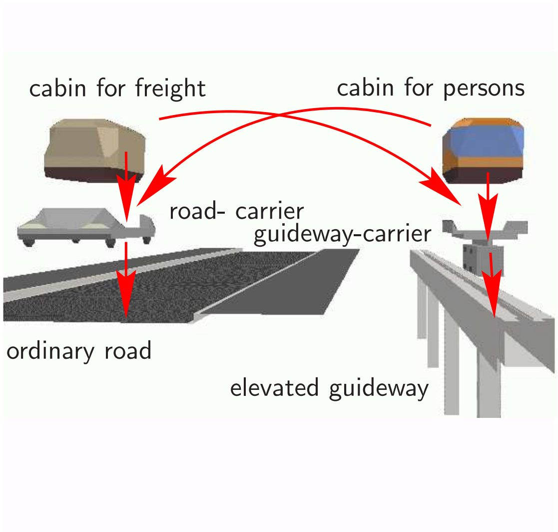
  The economic viability of any new transport system strongly depends on the portion of people that change from their car to this new system [1]. The more the features of the new transportation system resemble the conveniences of the private car, the more people will use it. For economic considerations, see Section 3.2.
- *Automated freight delivery service*: MAIT can automatically deliver light freight (up to a certain size and weight) to customers who install an *automated parcel box* beside the MAIT guideway (see Section 1.4). The system can provide fast, low-cost delivery of goods that have been previously ordered, for example by the Internet. Everyday items could be conveniently delivered and picked up. Automated freight delivery could optimize the just-in-time production in manufacturing [1]. Furthermore, MAIT can have track extensions inside a factory so parts could be routed directly to where they are needed.
- *Unique operation and transport*: MAIT 's implementation of automated transport utilizes a variety of propulsion and guiding techniques (see Section 1.3) but the passengers do not have to be concerned with that; The operation of MAIT is everywhere the same and they stay in the same cabin from departure to destination. See trip examples in Section 2.

A more complete list of possible MAIT services is given in Section 1.4, after the description of some MAIT essentials.

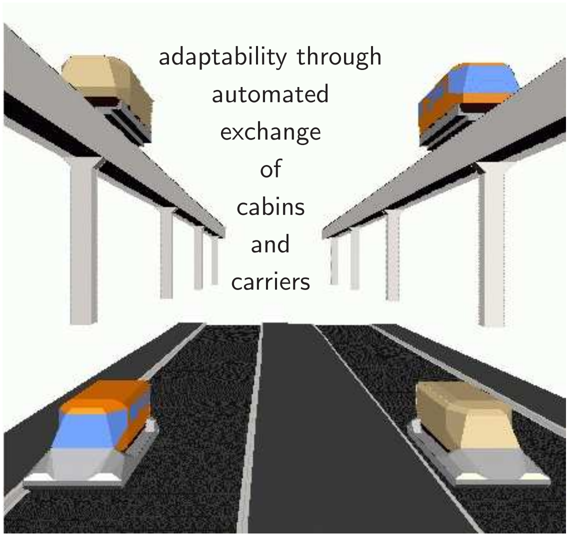
[1] Just in time production means that a supplier produces a subcomponent of a product short before it is needed for the assembly of the final product. In such a way, expensive storage can be reduced. The more efficient and reliable the transport system between supplier and the assembly the fewer storage is required.

1.2 General concept of MAIT: cabins, carriers and tracks

Transportation systems are usually composed of vehicles (the moving parts of the system) and its rails, roads, or guideways (the fixed part of the system). However, the overall performance of an automated transportation network can be considerably higher if a third component is added: the carrier. This is indeed the most significant characteristic of MAIT . The physical and logistic division of *Cabins, Carriers and Tracks* is sketched in Fig. 1:



(a)



(b)

Figure 1: Example to illustrate the modular structure of MAIT . (a) *Cabins*: Cabin for freight (top,left), Cabin for passengers (top, right). *Carriers*: Carrier with specialized wheels for ordinary roads (middle,left), Carrier specialized for elevated guideways (middle,right). *Tracks*: Ordinary street (bottom, left), elevated guideway where the wheels of the carrier roll inside the guideway body (bottom, right). Both cabins on the top can be mounted on all carrier types but the carriers are specialized and can only move on tracks for which they are designed. (b) All possible cabin-carrier-track combinations composed by the example modules shown in (a).

Cabins

A cabin provides the space in which the passengers or freight reside during a trip. They are essentially rigid cases with an aerodynamic shape and are approximately the size of a small van. The cabin dimensions are approximately *3.2 m* length, *1.5 m* height, *1.6 m* width. Depending on their purpose, cabins can be equipped with seats, air conditioning, or configured to carry industrial pallets, small containers or bikes. The empty cabin itself has a weight of *100 kg* to *200 kg*. The total charge (passengers with luggage or freight) should not exceed *500 kg*. Cabins for passenger transport contain a computer terminal to communicate with the MAIT system, an emergency break and emergency button. They can be hooked onto all types of carriers, using a *standardized* mechanical, electrical, and data interface, see Section 4 for more details.

Carrier

The carrier is responsible for the propulsion. There are different types of carriers and each is designed to run on a *specific* track. Carriers can automatically "pick up" cabins, and serve as the "mechanical interface" between cabins and track. The basic components of carriers are:

- A gliding system that allows the carrier to move on the track. A gliding system can consist of either wheels, magnets, or pressurized air that keeps it elevated over the track.
- A guiding system that allows the carrier to move along the track and to diverge into another branch of the network when necessary.
- An engine for propulsion. This is usually an electric motor.
- Braking and other emergency systems.
- An air conditioning system.

Tracks

All fixed components necessary to guide carriers to a desired point of the network are considered *track*. The functional elements of tracks are:

- Uni- or bidirectional guideways or "roadways" that guide and control the carrier.
- Diverges, where one line splits into multiple lines.
- Merges, where multiple lines merge into one line.
- Stops, where people enter and leave the cabins. The platform of all stops are flush with the floor of the cabin.
- Carrier exchangers, where cabins are automatically moved from one carrier type to another.
- Carrier and cabin stores, where unused cabins or carriers are temporarily parked.

A vehicle, the moving part of MAIT , is defined as one cabin attached to one carrier. A MAIT network consists of interconnected track clusters, where each cluster usually employs a different carrier-track technology; one that is well suited to the local transportation requirements. The carriers are designed for a particular track technology and cannot migrate from one cluster to another. For this reason, the various track clusters are connected via *carrier exchangers*. Carrier exchangers are specialized elements of the track, where cabins are automatically unmounted from one carrier type and mounted onto another. Of course, during the carrier exchange, the user or freight remains in the cabin. Clearly, *two* essential processes are automated with MAIT :

- the control of carriers along a desired path on the track.
- the mounting and unmounting of the cabin from one carrier type to another at carrier exchangers.

Using the carriers as "mechanical interfaces", any cabin can run on any track-type in the network, regardless of which technology is being used. The design of the carrier and track can be easily optimized for a *specific* transportation problem. In Section 1.3, examples of carrier-track technologies are proposed to address some typical transportation problems.

Cabins, carriers and tracks are controlled by a vast computer network via digital communication links. A part of this computer network is owned by *user-services*. User-services are the interface between MAIT and the MAIT -user, and guarantee easy operation of the system. Section 1.4 explains the role of user-services in more detail.

1.3 MAIT implementations

Various carrier-track technologies can solve typical transportation problems such as intercity links, inter-urban connections or local traffic. Below, different carrier-track technologies are proposed for the most typical transportation problems. In fact, most of the technologies have already been developed and tested. Finally, an example of a MAIT network based on two different carrier-track systems is analyzed in more detail.

1.3.1 International and intercity links

International and intercity links are characterized by

- long-distance: greater than *50 km*.
- high speed: faster than *200 km/h*.
- simple network topology: few stops, merge or diverge points.

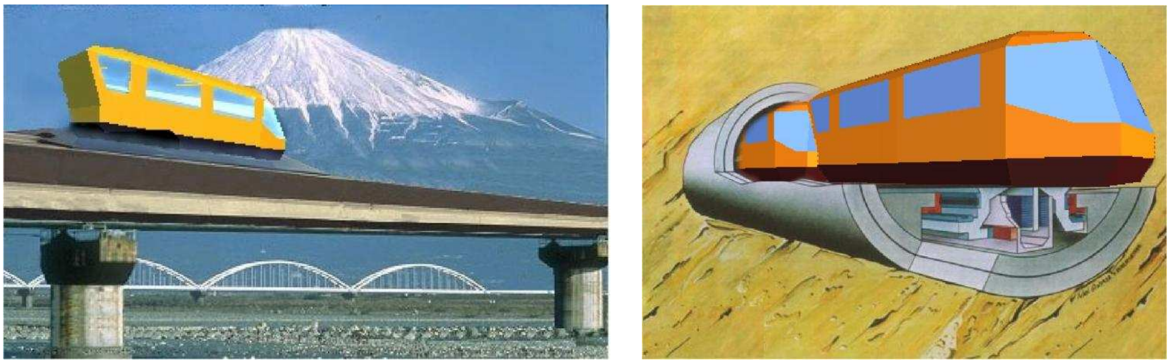
An appropriate technology for these connections might be high speed rails or magnetically levitated (MAGLEV) carriers with linear electric motors running on, above, or under-ground as illustrated in Fig. 2. Large MAGLEV trains for 800 persons, have achieved velocities of more than *500 km/h* [2]. There are even developments that use MAGLEV guideways in underground vacuum tubes [3]. Each vehicle on this track has a constant speed [2]. Vehicles that enter/leave the high speed track get accelerated/decelerated on a separate lane, similar to an entrance or exit of a motorway.

