Tampere University of Technology 2005

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INTRODUCTION
FOREWORD

Congestion at road and street network, air quality problems in urban areas and sustainable transport strategies have encouraged to develop innovative travel modes providing alternatives to the private car use. Personal rapid transit (PRT) systems offer possibility to travel in a public transport system, and yet embody many of the convenient features of private car. These innovative transport systems are at the moment developed in many countries.

In Finland TechVilla Ltd in co-operation with its partners has developed the concept of Automated People and Goods Movers (APGM). The background of the development work is leaning on elevator technology and thus differs to some extent technologically from other PRT concepts under development. APGM is at the moment approaching a prototype phase and therefore further information of its feasibility in different kinds of urban areas is needed.

The purpose of this study has been to assess the feasibility of the APGM system in densely built urban areas in Tampere. The principal case study area is the suburb of Hervanta, where the planned APGM network connects the Technology Centre, University campus and residential areas to the local centre of Hervanta. In addition, the Tampere University Hospital area has served as a supplementary case study area.

This feasibility study of the APGM system has been conducted at the Tampere University of Technology (TUT) in co-ordination with the Institute of Urban Planning and Design and the Institute of Transportation Engineering.

The study has been financed by National Technology Agency of Finland (Tekes), Hervanta EU Programme, Hyvinkää TechVilla Ltd and its partner companies. The project has been guided by a collaboration group having participants from the financing parties, City of Tampere, Tampere City Transport, Tampere Science Parks, Technology Centre Hermia, Pirkanmaa Hospital District and the Institute of Hydraulics and Automation of TUT.
“Transport is part of life in its own right”
“Movement should be a pleasure” François Ascher
Introduction

NEW URBANITY

Half a decade after the second millennium, we are well aware of the new urban around us and new urbanity we are living. After a couple of decades’ discussion about fragmentation and dissolution of urban form, there is a mutual understanding of a new polycentric and mobile city. The characteristics of this city are:

- physical form is extensive, discontinuous, heterogeneous and multi-centred
- mobility is increasing and creating transformations in the physical structure
- people, information and goods are transported and stored in overlapping and interpenetrating networks and scales
- new social forms are born, there is increasing individual control of people’s own space and time, people choose individual means of transport and portable objects of communication and media.
- simultaneous local differentiation/diversification and global homogenisation

In latest descriptions of new urbanity, a lot of significance is put on the mobility and flows of the urban system (Oswald & Baccini 2003). As François Ascher points out, the shape of the city and the functional and social organisation of urban spaces interact with the techniques how people, goods and information are transported and stored. Transport and storage methods are both the consequence of urban dynamics and condition for those dynamics (Ascher 2003). In our new urbanity these transport and storage methods are under transformation all the time.

INDIVIDUALITY AND MOBILITY

Along increasing mobility new urban situations and topologies are born. Simultaneous processes of homogenisation and differentiation are creating and resulting in new desires and needs, new means and products. In order to achieve a maximum, people and organisations use every opportunity to extend their mobility. The result is a mobile, telecommunicating city, finding a new balance in transportation of people, information and goods (Ascher 2004).

Life within the new urban form is characterised by increasing individualism and social differentiation. People want to have more freedom to choose and more control over their use of time and space (Ascher 2003). These choices are made in overlapping consumer networks which consist of both mass-consumerism based on global-wide trends and super-differentiated personal life-styles.

Within this variety of choices, mobility is not the only, but the key feature of accessibility to these networks. The more mobile people are, the more choices they have. At the same time, mobility is also an important
element in the construction and expression of each individual’s personality. (Ascher 2003)

The new polycentricity of cities consist of new locations of floating centralities and specialised nodes that have been born outside existing residential and service nodes. These new centres of commerce and leisure are located along the ring-roads and other peripheral locations that have good accessibility for private car drivers. Other locations of new differentiated leisure activities can have different peripheral locations, even with difficult accessibility. But as they are based on special needs of mobile customers, their locations can be highly diversified.

In addition, people have new preferences for choosing residential areas on out-fringes of cities. These areas are mostly of low-density single-family houses. Together with the travel demand between mass-centres and specialised activities, these peripheral locations of housing create a mobile society and a network of locations and activities, which are increasingly based on private car use.

People have different possibilities in how to connect into these networks. However, everybody has a right to mobility, right to choose their own space-time composition. It can be also said that the quality and efficiency of the city is based on the ability to offer alternatives and possibilities for mobility (Ascher 2003).