1.3.2 Inter-regional and inter-urban links

Typical characteristics of inter-regional and inter-urban links are

- Travel distances from *5* to *50 km*.
- Line speeds of approximately *60 km/h*.
- Stops, merges or diverge points every *1* to *10 km*.
- High throughput (persons per hour) and little space for guideways in and near city centers.

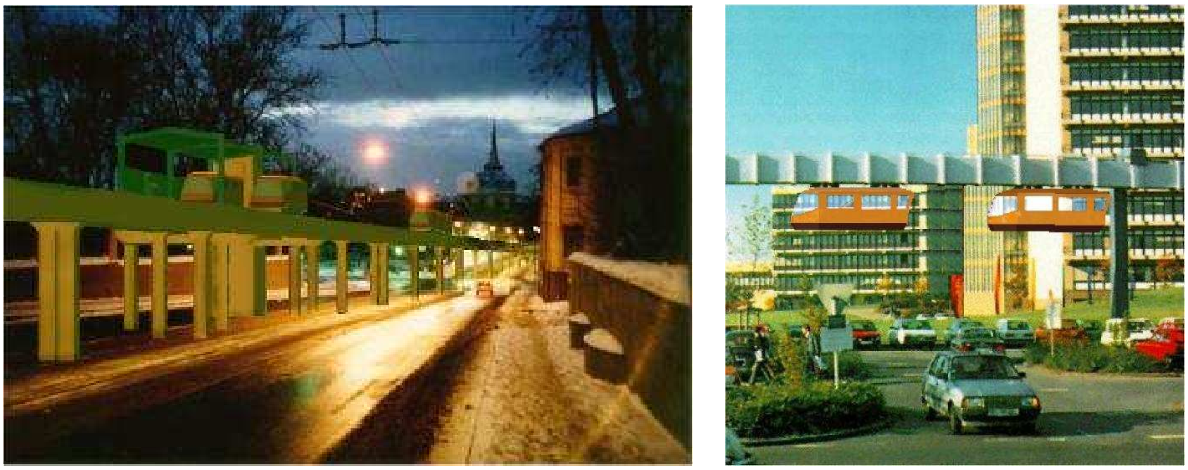
[2] This makes the speed control particularly simple and safe when using linear, synchronous electric motors.



(a) (b)

Figure 2: MAGLEV versions of MAIT . (a) elevated guideways. (b) guideways in underground vacuum tubes (see text).

The track must be designed to minimize visual impact, and to maximize throughput. Various technical solutions have been proposed, developed, and tested over the past *30* years to address this area and almost all of them have incorporated rubber tires and an electric motor for propulsion [4]. There have been developments with supported vehicles [5, 6], as well as suspended vehicles [7, 8]. There are many good reasons for both options. This is why interfaces of the MAIT cabin are designed to work with supported (see Fig. 3(a)) and suspended guideway technologies (see Fig. 3(b)).



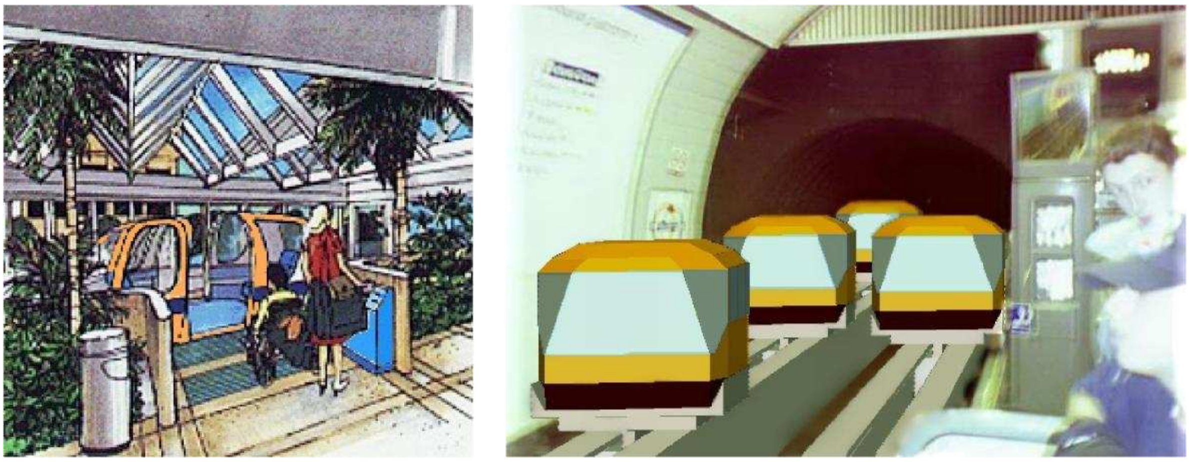
(a) (b)

Figure 3: (a) Example of a supported elevated guideway system with off-line MAIT stop. People can access the stop via elevator. (b) Example of suspended guideway technology.

Vehicle control strategies have been developed to ensure safe travel with very small distances between vehicles at speeds up to *60 km/h* [1, 9]. Reliable electro-mechanical emergency systems have a shorter reaction time than human drivers so they can safely accommodate shorter distances between vehicles than automobiles. A shorter distance between vehicles means more vehicles can pass a point on the guideway in a certain time interval. The system proposed by Anderson et.al. [5] has a maximum line capacity of *10 000 people per hour* which is equivalent to the capacity of a four-lane motorway.

The MAIT stops, where people can access the cabins, are usually *off-line*. This is required to provide non-stop, departure to destination service. On-line stations require that all vehicles approaching the stop either slow down or stop until loading or unloading is completed. MAIT off-line stops on an elevated guideway are shown in Figs. 3(a) and 4(a). The platform of the stop is also elevated and can be accessed by an elevator or escalator.

Most bigger European cities have a dense Metropolitan underground system that could be partly converted to join the MAIT network. One metro line is usually greater than *3 m* wide and can therefore accommodate two parallel MAIT guideways: the first line is used for acceleration/deceleration and off-line stops while the second line is reserved for through traffic. An underground MAIT stop is shown in Fig. 4(b).



(a) (b)

Figure 4: (a) MAIT stop integrated into a building. The floor of the vehicle is, as in all MAIT stops, flush with the floor of the building so wheel chairs (as shown in the picture), child carriages, or shopping carts can easily be rolled into the cabin. (b) Oxford underground station, London, UK, based on a guideway carrier-track system. The left line is reserved for through traffic, the right line for acceleration/deceleration and the off-line stops.

1.3.3 Local traffic

This transport category stands for short distance transport; for example, from a residence to the local shopping center, or to the nearest interregional or intercity MAIT connection. Its characteristics are:

- Travel distances up to *5 km*.
- Maximum speeds of *25 km/h*.
- Short distances between stops, merges, or diverge points.
- High traffic density in city centers, in most European cities also few space.
- Low traffic density in residential and rural areas.

Track for such local traffic must be small and flexible in cities where space is limited yet inexpensive so that it can be cost effective where ridership is lower, such as in rural areas.

The technology for automated vehicles with wheels that can roll on ordinary roads is already availlable [10, 11]. The MAIT road carriers with cabins are illustrated in Fig. 5. The carrier is guided by small induction loops inside the road and its propulsion is performed by a battery driven electric motor. If trips are short and the carrier can frequently enter service points to re-charge, the size and weight of its battery can be kept small.

In busy town centers, road-carriers are able to share the road with pedestrians. In this application the vehicles move at walking speed and a redundant set of sensors ensures that the vehicles slow down and stop if obstacles are in their way. Where there are grade separated lanes available that are inaccessible to pedestrians the vehicles can run at speeds up to *25 km/h*.

(a) (b)

Figure 5: (a) Road-carrier with wheels and tires in Camden, UK. Here, people share the road with MAIT vehicles. Even though it only travels at walking speed the road-carrier must be equipped with infra-red and ultra-sonic sensors to detect obstacles. Slow speeds are not a drawback since the trips with this carrier type are usually short. (b) Road-carrier vehicle is passing by an off-line stop with shelter on a low traffic density street in London.

1.3.4 Example layout of a MAIT network

By means of this example layout one should get an idea on how a complete network may look like when implemented in a real city. This case study considers a possible MAIT network around Victoria station, London, UK. The aim is to replace the present traffic solution with a MAIT system that can handle equivalent capacity. This place has been chosen because the traffic around Victoria station is extremely dense and there is few space in this historically grown quarter of London. The implementation of MAIT is simpler if there is more space between buildings, as it is the case with most America cities.

Victoria station is located in central London and is presently one of the traffic hot spots in England's capital. Victoria station itself is a railway station. The interregional trains leaving from there mainly serve the suburbs of south-west London. Around Victoria station there is a bus terminal for the double-decker London busses, a terminal for inter-city busses, and a London Underground station at the intersection of two metro-lines.

The transformation of the present metro-bus-car-train transportation to a MAIT network has the following features:

- Equivalent or greater throughput of people.

- Greater safety standards as compared to the metro system.
- Standards of service and comfort similar to the automobile.
- Minimization of visual impact.
- Minimization of traffic on the ground level.

Two types of carrier-track technologies are chosen to meet the desired objectives: the road-carrier to provide door-to-door service even in small streets (see Section 1.3.3), and a high capacity guideway-carrier that is handling the main traffic flows (see Section 1.3.2). If necessary, cabins are moved from road- to guideway-carrier, or vice versa, at carrier exchangers as shown in Fig. 6(a).

(a) (b)

Figure 6: (a) Some of the platforms at Victoria Station have been transformed into carrier exchangers. Here, cabins are automatically unmounted from a road carrier (see Section 1.3.3) and mounted onto a guideway carrier (see Section 1.3.2). (b) The faster high-capacity guideway carriers take cabins to more remote, predominantly suburban destinations. After the introduction of MAIT traffic congestion (in grey) below the guideway may be a thing of the past .

A possible MAIT network layout, as shown in Fig 7, has been designed with the following criteria:

- the road carrier system (blue) serves local traffic. A road-carrier stop, which is simply a space on the street that is reserved for one road-carrier vehicle, is placed in front of each door. Longer distance traffic and through traffic use high capacity underground (red), on-ground (green), and elevated (bold green) guideway-carrier systems.
- main installations, including carrier exchangers, are either inside Victoria Station or underground.
- minimized elevated guideway infrastructure. The main part of the guideway-carrier system is either underground and a replacement for the metropolitan lines (see also Fig. 4(b)), or on the surface where the railway runs now. Neighborhoods south east of Victoria Station need to be served by a high capacity bidirectional elevated guideway since they do not have an underground.

- because there is few space on surface level, the road-carrier network is a one-way system so that MAIT occupies just one lane per street with the addition of some off-line stops (see Fig. 5). The width of a road-carrier lane is approximately *1.60 m* so on most streets MAIT leaves room for at least one free lane which can be used for large and heavy loads, for emergency vehicles, or during the transition, automobile traffic.

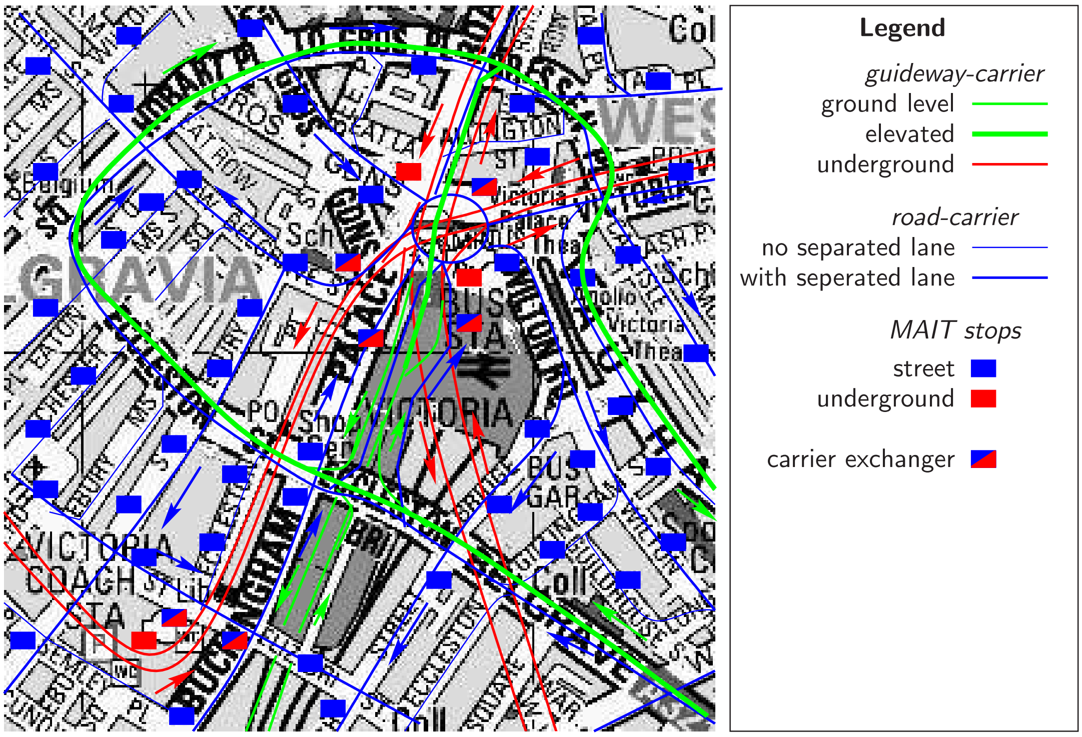


Figure 7: Case study of a MAIT network around Victoria Station, London, UK. Two carrier-track technologies are used to provide a complete car-like transportation service: The road-carrier and the guideway-carrier. The cabins are moved from one type of carrier to another at carrier exchangers.

1.4 MAIT transport services

1.4.1 How to profit of MAIT services ?

If a customer wants MAIT to perform a particular transportation service, they need to contact one of the MAIT *user services*. User services are similar to travel agencies. They take an order from the customer and plan the trip by giving the appropriate instructions to a vast computer network which is controlling the vehicle traffic on the MAIT system. The tasks of user services include: planning, optimal routing, booking, and charging the customer's bank account after the successful completion of the ordered transport service.

Before using MAIT for the first time one needs to get an account with one of the user services. A new passenger or freight customer receives a MAIT card with a user-ID number from the user service. From now on they can order MAIT services through the user service by Internet[3], by phone or from one of the MAIT terminals that are installed near each MAIT stop.

Communicating or making transactions with user services is quite simple:

1. *authentification*: the customer communicates his user-ID by inserting his MAIT card into the slot of a MAIT terminal or by typing the user-ID when ordering via Internet or phone.

2. *transaction*: the user selects the desired destination station of the next trip, one of the option listed in Section 1.4.2, or other services that are offered by the user service. The selection of the action is done via user-friendly, menu driven, graphically supported displays.

Usually the transaction contains the desired destination station of the next trip. The customer may than insert their travel card into the card-slot of an empty MAIT vehicle and enter. Thereafter the vehicle will bring him fully automated, and non stop to the desired destination station. Section 2 gives detailed descriptions of trips with the MAIT system. Below, we sketch a part of the spectrum of possible options and services that MAIT can offer with its modular structure and the concept of user-services. Note that different user-services may offer a different choice of options and services.

1.4.2 Customizing the behavior of MAIT

The customer can significantly influence the overall behavior of MAIT by providing user-services with the appropriate *travel options*. The user may select

- *a default destination:* this will be the destination for each trip unless the customer specifies a different one (see Section 2.1).

- *cabin type:* where possible, user-services will book a cabin of the selected type. Here are some examples of (non-standard) passenger cabin types:

  - cabins with fewer seats but more space for luggage, bikes, e.t.c.
  - cabins with special equipment like phone, computer with Internet-access, baby-seats, e.t.c.

[3] it is anticipated, that most cellular phones have web access.

- *operation:* user-system interaction can be modified. The list below shows that even little features, that are easy to implement, can be of considerable help; in particular for people with limited abilities.
  - *persons with wheel-chairs or with child carriages* the seats fold back automatically when passengers enter the cabin.
  - *visually impaired* all system messages, such as destination station, door closing, *come from loud speakers* in addition to displays or visual signals. Special messages could be added to help improve the journey.
  - *the physically disabled and elderly people,* cabin doors would not close too quickly to allow them extra time.
- *route selection.* One has the option to:
  - select the path that minimizes travel-costs.
  - select the path that minimizes travel-time.
  - select the path with a scenic view.
  - select the path that does not use carriers with suspend cabins (see Fig. 3). This is an option for people with hight sickness.
  - select path that never uses underground lines (see Fig. 4(b)). This is an option for claustrophobic people.
- *language selection:* all system information are displayed or spoken in the selected language.
- *defining alias names for destinations:* the customer can define alias names instead of numbers for frequently used MAIT stops.

All the above mentioned settings can be changed at any time at MAIT terminals, via Internet, by phone, or directly at the offices of MAIT user-services.

1.4.3 Automated freight delivery services

It is apparent that a true automated transport system must be able to transport freight without a human driver. Freight plays an important roll in the MAIT concept: the same carrier can be used to transport people during the day (when mounted with a passenger cabin) and freight during the night (when mounted with a freight cabin), as illustrated in Fig. 8(a). Tracks and carriers are in use during day *and* night which increases the overall efficiency of the system (see Section 3.2).

The essential element of MAIT 's *automated freight delivery* is the *automated parcel box*. The automated parcel box is installed beside MAIT tracks and is automatically filled or emptied by specialized freight cabins.

In order to use the MAIT automated freight delivery service one has to purchase an automated parcel box and install it beside the MAIT track. Goods can be ordered (for example over the Internet) and automatically received by the MAIT network, or one can send parcels to another person or business if they also have an automated parcel box. MAIT vehicles with freight cabins that deliver parcels are shown in Fig. 8(b).

(a) (b)

Figure 8: (a) after peak times in the evening, freight-cabins (shown here in brown color) are loaded on carriers that move passenger-cabins during the day. (b) Automated delivery of goods at night using specialized freight delivery cabins. The freight is inserted into automated parcel boxes (shown in blue) that can be automatically accessed by the freight delivering cabins.