Individuality has also increased the popularity of private car in the mode choice. The share of public transport has in the long run decreased notably. Travelling by public transport includes parts which are not familiar to the private modes - e.g. waiting time and possibly transfer time to other public mode. These parts are usually conceived as additional strains
connected to a public transport trip. Private car has turned out to be especially competitive in the leisure travel, which is a fast increasing part of the daily travel needs. On leisure trips the destination and time vary according to the individual choices and preferences more than in other trip groups. Consequently public transport has difficulties to compete with the private modes on leisure trips.

As Francois Ascher says, in this new complex urban (Ascher calls it metropolis) there is a great need for new forms of transport and for more individual, door-to-door type connections indeed. APGM is one answer to this urgent demand. It is a new link into multi-modality, by offering an on-demand personal vehicle. Thus automatic people mover can offer a mode between private and public mode. It can e.g. connect people to nearest centre, from which a rapid public transport connection may take them further. With on-demand services APGM can provide short wait and transfer times, and thus better level of service compared to the timetable based public transport.

The specific characteristics of APGM create new places of movement, new urbanity and new identity. Therefore it is particularly important that planning, design and implementation of new facilities are sensitive to their environment, and create an additional exiting architectural element.

**INTERMODALITY**

The future of automated transport systems is systems is most likely a non-restricted access to the road network, without the guiding travelway. Despite of this fact, there are some important aspects that support also the idea of separate travelways – and the whole APGM concept indeed.

In Europe, the road network is in its central parts threatened to be paralysed by increasing congestion. The road network is already transporting 44 % of all goods and 79 % of all passengers. The amount of traffic is still expected to increase as the European Union and its economic area are enlarged – and because the private car will furthermore be the dominating mode of private mobility. Problems concerning traffic safety, emissions and sustainability are well-known. But also costs of the congestion are remarkable composing almost 0,5 % of the whole European GNP and expected to increase to 80 billion euros per year until 2010. (European Commission 2001.)
Recommendations how to avoid congestion are several. They concern logistical innovations and co-operation, transport pricing, support of short distance shipping and building better transport infrastructure (European Commission 2001). In addition to these measures, also the improvement of intermodality between transport systems is one notable solution. Intermodality in freight transportation has been promoted with a number of concrete initials on European level during recent years. In the wake of freight transport, questions of intermodal passenger transport has also raised on the agenda. (Towards Passenger Intermodality 2004) Flexible and seamless intermodality is one possible way to promote balancing the uneven division between different travel modes.

Definition of the intermodality is that it provides passengers a chance to use different modes of transport in a combined trip chain with a seamless journey (Towards Passenger Intermodality 2004). Within a long-distance inter-city trip chains there are several points of seams to be filled. Automated systems that are well integrated to the public transportation system and most important nodes of the urban structure are the possible complements. In the door-to-door and on-the-demand operation APGM system is a possible complementary link.
1.2. APGM SYSTEM

WHAT IS APGM?

APGM (Automated People and Goods Mover) is a driverless transportation system providing on-demand transport services for individual travel needs. APGM system consists of an interconnected area-wide network of tube-formed elevated travelways with off-line stations that permit fully automated vehicles to provide a direct non-stop origin-to-destination service. The APGM network system operates under fully automatic electronic control. Vehicle control principle is asynchronous and propulsion is produced by electric motors.

APGM SERVICE

APGM system offers rapid, affordable, personal, non-stop travel on demand. At each station, there are several ticket machines including a route map where to define travel destination. After paying the fare the system allows an entrance to station and to vehicle, which automatically recognizes the defined destination. The fare can be paid by a public transport smart card or by mobile phone. The vehicle can also be reserved in advance by mobile phone.

Each station is equipped with a different amount of free vehicles, depending on the passenger demand. Waiting time for a vehicle is zero in off-peak periods and generally at most 1 - 2 minutes in peak periods. One vehicle is always reserved for one passenger or group of passengers similar to taxi services. The trip is made to destination without any intermediate stops.

APGM can also be used in delivering goods between stations. User reserves a vehicle in the station or in advance by mobile phone, chooses destination and pays the fare. After loading the vehicle the goods are transported to the destination station, where the vehicle can be opened by a safety code transmitted by mobile phone.

APGM TRAVELWAY

The APGM travelways are to be set approx. 5 metres above ground level in order avoid crossing with ground-level vehicle traffic and pedestrian walkways. Elevated travelways increase the safety qualities and enables higher travel speed when intersections are not needed and system is independent of possible congestion at the street network. In situations where the site topography or traffic conditions are propitious, the travelway can be built also on the ground level – or any needed height to meet the required conditions. Travelway can also be integrated to buildings.