Automated freight delivery service may also play an important role in manufacturing. The flexible structure and small dimensions of the MAIT system allow it to extend into factories. The automated parcel boxes that charge and discharge freight cabins can be designed to serve as input or output queues for machine tools. The output queue of one machine tool can be connected via MAIT with the input queue of another machine tool located in a distant factory. MAIT could therefore optimize just-in-time manufacturing and decentralized production.

2 How to use MAIT ?

MAIT offers a large variety of modes to transport passengers and freight (see Section 1.4). Below the details of passenger transport are explained. Even though the mechanics and control of the system are complex and its form and appearance quite diverse, operation is simple. The user first needs to purchase his personal MAIT card from one of the *MAIT user-services* [4]. The user-service is then the correspondence partner for the MAIT user from the booking on until payment, and subsequently each time he makes use of the MAIT card (see also Section 1.4). Equipped with one's card, the user can travel on MAIT by following the three steps listed below:

Step 1: *Specification of destination and, if desired, travel-options.*

The user identifies themselves by inserting his MAIT card into the MAIT terminal which is located near MAIT stops (see Fig. 9(a)). The destination is then programmed at this terminal. Alternatively, a trip can be specified and booked in advance on any computer via Internet[5]. It is also possible to specify default options (see Section 1.4.2). If the default destination is used **step 1** can be skipped. See the example in Section 2.1.

Step 2: *Entering an available vehicle.*

[4] The MAIT card has some similarities to a bank card. If desired, the functions that are necessary to communicate with the MAIT system can be integrated with other services on one card.

[5] it is anticipated, that most cellular phones have web access.

At the MAIT stop (see Fig 9(a)), the user inserts his MAIT card into a slot beside the door of an available MAIT vehicle. Like taxis, MAIT vehicles are either by chance available at MAIT stops or they can be ordered in advance during **Step 1**. A vehicle signals its availability with a blinking green light beside the door. For visually impaired persons, the door also buzzes. The door of the vehicle opens and the user can take a seat along with accompanying passengers and their bags or shopping chart.

Inside the cabin, a display shows the destination of the present trip. The doors close after a moment and the voyage begins. The user has the option to interrupt travel at *any* time by pushing the "interrupt" button. For example, if the displayed destination station is not the correct one then the user presses the interrupt" button. In this case the vehicle stops at the next MAIT stop. The user has also the possibility to reselect a destination by means of the user terminal inside the cabin.

Step 3: *Leaving the MAIT -vehicle.*

After arriving at the destination station, the user vacates the vehicle. The door closes after the vehicle is empty and the user takes back his MAIT card from the slot.

This is generally how MAIT is operated. Following are some examples of MAIT trips.

2.1 Case 1: simple trip

On a straightforward ride with MAIT , a passengers get on an unbooked available MAIT vehicle and travel to their destination. This example trip begins at a MAIT stop at the main entrance of a down-town shopping center and the destination is a road-carrier stop in front of the passenger's home in a more sparsely populated residential suburb. A high speed, high capacity guideway, as presented in Section 1.3.2, will take the user out of town. The guideway network, however, does not reach each house in the residential neighborhood so, the cabin, including passenger, is moved from the guideway-carrier to a road-carrier with wheels as shown in Fig. 5. This new carrier then brings the passengers via ordinary roads to their destination.

Three steps are required for the user to make an entire MAIT trip as explained at the beginning of Section 2. Here again are these three user-steps only they are now applied to the present case-study:

Step 1: The user proceeds to the MAIT stop shown in Fig. 9(a). It is an off-line stop on an elevated guideway-track system. An elevator moves passengers up to the platform where empty vehicles are waiting. On the platform the user has two choices.

- *The user chooses the default destination*: in this case, the user can pass directly to **Step 2**. The user has the option to set or change this default destination at any time at a MAIT terminal, via Internet, by phone, or through offices of their user-service. The MAIT vehicle will always take the user to the default destination unless another destination is explicitly specified.
- *The user wants to choose a destination different from the default destination*. In this case he inserts the MAIT card into the MAIT terminal which is right on the platform (see Fig 9(a)). The terminal prompts for the number that corresponds with the new destination stop. The user inserts the stop-number and takes back his card.

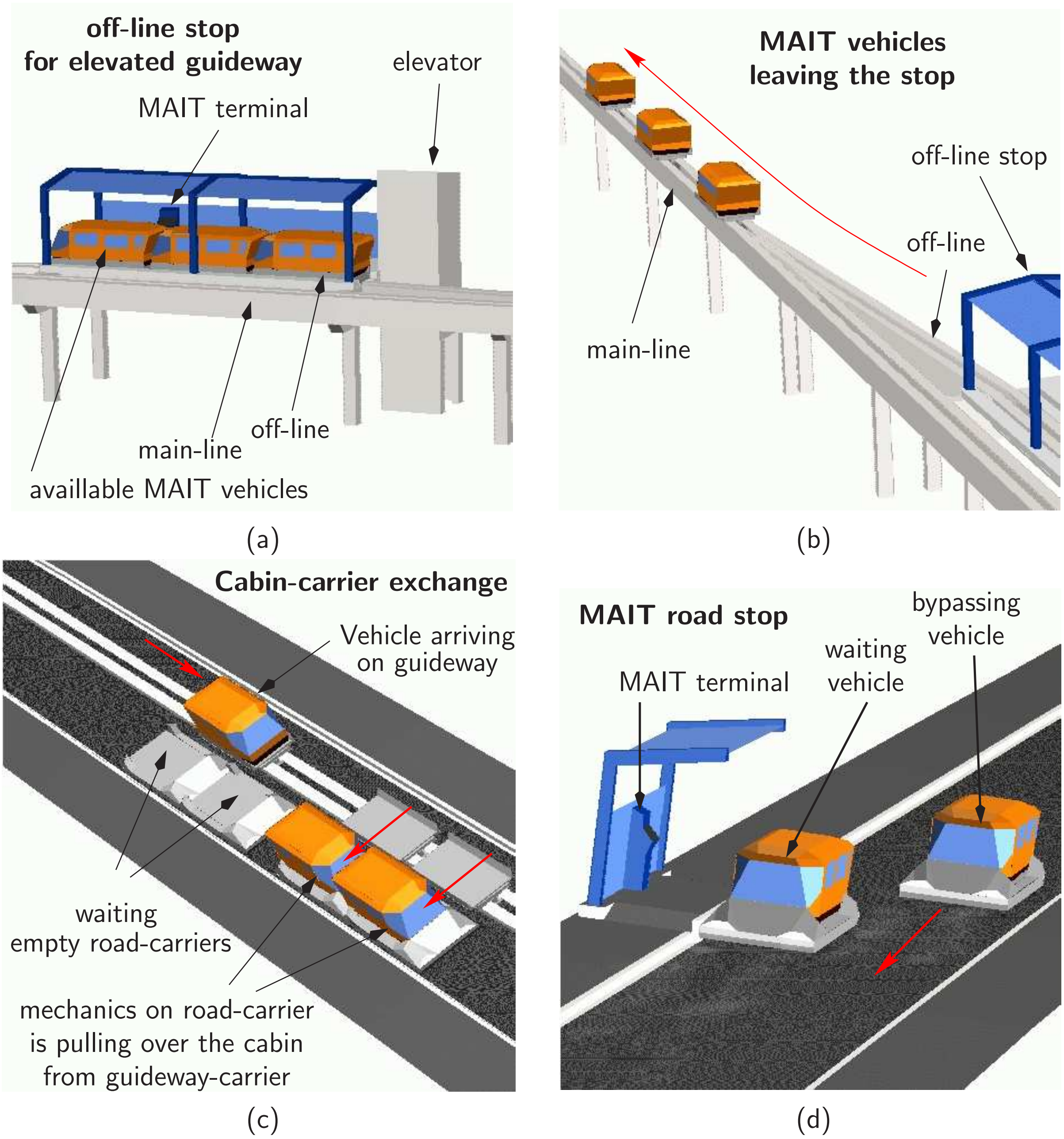


Figure 9: Case 1: a simple trip with MAIT : (a) the trip starts at a MAIT off-line stop on an elevated guideway. The platform is accessed by an elevator. A MAIT terminal is available on the platform to program a destination stop. At this stop there is space for a maximum of three vehicles. (b) The three vehicles are leaving in block-configuration similar to a metro. If there is low demand, vehicles can leave one at a time. (c) Carrier exchange. Empty road-carriers are waiting to be loaded with cabins from guideway-carriers. (d) Cabin arrives at an off-line MAIT stop on a road carrier. For details see text.

Step 2: The user checks which one of the waiting vehicles (see Fig. 9(a)) is available. Cabins signal their availability with buzzing, and a blinking green light just beside the door, close to the slot for the MAIT card. Usually the first empty vehicle in the queue of waiting vehicles is signaling its availability. Inserting the card into the slot of the available vehicle opens the door to the cabin and the passenger can now take a seat. Passengers may also travel in small groups and as many passengers can enter the cabin as there are seats (usually 5). Co-passengers do not pay extra, just like with taxis.