Because of the Finnish weather conditions, the travelway is a covered and forms a continuous tube construction. It consists of 1- and 2-way sections, where tube construction and supporting pillars are made of prefabricated modular system parts. The travelway temperature is heated in wintertime and cooled to prevent overheating in summer.

As the travelway system will be a highly visible new infrastructural element in urban landscape, the recommended travelway design is as light and transparent as possible. The structure has been outlined to consist
of mostly steel and glass, where different combinations of transparency and closed parts can alternate according to the needs of the urban environment. A good quality of the travelway design and implementation is a necessary factor in all environments where the system is built. The feasibility of different travelway types is evaluated in chapter 2.

**APGM VEHICLES**

The APGM vehicle is a car-like lightweight rubber wheeled vehicle for 4 passengers seated abreast and opposite on individual seats. In cases when fully seated, there is still room for carry large items (luggage, wheelchair or bicycle) on board. Vehicle consists of a chassis and a cabin for carrying both passengers and propulsion and guidance equipments etc. systems necessary for operating the system. The vehicle is approx. 3,1 m long, 1,5 m high and 1,6 m wide.

The power is supplied to the vehicle by electric brushes which are mounted under the vehicle, collecting electric power from rails running along the driving line. For the navigation of the vehicle a special wireless data transfer system is used between the vehicle and the system controller computer.

The cabin contains a monitor for passenger information, communication with system controller and also possibility for advertising. The cabin is equipped with safety belts and air-bags – as well as automatic climate controlled air-conditioning and heating.
APGM vehicle in varying colors and themes

Visions of the APGM travelway
APGM STATIONS

Due to the character in-between public and private transportation, the location of stations can have different variations. They can be built on private property or on public transport areas – or they can be built along the main travelway or along separating routes. Also, they can be built as stand alone stops or as integrated stations next to or within buildings. In addition, the size of stations can vary from small stops to large stations which are depot areas for multiple vehicles, depending on the travel demand. All stations are closed areas, indoor designs and part of the travelway construction.

Like the travelway, the stations are also elevated above the street level. Thus all stations are to be designed to provide full accessibility to all passengers - the elderly, disabled, prams, etc. - without requiring any additional facilities. Each station is also an information centre with route maps and real-time travel information.

Similarly to travelways, stations and stops are space-demanding new urban elements, which need to be carefully designed in different kinds of contexts. The architecture of stations is more closely presented and assessed in chapter 2.

1.3 OBJECTIVE AND METHOD OF APGM FEASIBILITY STUDY

The objective of this feasibility study was to investigate how the APGM system can be adapted as an internal public transport system in the case study area of Hervanta suburb. The focus of the study has been on the connections between the busiest areas - the connections between the local centre of Hervanta, the Tampere University of Technology and the Technology Centre Hermia. In addition, another purpose of the study was to examine the applicability of APGM as a feeding public transport connection from local residential, working and campus nodes to the main bus or light rail routes to Tampere City centre.

The feasibility of the implementation alternatives of APGM were studied in Hervanta and complemented with examples from the second case study area of TAYS (University Hospital of Tampere). Thus the feasibility of APGM system was assessed and tested on more general level.

The study was implemented as a co-operation of two institutes at the Tampere University of Technology (TUT): Institute of Urban Planning and Design (IUPD) and Institute of Transportation Engineering (ITE). The research work consisted of following areas:
IUPD:
- placing travelways in varying topography
- placing travelways on traffic areas or within built structure
- assessment of functional and aesthetic obstacles caused by travelways, their support structures and stations
- assessment of architectural image related to travelways, their support structures and stations
- integrating stations to buildings in ground and first floor
- discussion of detailed land-use planning and land-use easement procedures
- assessment of aesthetic impacts

ITE:
- planning of APGM route network and station locations in the viewpoint of passenger demand
- planning of the APGM transport operations (timetable / dial-a-ride) and service periods
- assessment of the preferences for information and ticketing systems
- assessment of passenger demand
- assessment of capacity and vehicle demand
- planning of the connection to pedestrian network, public transport routes and parking areas
- assessment of impacts on modal split
- assessment of environmental impacts
- assessment of operating costs and income

RESEARCH METHOD

NETWORK ANALYSIS

The APGM network was drawn as a hypothetic traffic network according to urban morphology based on GIS-data of population, workplaces, services and traffic network. The network was later composed in a public transport assignment model VIPS/3, and tested in the Tampere regional traffic model (TALLI 2000) in order to be able to evaluate the travel time between demand points and the accessibility and travel time in different network alternatives.

APGM network is connected to the transport system through stations, parking arrangements, and connections to pedestrian areas. In the location of stations the walking distance to destination has an important role, because the walking time to the stop is in the public transport system perceived to be 2 - 3 times longer than the riding time in the public transport vehicle. Connections to the transport system are essentially important, because an APGM ride would in Hervanta primarily be part of a longer trip chain.

FUNCTIONAL AND AESTHETIC ASSESSMENT WITH 3D-MODEL

Based on network analysis, the selected part of APGM network was modelled in photo-real 3D-model imitating the real urban conditions and landscapes. The assessment of aesthetic and functional properties
of APGM system was made on the basis of this model where different situations of placing the travelway were tested and movement of vehicles was animated.

**ASSESSMENT OF PASSENGER DEMAND**

The forecast of the APGM passenger demand has been made by using the Tampere regional traffic model, which describes the daily travel behaviour in the Tampere Region. The effects of different factors like travel time, costs, information services and security and safety issues have been assessed partly with the traffic model and partly with the help of focus group interviews of potential passengers.

Both institutes (IUPD and ITE) took part in the design and planning of the APGM network. The aesthetic and functional analysis of travelway, supporting structure and stations were made by IUPD. The planning of the connections to the transport system and the assessment of passenger demand was conducted at ITE.

**FORMULATION OF RESULTS**

Different situations of Hervanta and TAYS case studies are typologised and then collected as a matrix that can be used as test system when estimating the feasibility of APGM system in similar urban contexts. This matrix is presented and each studied viewpoint is elaborated in chapter 2. Results and future perspectives are concluded in chapter 3.

### 1.4 CASE STUDY AREAS

Figure 1.1. Case Study areas
SUBURB OF HERVANTA

The district of Hervanta is located approximately 10 km south of Tampere city centre (Figure 1.1). Hervanta is the largest distinct suburb of the city of Tampere with almost 25 000 inhabitants and 8 300 work places. Planning of the suburb area begun in 1965 and the first inhabitants moved to Hervanta in 1973. (Kultalahti 2003)

In Hervanta the average age is to some extent lower than in the city of Tampere on the average. The share of under 15 years old inhabitants is 15 % and the share of over 65 years old inhabitants 10 %. Around 8 % of population the inhabitants are immigrants. (Kultalahti 2003)

The suburb of Hervanta has during the years transformed from suburb into a technopolis area without significant changes in the townscape. Hervanta has an enlarging technology centre and a large university campus area. Connections between technology centre and residential areas have remained narrow and are in need of active development. The elements of Technopolis-Hervanta - technology centre, university, development stages, traditional industry and housing - should be more closely connected together.

In the Technology Centre Hermia there are approximately 100 000 m² business premises providing working environment for around 150 companies or organisations. In Hermia there is near 3 500 work places. In the Tampere University of Technology (TUT) there is approximately 1 800 employees and 10 000 students. Technology Centre Hermia and TUT are situated in proximity to each other. The distance to the local centre of Hervanta is from the University campus 1 km and from Hermia 1,5 km.

Hervanta is connected to city centre and other northern districts by an arterial four lane street (Hervannan valtaväylä). There is also road connection westwards to Helsinki motorway. Hervannan valtaväylä is one
of the busiest streets in Tampere with more than 30 000 vehicles per average day. Eastern by-pass road of Tampere passes Hervanta in north with an amount of 22 000 - 27 000 vehicles daily (Figure 1.2). The travel time from Hervanta to city centre is by car normally approximately 15 minutes. There is modest congestion in Hervannan valtaväylä during the morning and afternoon peak hour. (Kalenoja and Hintikka 2005).

The public transport services to Hervanta are based on four bus routes to city centre and one transverse route between two hospital areas of Tampere. Also a light rail connection to city centre has been planned during the last decade. An average travel time by bus from bus stop to bus stop between Hervanta and city centre is normally 25 minutes.

Travel behaviour in the Hervanta district is somewhat different from the behaviour in Tampere on the average. The inhabitants of Hervanta do 46 % of their trips by car, 34 % by walking or by bicycle and 19 % by public transport. The car share is in Tampere on the average almost 50 % and public transport share 17 %. In Hervanta the car density is lower and households have more seldom two cars than in Tampere in general. (Kalenoja 2005)

**TAMPERE UNIVERSITY HOSPITAL AREA**

The Tampere University Hospital (TAYS) is situated 2 km west from the city centre of Tampere near the arterial road leading eastwards (Figure 1.2). The university hospital area is a large health care complex with more than 4 000 work places and 800 bed places for patients. In addition there are extensive out-patient departments in the central hospital area. There is also a separate hospital for joint replacement (Coxa) in the hospital area.