The destination station is displayed on a terminal *inside* the vehicle. At this point, the doors are still open and the user can choose to leave the cabin and take back his travel card from the slot. After a moment, the cabin attempts to close the door. The doors can be kept open or reopened by pressing the "open door" button which is placed inside the cabin beside the door. This is similar to the operation of an elevator

Since the station shown in Fig. 9(a) is situated in a busy city center, MAIT will wait until all three vehicles are occupied with people. Then all vehicles will start moving simultaneously, leaving the station in block formation as illustrated in Fig. 9(b). This behavior has proved to be most efficient in terms of traffic throughput [4]. During off-peak times the first occupied vehicle in the queue will start as soon as the doors have been closed.

The vehicle moves along the guideway towards the destination and during the trip no further user-system interaction is required. However, the user *always* has the option to press the "interrupt" button, in which case the vehicle will stop at the next MAIT -stop.

As mentioned above, we assume that the trip will end in a residential neighborhood and that the guideway-carrier will need to be exchanged for a road-carrier. The carrier exchange is illustrated in Figs.9(c). The guideway-carrier with cabin rolls beside an empty road-carrier and stops there. The cabin is then moved sideways from the guideway-carrier onto the road-carrier [6]. After the exchange, the road-carrier brings the user to his final destination and the now empty guideway-carrier begins searching for another cabin to be transported. The carrier exchange process is fully automated so passengers remain in the cabin during the exchanges.

Step 3: After arrival at the destination station the door opens and all passengers exit the cabin with their bags. The user takes back the travel card from the slot outside the cabin, the door closes, and the empty vehicle moves ahead. After removal of the MAIT card from the slot, the user-service determines the total cost of the trip and bills the bank account associated with the travel card.

2.2 Case 2: a booked trip

Both passenger and freight MAIT vehicles can be reserved in advance. There are two advantages to booking MAIT vehicles:

- vehicles are ready when needed.
- passengers receive a discount for reserving in advance. When the MAIT computer network is given information in advance it can better predict demand, allocate resources, and distribute empty vehicles. The consequence of this increased system efficiency is higher mean-usage of vehicles and thus lower overall operating costs which, in turn, results in lower prices for the user. Similar cost structures exist in airline ticketing.

[6] the mechanism for the cabin-movement can be either a part of the track or the carrier.

Case-study 2 describes a booked MAIT trip from a passenger's home address in one residential area (subsequently called "Home") to a friends place (subsequently called "Joe") in another residential area which is located at the opposite side of the city. The stop-names "Home" and "Joe" are user-defined and can be selected instead of the number of the corresponding destination stop because names are easier to remember. The focus of Case-study 2 is on the booking process. As in Case 1 the three user-steps are described in detail:

Step 1: The user proceeds to either a MAIT -terminal or a computer connected to the Internet. In both cases the user connects to his user-service. The user identifies himself either by inserting a MAIT card into the MAIT terminal or by entering his user-ID in the computer. The user can then determine how many, and which type of cabins, should be at which MAIT stop at what time and with what destination. In this case the user orders an ordinary cabin to be at stop "Home" at 9:00am, destined for stop "Joe".

Not all MAIT stops can be booked in advance such as the stop in Case 1 (Fig. 9(a)) which is a busy station downtown with a high throughput. There, a booked vehicle waiting for the user would block other cabins. In general only off-line stations, that have spaces for single vehicles, can be booked. A typical bookable stop is shown in Fig. 9(d).

Step 2: At 9:00 the booked vehicle is waiting at stop "Home". A small display beside the door indicates the user-ID of the costumer who booked this vehicle. The user approaches the vehicle; inserts his MAIT card; the vehicles door opens, and the user enters. If a different user wants to access the booked vehicle its door will not open. If the user does not arrive at 9:00, the vehicle will wait. After a certain time, which can also be specified by the booking, the vehicle will leave the stop without its passenger. The users pay a price for each booking, whether they actually take the ride or not. As far as the user-system interaction goes, the trip will be identical to the one described in Case 1 from now on: the destination station "Joe" is displayed on a terminal *inside* the vehicle, the doors close after a moment and the vehicle starts moving.

As mentioned above, the trip in Case 2 begins in a residential area so the cabin starts on a road-carrier and later exchanges for a faster guideway-carrier, as sketched in Fig 9(c), but in reverse order. Since stop "Joe" is also located in a residential area, the cabin will need to change again. This time from the guideway-carrier to the road-carrier as shown in Fig 9(c).

Step 3: After arriving at the destination station the door opens and the user exits the cabin. He then takes back the travel card from the slot outside the cabin.

From the operational point of view the trips in Case 1 and Case 2 are identical, except for the preprogramming of destination and travel options during **Step 1**. The available options, such as the type or number of cabins, and the way they are selected during **Step 1** depends on the user-service.

3 Why Modular Automated Individual Transport ?

For more than a 100 years the rail&road transport has not changed principally—only extended, and improved considerably. What will now change things dramatically is computer and information technology. In the past, the human driver has been the only alternative for operating vehicles but nowadays computers can perform, and take over, many operational tasks. Computer systems have become cheaper, smaller and more powerful so decentralized control-structures are now a reality in many industrial processes, and may soon be possible in traffic systems. A computer can be installed in each vehicle to make intelligent decisions—humans are no longer required to do this job. It is possible that through decentralized control and automation, transport systems could be significantly changed from what we know today. Numerical studies summarize the potential benefits of an automated transport system installed in a city [12]:

- 24 hour availability.
- Reduction in average trip time by a factor of more than two.
- Reduction of infrastructure costs by a factor of six.
- Reduction in energy usage by a factor of ten.
- Reductions by a factor of ten in emissions compared with peak hour car traffic.
- Fare levels comparable to current public transport.
- Car parks and streets made over for people.
- Injury and death on the road significantly reduced.
- Accessible to at least 75% of disabled or elderly people.
- Better quality of life for both users and non-users.
- Capital costs between one sixth and one twelfth the cost of roads due to small scale infrastructure.

Below are more details on how and why MAIT positively effects every day lives, the economy, the environment, and land use.

3.1 Public advantages

Who is profiting and how with respect to present transport systems?

Everybody (MAIT users and non-users)

- Lower risk of injuries and casualties. The primary cause of accidents, human failure, is minimized by MAIT ; as well, accidents due to system failure can be reduced to almost zero with proper system design.
- Valuable land (especially the inner city) previously required by transit systems is now available for other uses because MAIT requires *less* space for guideways and other installations than a road with the same throughput of cars (see Sections 1.3.2 and 3.3). Large amounts of parking space inside the city is no longer needed since empty MAIT vehicles are reused and unused vehicles are redirected to an out-of-town storage facility.
- Better air quality and less noise pollution. MAIT vehicles are electrically driven, contain no local emissions, and are almost silent.

(a) (b)

Figure 10: MAIT leaves more space for people: A parking lot in a residential area will be obsolete after the introduction of MAIT because unused vehicles are automatically brought to an out of town storage area. (a) Before and (b) after the introduction of MAIT .

All MAIT users

- Stress-free, convenient, individual, 24 hour, non-stop, door-to-door transport. For a detailed descriptions of MAIT trips see Section 2, for travel options see Section 1.4.2.
- Travel on MAIT is faster: A computer network optimizes traffic flow and prevents traffic jams. There are usually no intermediate stops at traffic lights. MAIT is demand responsive and does not have to run on fixed time schedules. The waiting time for a MAIT vehicle is only up to few minutes if none is already available, where needed. There are no waiting times for transfers since all trips are non-stop.
- Travel time is not wasted. Considering the passenger does not drive, their time during the journey can be used for other purposes. Furthermore, one can book cabins with completely equipped with office equipment or Internet connection (see Section 1.4.2).

Accessible to people off all ages and abilities

MAIT is easy and safe to use (see Section 2), does not require a human driver, and is therefore available to most people who are not able to or should not drive a car. Baggage can be easily transported because the floor of the cabin is flush with the platforms at the MAIT stops, and it remains in the same cabin during the entire trip. Furthermore, MAIT supports people with various needs (see Section 1.4.2).

Persons and families with low income

MAIT also offers personal transport to people with lower incomes, who cannot afford to buy and maintain a private car, or who may need access to jobs outside cities where increasingly more companies are finding it to be economically attractive to locate. Those industrial sites are, in general, badly served by public transport, whereas MAIT may be operated economically, even in more sparsely populated areas that are fat off the city center.

People without access to individual transport find it hard to shop at the large discount commercial centers and malls, which are placed far outside downtown, and are often difficult to reach by public transport. Fortunately, shopping malls and other activity centers will likely be the first places linked by a MAIT network.

MAIT will give low-income families access to destinations that currently cannot be reached by public transport at lower cost, because ownership of the vehicle is not required, and the price of MAIT is based on the *distance* the vehicle traveled and *not* on the number of persons inside.

3.2 Economical benefits

If MAIT is to have a successful introduction, it must prove to be economically attractive to potential investors and users. Of course the exact installation, operation, and maintenance costs will vary depending on many factors such as traffic-density patterns, network topology, system technology as well as decisions of potential costumers, landowners and officials. A preliminary and general cost comparison of MAIT and the car-road system indicates that MAIT might be at least as cost effective as the car-road system, and could, at the same time, offer a broader range of services (see Section 1.4).

Infrastructure costs

Due to the modular structure of MAIT (see Section 1.2), the applied transport technology and associated infrastructure may be appropriately designed according to the local traffic density. For the MAIT road-carrier system (see Section 1.3.3), an ordinary road with small induction loops inside would be sufficient to guide and communicate with the vehicles so the costs of this MAIT infrastructure would be almost identical to the road system used by cars. Road-carriers would usually use lanes of already existing roads, which can be equipped with induction loops and the necessary navigation system at relatively low costs.