The hospital area is an important trip production and attraction area. The number of annual work trips to the area is approximately 436 000. Annually almost 345 000 patients, 183 000 escorts of patients, 47 000 business related visitors and 97 000 visitors of patients visits the hospital area. The personnel of the University Hospital do annually around 500 000 internal trips between different buildings inside the hospital area. As the hospital area is relatively large and scattered, patents and visitors have
often difficulties in locating the correct destination. (Säily 2004)

Beneath the hospital area there is healthcare and biotechnology research centre Finn-Medi and a planned enlargement of the research centre (Finn-Medi Park). In the same area there is also the Faculty of Medicine of the Tampere University and activities of Tampere University of Technology. The area composes relatively large science park concentrating on biotechnology, health care technology and medical technology. At present there is more than 200 000 square metres floor area in the hospital area (Table 1.1). During the forthcoming decades the building area has been estimated to increase by almost 50%.

Table 1.1 The floor area in Tampere University Hospital area in 2004 and a forecast for the years 2010 and 2020. (Kalenoja and Hintikka 2005a)

<table>
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<tr>
<th>Location</th>
<th>in 2004 floor area (m²)</th>
<th>change in 2004 - 2010 floor area (m²)</th>
<th>change in 2010 - 2020 floor area (m²)</th>
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<tr>
<td>Tampere University Hospital</td>
<td>106 000</td>
<td>+ 35 000</td>
<td>+ 30 000</td>
</tr>
<tr>
<td>Research Centre Finn-Medi</td>
<td>46 000</td>
<td>+ 20 000</td>
<td>+ 20 000</td>
</tr>
<tr>
<td>Research Centre Finn-Medi Park</td>
<td>4 000</td>
<td>+ 40 000</td>
<td>+ 55 000</td>
</tr>
<tr>
<td>Tampere Polytechnic and Pirkanmaa Polytechnic</td>
<td>52 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Tampere</td>
<td>8 000</td>
<td></td>
<td>+ 2 000</td>
</tr>
<tr>
<td>other activities</td>
<td>3 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>altogether</td>
<td>219 400</td>
<td>+ 95 000</td>
<td>+ 107 000</td>
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In addition, two Polytechnic units are situated in the hospital area. In Tampere Polytechnic and in Pirkanmaa Polytechnic there are altogether 5 000 students within the University Hospital area. In the University Hospital, Finn-Medi, Tampere University and Polytechnic units there are altogether almost 10 000 work places.
There are at present relatively large congestion and parking problems at the University Hospital area. Although the area is rather congested, private car is the most common mode as the daily work trip mode. Employees of the University Hospital use relatively often also public transport or walk their work trip. Figure 1.3 presents the modal split on the work trips to the University Hospital during winter and during other seasons. Altogether 41 - 48 % of the work trips are made by car and 14 - 17 % by public transport.

The daily amount of vehicles arriving in the area is 9 500, of which approximately 200 vehicles are lorries or vans. There are altogether 2 800 parking places in the area, which are partly reserved for employees. On the internal service roads there is comparatively much traffic due the internal passenger and goods traffic. Internal goods transport is primarily based on van transports along the service roads and forklift transports along the underground access tunnels. Most important goods transport groups in the area are food, laundry and waste. (Säily 2004, Kalenoja and Hintikka 2005a)

Public transport connections along the Teiskontie are relatively good, but on there is only one bus route entering the Hospital area. The distance to the Teiskontie bus stop is from University Hospital 200 - 300 metres, from Finn-Medi area 400 metres and from Tampere Polytechnic 100 - 200 metres.
1.5 APGM NETWORK IN CASE AREAS

APGM NETWORK IN HERVANTA

The APGM network was in Hervanta case study area primarily planned as a feeder network of public transport. The objective was to create a network between the local centre of Hervanta and the TUT (Tampere University of Technology) campus area, Technology Centre Hermia and southern residential areas of Hervanta. In addition to feeding public transport system between Hervanta and Tampere city centre, APGM is also serving as an internal public transport network of southern Hervanta. The planned network covers an area of approx. 4 km² and the network is 16 km long.

The amount of potential passengers was hypothetically biggest in the TUT campus area, in the Hermia area and in the most densely built residential areas. In addition to these areas, also residential areas with very low densities were covered with the network in order to study the threshold values where the system is still profitable. Thus the network is not optimised according to the passenger demand, but serving the purpose to study the boundary values and different application areas in urban context.

The planned network consists of both 2-way main lines and 1-way loops that depart form the main line and create a loop-based network outside the main line. 2-way main lines serve between connections that need the biggest capacity and also connect 1-way loops in order to create shortcuts within the loop-based network. 1-way loops serve the individual blocks and buildings. Their travelways are placed closer to built structure and sometimes within the structure – blocks and buildings – itself.

There has been assessed to be totally 12500 inhabitants and 11500 work places in the case study area of Hervanta in 2020.
The total length of 2-way lines is 4.3 kilometres and 1-way lines 7.4 kilometres. The preliminary planned amount of stops and stations is 47, of which 2 are located in the local centre of Hervanta, 21 in the residential areas and 24 in the areas of the University and the Technology Centre.

The network was optimized to cover as large an area as possible with the minimum network length. The average distance to an APGM station is 100 m by walking. As mentioned above, also low-density areas where taken into account even though they hypothetically were not the most applicable areas for the APGM system, but were needed in the studies about threshold values for the system (chapter 2.4).

In addition, network was planned without hesitation to place it in different urban morphologies and landscapes. This was done in order to cover different situations of urban context - how to place the system in different streetscapes and traffic areas or how to integrate it to built structure - and in order to build as complete a typology of different situations as possible. This typology was complemented by the other case study area, TAYS.

**APGM NETWORK IN TAMPERE UNIVERSITY HOSPITAL AREA (TAYS)**

Even though APGM network in Hervanta case covers various sections and different typologies, Tampere University Hospital area complements typologies with several different situations. This is due to the built structure of hospital area, where the core of the area is huge hospital complex consisting of several hospital wards and departments that are physically connected to each other. There are “regular” network planning problems about how to solve different transportation situations in connecting hospital area functions or placing the travelways in urban context. Additionally, the hospital area offered the problematic of how to plan a network for a building complex, partly integrated with it. Travel demand is in the hospital area different from Hervanta consisting of mainly internal trips and APGM is in a different role in channelling these streams. There is also significant demand for goods transport in the hospital area, e.g. laundry is a typical goods circulating within the area.

In the beginning of the study, two alternative examples of APGM-networks were planned for the Tampere University Hospital area. Both networks consist of 2-way main lines and 1-way loops. The first network was based on skeletal 2-way main line penetrating the hospital complex and complemented with 1-way loops separate from the main line and serve locations outside the hospital complex: bus stop, parking areas, customer hotel, separate clinics, Finn-Medi centre, Finn-Medi Park on the northern side and university buildings in the east. The second was based on 2-way main-line that surrounds the hospital complex and 1-way loops are making separating loops inside and outside of this ring. In the first network alternative, the total length of 2-way lines was 2.1 kilometres and 1-way loops 1.8 kilometres. The amount of stops and stations was 26. In second network alternative, the total length of 2-way lines was 3.3 kilometres and 1-way loops 1.7 kilometres. There were altogether 24 stops and stations in the second network alternative.
On the basis of ideas of these two network alternatives a smaller APGM network was planned. This network was optimised to serve as a possible APGM pilot network between the Finn-Medi centre, the Finn-Medi Park and the hospital areas. The network is based on one skeletal main line, which is divided in one-way loop in the middle part of the line in order to serve as many buildings as possible along its route – and also to provide better integration possibilities with buildings.

The total length of the network is 1,3 kilometres, where 0,9 kilometres is 2-way main line and 0,4 kilometres are 1-way loops. There are 8 stations in the network and several other possibilities for integration with buildings.

THE STUDY: TWO NETWORK ALTERNATIVES FOR TAMPERE UNIVERSITY HOSPITAL AREA

THE OPTIMISED APGM NETWORK FOR TAMPERE UNIVERSITY HOSPITAL AREA
FEASIBILITY STUDY
Placing APGM in different urban contexts faces different kinds of challenges. On the global level, urban environments are both homogenising and locally differentiating. Airports, science parks and shopping centres are examples of environments that are based on similar typologies all over the world. They are also central nodes and hubs in the transport network – and most probable locations for APGM systems as a transit mode from parking places and other modes of transportation. In these environments, the scale of buildings and public space is rather big and they are relatively recently built. Thus new infrastructures are quite easy to fit in these locations.
2.1 APGM NETWORK IN URBAN CONTEXT

APGM AND URBAN MORPHOLOGY

All urban morphology is closely related to the particular transport system of a particular local urban context. Cities consist of buildings and private and public spaces between them. Part of this public space is reserved to transportation, in its different forms. In most of the cases urban morphology is based on traditional system of streets and blocks together with their modern variations. Street network is an open system that we can take part in multiple ways – as pedestrians or by driving different vehicles. In the urban morphology, APGM and other PRT systems are similar to those modes of public transportation that need separate infrastructures for moving – which is usually rails. They are closed systems that include access only through terminals, stations or integration to buildings in order to enter the travelling. Otherwise, they create obstacles of different quality and level in urban space. As a transportation network, APGM travelways are quite light and small, and they move through built areas without reserving other land than its’ supporting structure needs. Thus APGM system also reminds of technical infrastructure lines.