The costs for one lane of a high capacity carrier-track system (see Section 1.3.2) are expected to be *lower* than for a 3-4 lane (one direction) motorway with the same capacity, due to the following reasons:

- One MAIT guideway can achieve a higher throughput (persons per hour) than a one lane motorway (see Section 1.3.2).
- Motorways are built for cars *and* trucks even though trucks make a smaller contribution to total traffic than cars. MAIT guideways are designed for vehicles of only one to two tons [7] and the lighter construction has cost advantages. In many cases the load of one heavy trucks can be distributed over a larger number of MAIT freight cabins.
- MAIT network may be designed for a smaller capacity than a road system that is covering the same area. Freight can be predominantly delivered during the night, (see Section 1.4.3), which leads to better distribution of traffic over the 24 h and leaves the system open for passenger transport during peak times.

MAIT causes also *additional infrastructure costs* in form of carrier exchangers, which sometimes necessitate larger waiting queues for empty carriers (see Section 1.2 and Figs. 6(a), 9(c)). However, these costs may be kept small on the account of:

[7] The vehicle weight depends considerably on the weight of the carrier. The cabin alone weights approximately *200 kg* plus a maximum charge of *500 kg*

- carrier exchangers constitute only singular points in a MAIT network, where tracks with different technologies are interconnected. It is further the aim of the MAIT network design to minimize the number of carrier exchangers. The costs of carrier exchangers may therefore be small compared to the costs of the entire network.

- the necessary system to move the cabin from one carrier to another is simple and small since the cabins are of "light weight". The actual mechanics for the carrier exchange may be located on the cabin or carrier itself. See also Section 4.

Vehicle costs

A MAIT vehicle consists of a cabin plus a carrier, and is approximately the size of a small van. All components of a MAIT vehicle are mass produced.

MAIT carriers are driven with electric motors. They are incomplex and lighter since the speed of the electric motors is controlled by inexpensive electronic circuits; there is no heavy transmissions. On the other hand, MAIT carriers do need an additional system for automatic exchanging of the cabins. In the end, the total cost of the vehicle (carrier+cabin) is expected to be about that of a larger family car or a small van. However,

- the usage and costs of MAIT vehicles are *shared*, empty vehicles will automatically search for new customers.

- the same carrier can transport passenger cabins during the day and freight cabins at night.

Therefore the cost of the entire vehicle fleet of MAIT may be *reduced considerably* compared with the costs of cars and trucks with an equivalent transport capacity.

Unfortunately, the assumption that one cabin is always mounted on one carrier is an idealization. In reality, a certain number of *empty* carriers are needed to wait for cabins at carrier exchangers (see Fig. 9)(c)). This "carrier buffer" is required so that a cabin does not have to wait for an empty carrier at the carrier exchanger. The total of empty carriers in a network is called the *carrier overhead*, and if the network is properly designed, the carrier overhead can be minimized so that the cost of these additional carriers is not significant compared to the total cost of all carriers.

Operating & maintenance costs

MAIT is fully automated and works 24 h a day. Low travel costs, similar or below the tariffs of public transport, efficient vehicle management, and overnight freight delivery are expected to guarantee a high attraction and usage rate for the system. The energy consumption of a MAIT vehicle per kilometer is less than that of a car as electrical motors are more energy efficient than combustion engines. In addition, electric motors have a longer life time and need less maintenance. The organization and guidance of vehicles, as well as the exchange of carriers, add no labor costs, except for maintenance. The cleaning of vehicles and standard system checks are expected to be at least partially automated. The operator's employees deal mostly with user-services and maintenance such as:

- consulting.

- programming and vending of MAIT cards.

- providing costumer customer service.
- repairing, cleaning and maintaining vehicles and track.
- deploying trouble shooting crews, consisting of technically qualified people who can rapidly resolve such difficulties as computer breakdowns or when a defective vehicle blocks a guideway.
- surveillance and security. MAIT stops and parts of the tracks are camera supervised. Security units need to take action if needed.

Competition

The *modular structure* of MAIT does not only mean flexibility in technology and service, it enables marked competition on multiple levels. First, there is competition for the manufacturing of each module of MAIT (cabin, carrier, track, computer network). Second, there is competition for the best service. The MAIT network is easily separable into track-clusters, where each cluster may be owned by a *different* operator. Even in the same region, multiple and overlapping track-clusters, possibly implemented with different carrier-track technologies, can compete for the best transportation service. Other companies own fleets of cabins, or carriers, or they provide the management of user services. Such a multilevel competition may lead to a diversification of services at the lowest possible prices. It further prevents monopolistic structures since all interface definitions and communication protocols (see Section 4) are public and therefore known to potential competitors. Hence, the organization of the MAIT network could become similar to the one of the Internet.

Scalability

The MAIT network needs have a certain initial coverage in order to be acceptable and usable for a reasonable quantity of people, i.e. it has to link at least all important activity centers and residential areas of a city. But beyond this "threshold-size", MAIT is highly *scalable*, which means that investments can be well matched to an increasing user demand. Scalability is an important quantity during the start-up phase of MAIT (see also Section 5) since it lowers the risk because capital can be invested in smaller portions and returns an immediate profit.

The reason for the high scalability of MAIT is that, once a skeleton network with a sufficient capacity is implemented, the it needs to be only *refined* in order to reach more residences of users. The costs for this refinement are mainly determined by two factors:

1. the costs for a road-carrier track. It is assumed that the road-carrier system is the carrier technology that predominantly accesses homes and serves as feeder for the high capacity tracks via carrier exchanger.
2. the costs for an extended fleet of cabins and carriers.

Both costs can be well adapted to the number of potential users. Dependent on the city and average vehicle usage, 10 m of road-carrier track and one additional vehicle may allow *four* more potential customers to use the MAIT network. Because the road-carrier technology is considered inexpensive the extra cost per additional user is expected to be low.

3.3 Environmental benefits

Widespread implementation of MAIT could help to *reduce* the present waste of energy, land, and other natural resources, on a large scale:

- MAIT vehicles are usually driven by electric motors which have a higher energy efficiency than fuel engines [8] The use of electric motors is possible as a result of powered guideways, similar to electrified railways. Electrical or fuel-cell battery powered carriers are also possible because they can be programmed to automatically access a charging station when their batteries run low. Carriers would only make short trips when using their batteries (see Section 1.3.3).
- The traffic flow is controlled and optimized by a computer network to avoid energy wasting stop and go traffic, searching for parking space e.t.c.
- Vehicles are usually shared which reduces the total amount of material (i.e. to built the vehicles) and land needed (i.e. parking) by the MAIT network when compared to the private car system.
- MAIT is designed for passengers and small freight, so the scale of its infrastructure is smaller than today's highways. At present highways, and railroads are designed for both passenger *and* freight transport, therefore their infrastructure has to be sized to handle heavy loads. If transport tasks were shared so that passengers and light freight used MAIT and heavy freight was delivered predominantly by rail, then considerably less infrastructural resources would be required. The railway network would have more available capacity for heavy freight since it would not be concerned with passenger service.
- When high capacity is needed, *one* MAIT guideway can achieve a higher throughput (*persons per hour*) than a *four* lane motorway (see Section 1.3.2). This means for the *same* capacity, MAIT requires *less* infrastructure.
- Transporting people during the day and freight at night helps to better distribute traffic. Less materials, energy, and land is needed for vehicle and guideway construction (see also Section 1.4.3).
- the use of electric motors has an indirect gain: their life-time is longer than combustion engines and less material and energy is required for their manufacture and maintenance. Some carrier-track technologies, like MAGLEV (see Section 1.3.1), have low friction, very few mechanical components, and therefore very long life-times.

3.4 Improvements in architecture

MAIT can enhance the architecture of a city:

[8] Modern electric motors convert electrical to mechanical energy with an efficiency of more than 90%. The electrical energy in power plants is generated with an efficiency of approximately 35% for oil and coal, and 42% for gas as primary energy resource. Therefore the total efficiency of electric motors is at least 30% which is higher than the efficiency of any available fuel engine today (using oil as primary energy resource). If the cooling system of the power plant were used to heat buildings or water, their efficiency could rise up to %95 as it is the case for the power plant in Vienna. Moreover, the emission filter systems of power plants retain usually a higher portion of toxic ingredients than the one of automobiles which results in a lower air pollution

- The total number of installations devoted to traffic in general *decreases* with the introduction of MAIT (see Section 3.3). The newly gained space opens up a large spectrum of design options to city planners and architects.

- The MAIT concept makes no restrictions on how the cabins are transported, so the carrier-track system can be integrated well with the architecture of any city.

The installation of MAIT guideways (in particular *elevated* guideways) are often subject to criticism because they are seen as a visual intrusion. However, for a fair comparison one should look at transport infrastructure *before* and *after* the introduction of MAIT . A considerable number of roads, parking lots, and bridges will disappear once car-road transport has been shifted to MAIT (see Figs. 11 and 12).