Most likely APGM will be a new-comer that will be integrated in existing structure – which is the case of this feasibility study too. But APGM system can be integrated into built structure right from the beginning of a planning and building process of a new area. Thus APGM and other PRT systems can create entirely new urban morphologies, where the allocation of buildings and transportation spaces is already based on their operation principles. Most likely they will be mixed systems, where the APGM is a part of more complex transport network – complementing private and public transportation networks of smaller scales. But still, entirely new environments can be created on the basis of this new mode of transportation.

Placing APGM in different urban contexts faces different kinds of challenges. On the global level, urban environments are both homogenising and locally differentiating. Airports, science parks and shopping centres are examples of environments that are based on similar typologies all over the world. They are also central nodes and hubs in the transport network – and most probable locations for APGM systems as a transit mode from parking places and other modes of transportation. In these environments, the scale of buildings and public space is rather big and they are relatively recently built. Thus new infrastructures are quite easy to fit in these locations.

If the multi-modal transportation is understood widely, APGM will also be a vehicle to percolate through urban environments outside the biggest hubs and nodes, serving local neighbourhoods. These environments have their local typologies that will vary in their scale, style and age – and placing of new infrastructures like APGM travelways is a more difficult task.

It is quite obvious that the more dense the urban environment is, the less there is space for new infrastructure. In addition to the need of actual
APGM in different urban contexts faces different kinds of challenges. Urban environments are both globally homogenising and locally differentiating.
space for travelways and stations, the visual disturbance caused by these - especially in historical and cultural environments - is a remarkable feature. Still, it must be noted, that in certain environments new infrastructure with high-tech imago can be a very positive factor for the area, no matter how densely it is built. Thus there is no simple rule where to place APGM travelways or not, instead set of rules (see streetscape typologies) can be given to be locally assessed.

APGM travelways can be placed either in the streetscapes or within the built structure, inside the quarters and blocks. From the implementation point of view, placing the travelways in the traffic areas is more recommendable. When locating among other traffic infrastructure, travelway causes less disturbance to the built environment. Also, traffic areas are usually publicly owned. The less there is private ownership in the plots the travelways are crossing, the less there are any obstacles on the way to implementation. On the other hand, placing travelways on the traffic areas means more remote connection to built environment and the access is more difficult and expensive to build. Thus designing the APGM network means balancing between these different interdependent variables.

**APGM TRAVELWAYS IN URBAN LANDSCAPE**

Even though APGM travelways are elevated above the street level in order to avoid creating obstacles to other traffic - and thus free to meander without limitation of ground level - the travelway has some limitations of its own. These are the changes in vertical and horizontal directions of travelway lines.

Concerning the verticality, APGM is like most of the other transport systems, it has to deal with the topography of particular environment. With APGM travelways the maximum gradient is 1:10, which is close to the usual maximum gradients of roads (1:8) and greater than average gradients of trams or trains (1:20-1:40). Thus APGM manages urban topography alternations as well as the street network - or even better, because APGM does not have to follow the topography directly due to the supported travelway structure. Travelways can be adjusted on certain height level, where alternations are as minimal as possible. This is desirable both from functional, aesthetic and economic point of view. The less there is height differences in close sequences, the less they cause functional obstacle, visual disturbance and variations in travelway structure.

An important question concerning the vertical issues is the access to
APGM vehicles. When elevated in 3-5 metres, there are two choices to access the travelway – either to build stations and stops on the same level, or to lower down the travelway at stations. Placing stations on ground level is more economical and practical, because there is no need for stairs and elevators. However, in many cases there is no possibility to lower down the travelway, because the distance needed for climbing down to station and back to the normal level is over 50 m in 3 m height and over 100 m in 5 m height. Travelway gradients cause physical obstacles when lowered to street level. In addition, as mentioned above, sequential height level changes are visually restless and undesirable. Thus placing stations and travelways on the same height level is recommendable.