(a) (b)

Figure 11: (a) Typical four-lane street in the city center. (b) After the introduction of MAIT three lanes were unnecessary. An elevated guideway has been installed along the building of a shopping center. Off-line stops reside within the buildings (see for example Fig. 4(a)) so that passengers are already in the store after exiting the vehicle. One lane of the previous road has been kept for heavy freight transport, fire protection vehicles, and other extraordinary services.

(a)

(b)

Figure 12: A six lane motorway has been replaced by a bidirectional elevated guideway-carrier system. During the transitional phase two lanes have been preserved for heavy or special transport. In the future long-distance freight will be handled by railroads which will have increased capacity because passengers will be riding on MAIT . (a) Before and (b) after the introduction of MAIT .

There are several different strategies for *integrating* MAIT into the city environment:

- *minimization of visual impact:*
  - construction of underground guideways.
  - MAIT stops, carrier exchangers, merge and diverge points inside buildings, for example, in unused railway stations, or inside shopping centers .
  - minimization of guideway size.
- *adaption of guideways to city architecture*: i.e., choice of technology, materials, and guideway design.
- *secondary uses for guideways*: elevated guideways can be used as roofs for pedestrian walkways, bike paths, street markets, street cafes, galleries e.t.c. [9] A city with streets that are protected from rain and sun is more welcoming to both visitors and inhabitants.

Some of these strategies have been applied in the case study presented in Section 1.3.4.

4 Defining the standards

The standardization plays an important role in the structure and design of the MAIT system because

- cabins must be able to be mounted on different types of carriers.
- customers must be able to communicate with their user-service (see Section 1.4), always in the same manner and from any point of the MAIT network, independent of the local carrier-track implementation.
- the network-traffic (organization, redirection of cabins and carriers, the allocation of track capacity, e.t.c) needs to be independent of the carrier-track technology.
- Safety and reliability standards for the entire network.

Obviously, the above features require a high degree of standardization. On the other hand, it should be aimed at finding a *minimum set of necessary standards* in order to leave the largest possible space for design-creativity of the carrier-track technology. Such a minimum set of standards will include:

1. *Cabin properties:* the cabin need to meet some general standards such as
   - Maximum allowed Cabin dimensions (Maximum length and maximum cross section).
   - Maximum allowed weight.
   - Stability. The cabin must be able to withstand a certain impact and air pressure difference between the inside and outside of the cabin.

[9] Note that unidirectional MAIT guideways have a width of only *1.50 m* and are comparable in size to larger pedestrian walkways or "sky-ways".

2. *Cabin-carrier interface:* this is the most important interface since it guarantees that cabins can be hooked onto different carrier types. It is the (only) part that puts additional weight to the MAIT vehicle, compared with a vehicle that is specialized for a unique carrier-track technology. It is therefore necessary, that this interface is designed with care, aiming at a simple, light and inexpensive construction that is universal and reliable. Since the cabin has only a maximum weight of approximately *700 kg* (including persons or freight), it is reasonable to assume that the entire cabin-carrier exchange system can be realized with only few additional system components. Hence, all the cabin-carrier links listed below, are able to disconnect and reconnect each time the cabin changes to another carrier.

    - carrier exchange system. This is the electro-mechanical system that allows a cabin to lock and unlock with a carrier and to move from one carrier to another.
    - power supply connector. The power for the cabin is provided by the carrier, even though there is also a small emergency battery inside each cabin.
    - communication interface. This is the link for the exchange of general purpose information from carrier to cabin and vice versa.
    - air conditioning interface. The warm and cool air is generated by the carrier and piped into the cabin. The passenger can than regulate temperature by opening and closing the warm or cool air stream.
    - interface for auxiliary signals. These are signals, representing information that concern only cabin and carrier, for example if the cabin has locked with the carrier, if the cabin's door is open or closed, if the carrier or cabin is in an emergency state e.t.c.

3. *Cabin-user interface:* all sub-systems that concern the cabin-user interaction (see Section 2) must be identical for all cabins that allow person transport, such as

    - the location of the slot for the travel card, the light that indicates availability of the vehicle and the display that indicates the user name or ID (in the case of a booked cabin, see Section 2.2).
    - the user-terminal inside the cabin, that allows the user to interact with his user-service and to obtain information about the voyage (see below for specifications of MAIT terminals).

4. *Safety of carrier-track technology :* It is difficult to ensure safety by imposing system requirements for a broad variety of carrier-track technologies. The safety should be indirectly defined by:

    - the *extreme emergency case* such that the worst possible system failure results only in light injuries. Severe injuries, caused by the system itself, should be physically impossible.
    - probability of the occurrence of an extreme emergency case. All certified carrier-track technologies need to demonstrate with realistic test runs, that the probability of the extreme emergency case scenario is below set limits.

5. *MAIT terminals:* All MAIT terminals that are installed at MAIT stops (see Fig. 9) and inside the person-cabins should have the same look, in particular:
   - the instructions, written on the terminals should be the same.
   - the display needs to be of a certain size and have a minimum graphic resolution.
   - the keypad should always have the same relative position to the display.
   - for MAIT terminals at stops, the slot for the MAIT travel card should also have the same relative position to the display.
6. *Communication protocols:* The format of all protocols in the form of digital data that are exchanged between the MAIT modules i.e. MAIT terminals, user services, computer network, cabins, carriers and tracks need to be of an open standard, that means they are public.

The above are all system components that *need* to be standardized for MAIT , although it is highly recommended to standardize also other parts of the system. A well set-up framework of standards may help to ensure reliability and safety, to keep prices down and monopolies out of business.

5 Implementing MAIT

Even though the modular structure of MAIT leaves always space for new inventions, the basic technologies required for building a MAIT system have already been developed [13]. The innovative aspect of MAIT is the combination and synthesis of control technology (used for robotics or aviation), networking logistics (used for organizing data packages on the Internet), and conventional mechanical, electrical, and civil engineering.

Nevertheless, the development and deployment of a complete network, covering an entire nation or continent, is no doubt a huge task. Over the past 30 years, many projects have failed to install an automated individual transport system in cities, even though the technology has been available. Most projects have not been continued due to unfavorable political decisions [14], or funding, or unfavorable media. Therefore, the management of each newly launched project needs to be aware of these dangers.

Besides political and financial problems there are also some practical problems. During the transition from the present transport systems to MAIT , road traffic, tram, metros and trains need to coexist with MAIT until the MAIT network has sufficient coverage. This transition may take several decades since entire industry branches must emerge or change their product lines, employees must be trained, land must be acquired, e.t.c. Below, one possible strategy on how MAIT may be introduce is outlined, taking into account the previously mentioned problems.

Phase I: the software project

During phase I, a comprehensive *simulation software* should be developed that allows detailed static and dynamic analyses of a MAIT network, including failure behavior, emergency situations and cost analyses. It should be easy to use, such that city-planners or other interested persons are able to design a MAIT network based on a real city or region. The aim of this simulation software is:

- to demonstrate *feasibility*, *performance*, *reliability*, *safety* and *economical attraction* of MAIT by a possible large number of example networks. The *visual impact* can be shown, using 3D visualization software.

- to involve a variety of institutes and experts in alternative transport in the development process. In this way development costs and work can be shared and MAIT becomes known academic circles and interest groups. Experts from industry may be involved as consultants for technical feasibility studies.

- to provide a platform for further system (hardware) development, test and documentation. The software gives a clear idea of how the system physically appears and describes precise specifications for its technical components, which is important for further development.

- to convince city planners and potential hardware developers and suppliers.

The project may be conducted by different educational institutes or associations. The software development requires a broad spectrum of skills, such as computer science, logistics, telematic, mechanical-, electrical-, control-, communication- and civil-engineering, aerodynamics, industrial design and city-architecture. A modular structure of algorithms and data splits up the programming tasks, offering a wide range of interesting research-, interdisciplinary- or student-projects. All software, including the source code should be, at least initially, free such that all interested programmers can contribute to the project. The costs for computer hardware, if not already available, should not be a major problem since computer prices are constantly falling. High quality system and development software are in most cases freely available.

Phase II: the test project

In the second phase of the MAIT introduction a *1:1* test network should be built. Its total size may be small, but its complexity, in terms of number of diverges, merges and stops should be as high as possible in order to mimic a real network of a city. The aims are:

- to demonstrate the *feasibility*, *performance* and *economical attraction* of a real MAIT network.

- to establish safety standards for such a system.

- to involve as many companies in the development process as possible. In this way, development costs and work can be shared and MAIT becomes known in industry.

- to provide a nucleus from which a larger MAIT network can grow.

- to convince operators, investors, public, and in particular politicians or other decision makers of the MAIT concept. Efficient media work and publicity campaigns are of major importance *after* the test track operates successfully.

The test-track should be built on private ground and serve initially as a flexible on-demand light weight freight transportation system, possibly within a larger industrial complex. In this way, there is an immediate profit and many legislative hurdles can be avoided. As soon as the system proves to be safe, it can be opened to personal transport. For example, to get employees from the parking to their working place.

The project may be conducted by a consortium of all companies, who contribute to the test track. The modular structure of MAIT eases the distribution of the development task and investments on many suppliers. *Small and medium size companies* have the chance to bring in their specialized knowledge or to contribute with smaller system components. Their incentive is to be among the first suppliers on the market in the time that MAIT is operational. The specifications for subcomponents have been found with the help of the preceding software project, which also ensures that the different components are compatible with each other.

Phase III: the extension project

After the MAIT test track is successfully running for some time, the test network may be extended into the third phase. The extension should include main traffic lines but also local door-to-door traffic. The aims are:

- to demonstrate that MAIT works profitably in public use. It should further prove that the advantages listed in Section 3 are reality.
- to convince more operators to invest in MAIT and provide an example for other cities.

This project will already be organized and financed by either private or public MAIT operators who expect it to run profitably. An independent institution verifies that all MAIT components confirm to the MAIT standards (see Section 4). Nevertheless, Phase III needs the agreement of local politicians. The city has many good reasons to support the implementation of MAIT :

- the problems could be solved and the city may become more appealing to people (see Sections 3.1 and 3.4)
- in most cities, public transport is not profitable. If the city converted the public transport gradually to MAIT , either as operator or by selling a part of its properties to private operators, it could gain from transport instead of spending money in this sector.
- further tax money can be saved since cleaning and restoration of public buildings and monuments needs to be done less frequently due to zero gas pollution by traffic inside the city.
- the implementation of MAIT would create many job opportunities, especially for the local building industry.
- an industrial cite, equipped with a MAIT network, offers an efficient transport between all resident companies and to all costumers that are connected as well (see Section 1.4.3). Such an attractive environment may convince more companies to locate in, which is usually in conformity with the interests of a city.

However, it is a crucial point that the *public accepts* MAIT as a new and superior mean of transport and tolerates also minor inconveniences during its implementation. Apart from publicity campaigns it is of major importance that people with new access to MAIT can immediately profit. If this is not the case, negative propaganda will spread that can prevent a further expansion of the MAIT network or end the implementation of MAIT as a whole. On the other hand, should the first MAIT users, perceive the advantages of this new transportation system, more people may want to profit of it. It is of great importance that car drivers are not forced to use MAIT . Ideally, people should have the choice between taking their car and getting into a MAIT vehicle that is waiting front of their door-steps. A period of coexistence between MAIT and automobile makes problems, in particular in historically grown city centers. The following strategies may allow to develop the MAIT network towards a coexistence of both transport systems:

1. first the city should connect the city's main activity centers with a carrier-track technology that has a high capacity and *does not interfere* with the car traffic. This can be achieved either by the elevated or underground version of the guideway proposed in Section 1.3.2 or by the grade-separated road carrier, described in Section 1.3.3. If necessary, bus-lanes, tram or metro-lines need to be converted to MAIT tracks. At this moment MAIT takes over the task of public transport.

2. Next, park& ride places should be organized at the major arterial roads, where people who enter the city have the possibility to leave their cars and transfer to MAIT . As compensation, parking space in the city center can be shortened in favor of an expanding MAIT network. Until this point the inner town car traffic has not been disturbed, except for some construction sites.

3. the MAIT network is refined by providing door-to-door access even to small streets, using the road carrier system (Section 1.3.3). The road-carrier track can be implemented rapidly since it suffices to install navigation equipment inside and beside an already existing road. Additional fences or grades are required if the MAIT vehicles should be separated from the ground level traffic. As soon as a street is equipped with road-carrier stops in front of each door, its inhabitants have instantly access to all activity centers of the city. People who decide to install an *automated parcel box* in front of their homes can profit additionally from MAIT 's home delivery service (see Section 1.4.3). It is now required to reorganize the traffic on ground level in order to make homes accessible by MAIT *and* by car:

    - Bidirectional street-systems can be converted into one-way systems, where one lane is reserved for MAIT vehicles. All homes are still accessible by cars but the route may change.
    - Street-parking places can be converted to MAIT lanes. The idea is that residents leave their car, as usual, in their garage or on private parking places. Visitors coming from outside can park their cars at one of the out- of-town park&ride places and transfer to MAIT if their destination is already connected to the MAIT network.
    - As an increasing number of people uses MAIT , the traffic density decreases and additional lanes, previously required for cars, can be reserved for MAIT transport or for other purposes, as proposed in Section 3.4.

All these actions can of course, be problematic, since it requires the agreement of many administrative sectors. Resistance can be expected from people who are affected by these changes. Flexible agreements with the MAIT operators may help to guarantee and accelerate a smooth transient phase. For example, people who work in public transport will have the possibility to pass a free trainee program and to start working for a MAIT operator or supplier (see also Section 6).

The completion

If the MAIT system proves to hold the high expectations for one city and solve one of its major problems of traffic congestion, other cities may become interested and follow the example. In a last step, the cities are connected by a high speed MAIT network as for example the one presented in Section 1.3.1, and then finally the suburbs and the surrounding countryside.

Obviously, this difficult step needs the support of politics at least on the national level. However, it is hoped, that at this stage the experience of running MAIT networks, the simulation software and the pressure from media, cities, user- and interest groups are sufficient to gain the necessary political support. Furthermore, MAIT promises in short term, an innovative, fast growing industry sector with many job opportunities. On the other hand there may be an international competition: since the efficiency of an industrial production of a country depends heavily on the efficiency of its transport infrastructure, the first country who introduces a MAIT network will have an economic advantage over those which hesitate.

6 MAIT and the rest of the world

A national or international MAIT network has the potential to have a positive influence on society, the economy and the environment. The direct benefits of MAIT are straightforward and have been discussed in previous sections but there are many *secondary* benefits, depending on how well MAIT is introduced by industry, politicians and city planners, and accepted by the public.

The look of cities and suburbs will change significantly. Life in the streets will be safer; the air will be cleaner; there will be more space for people and less for roads. There will be more greens-space, more pedestrian walkways, more public places for people to meet and for children to play. A more attractive central core makes a city more appealing for both residents and visitors.

Food and dry goods can be delivered directly to private homes from stores where orders are submitted electronically. Stores that have to be driven to, and shopped in, will become less attractive. Not only the vending and distribution of goods becomes simpler, but also the collection of used items can be organized more efficiently. This may render the recycling industry more viable.

MAIT will optimize distribution of parts and supplies for just-in-time production; productions that required previously huge factories, can now be decentralized into smaller units. Depending on the type of production, cites could allow such smaller factories to locate in, or close to, residential neighborhoods so their employees can work much closer to home and traffic during peak hours is significantly reduced since people spend less time driving and traffic congestion is reduced to almost zero. Railroads will transport far fewer people but they'll carry more large and heavy-freight.

7 Conclusions

MAIT is a *new* transport concept that offers a *higher quality of service* (see Section 1.4) than the private car at a *lower price* (see Section 3.2) and with a *lower environmental impact* (see Section 3.3). Due to its fully automated operation and flexible modular structure (see Section 1.2) a *larger part of society* can benefit from this type of stress-free, individual door-to-door transport as well as the automated freight delivery services it provides (see Section 1.4.3). The automated freight delivery may also positively influence the efficiency of future industrial production (see Section 6).

A consequent modularization of automated transportation systems opens new perspectives for its *development and deployment*. *Synergy effects* can be exploited because modules, software and components that are common to all automated transportation systems, independent of their implementation-technology, can be developed once for all projects. This applies in particular for simulation, control, logistic software and development work. Even development costs can easily be distributed (see Section 1.3). The *interfaces are open* and institutes, industry and privates can contribute with software, designs, network-layout, system components e.t.c. In Section 5, a comprehensive *simulation software package* has been proposed as a *starting point* and *development platform*, since it allows to analyze the performance of arbitrary complex MAIT networks, maybe enough to convince sponsors to invest money for a test track. It would further be an integrating element for all automated transportation projects that follow a different technological solution. Networks for certain traffic scenarios could be designed, compared and analyzed, using one, or several guideway technologies that are linked together via carrier exchangers (see Section 1.2). In a later development step, the simulation package can furnish detailed system specifications, documentation and software to test system components separately. After the realization of a MAIT network, parts of the software package might still be in use, representing the "nervous system" of MAIT that lives in a vast computer network and organizes and optimizes the network's traffic flows.

MAIT is open to future technologies. Transport systems, using *newly developed technologies* can be linked to an already existing MAIT network; the user does not even need to change vehicles while transferring from the old to the new part of MAIT . For example, advances in super-conductor technology may drop the prices for generating magnetic fields which would lead to a new low cost MAGLEV guideway (See section 1.3.1).

The main additional expense of the proposed modular structure is the separation of the cabin (containing persons or freight) from the rest of the transportation system by an interface that allows the automatic transfer of the cabin from one carrier type to another. In Section 4, it has been claimed that this interface can be realized with only a few extra components, since the cabin is not a "heavy weight", and other additional infrastructure, such as carrier exchangers, may not contribute substantially to the total network costs. Furthermore, the broader service due to the modularity may increase the usage of the system and therefore, the return of the invested capital (see Section 3.2). The higher logistic complexity of a modular system requires essentially more computer hardware and more sophisticated software. Both items are not expected to increase system costs significantly.

Summing up the *benefits* and *costs* of MAIT , it is apparent that with little more investment (due to the modularization), the service and efficiency of the transport system can be significantly improved. This leads to a *higher acceptance* by the user, since they can see *automated transport as a real transportation alternative for the future*, covering *all* transportation needs (with the exception of heavy and large freight) at a *low price*. MAIT helps to avoid redundant development work and supports a decentralization of efforts and costs, which may facilitate its introduction. Thus, different automated transport projects in different places using different technologies can develop and grow independently until, one day in the far future, they are linked together to create the *World Wide* MAIT !

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