Concerning the limitations in horizontal direction, travelways are quite flexible – at least if based on the movements of the vehicle. The minimum curve radius for travelways is 5 meters in slow speed and 20 meters in full speed. A more limiting aspect to the horizontal alignment of the travelway is caused by standardisations of travelway elements, travelling comfort and the environment, in which the travelway is placed. From the viewpoint of the travelway production the equation is simple: the less there are different angles of curve elements, the more economical is the solution. On the other hand, adapting travelways in the polymorphic physical city structure and making the travel as comfortable and fast as possible, multiple travelway elements are needed. Densely built areas need quite small curve radii, while fluently running traffic means long and gentle curves. Another specific issue concerning travelways are the intersections. Together with curving routes, they can become quite large constructions.
Curve radius minimum 5m

10m/s maximum speed - Minimum curve radius 20m

Intersection, curve radius minimum 5m

Intersection, 10m/s maximum speed - Minimum curve radius 20m
APGM TRAVELWAYS IN STREETSCAPE

Urban morphologies are rich in variations. There are a lot of alternations in dimensions and proportions of streets and buildings. In following pages different kinds of situations of placing travelways in urban structure are collected, especially in different kinds of streetscapes in the case area of Hervanta, complemented with Tampere University Hospital area. Each type of the streetscape is commented by assessments of functionality and aesthetics – and combined with other possible notes and recommendations that are related to particular streetscape.
LOCATION:
- On traffic area.
- In the example the APGM travelway is placed in the middle of the 2+2-lane arterial street.

ADVANTAGES:
- Easy implementation from the viewpoint of land-owner-ship – traffic area is usually public property.
- Easy implementation from the viewpoint of land-use planning.
- Location in wide streetscape causes minor aesthetic disturbance and minor visual obstacles.

DISADVANTAGES:
- There is no direct possibility to integrate with buildings. Integration or better accessibility to the travelway means separating travelways from the main route.
LOCATION:
- Between traffic area and buildings, on public or private property.
- In the example the APGM travelway is placed along the collector street of residential area, on public property.

ADVANTAGES:
- Travelway can be placed in various locations on public or private property.
- Location can be chosen according to different situations, thus aesthetic and visual obstacles can be avoided by changing the location.
- APGM travelway can unify a scattered streetscape.
LOCATION:
- Above the pedestrian walkway, usually on public property.
- In the example the travelway is located in semi-wide streetscape of office blocks, on the wider side of the street.

ADVANTAGES:
- Travelway can be integrated as a part of the multiple selection of design elements of the public space (shelter for rain in walkways, bus stops, bicycle parks, benches, guide maps, etc.).
- Positive image effect. New infrastructure offers benefits for others than customers of its own.
- Pedestrian areas are usually publicly owned properties, which causes less procedural disadvantage during implementation.

NOTABLE:
- Advantages and disadvantages usually depend on the properties of the streetscape (width and quality) – see especially cases 2 and 6.
LOCATION:
- Within the privately owned areas.
- In the example between the parking area (and parking house) and office buildings.

IN GENERAL:
- The size and other properties within the building blocks are different already within one block – and thus different situations for travelways will occur.
- In the alteration of different situations it’s recommendable to follow the principles that are applied to types of different street sizes.

ADVANTAGES:
- Easy integration possibilities to functions within the building block.
- Accessible stations are easy to place.
- APGM can be a positive factor in creating new identity to the area.

DISADVANTAGES:
- Travelways makes densely built areas even denser.
- If not placed carefully, it can cause visual obstacles to 2nd floor views and aesthetic disturbance.
LOCATION:
- Among a building complex, on a privately owned property.
- In the example between buildings of Tampere University Hospital.

ADVANTAGES:
- Integration with buildings is easy as the travelway is placed very close to buildings.
- APGM can be a positive factor in the imago of a large institute and support its knowledge-based brand.

DISADVANTAGES:
- Travelways makes densely built areas even denser.
- Travelways cause visual obstacles for 2nd floor views.
- Buildings are connected with pedestrian bridges on 2nd and 3rd floor levels. This might cause physical obstacles for placing the travelway or need for new integration solutions.
LOCATION:
- In the narrow streetscape, where the traffic area is bordered with buildings.
- In the example the travelway is on a pedestrian walkway.

ADVANTAGES:
- Integration to buildings is easy from the viewpoint of short distance.

DISADVANTAGES:
- Travelways make densely built areas even denser.
- The role of the travelway becomes relatively big in a narrow streetscape – both visually and physically.
- In addition to views from the buildings, travelways cause visual obstacles in the streetscape.

NOTABLE:
- Depending on the qualities of the urban context, APGM travelways can be a positive factor and create new identity to the streetscape – or totally impossible to fit to the context, especially in historically and culturally valuable environments.
- Especially in narrow streetscapes, placing travelways need to be analysed carefully in each individual case.
APGM ON A CAMPUS AREA

LOCATION:
- On campus area, on private property between the buildings and campus park.
- In the example there are two alternative locations for the travelway on TUT campus: next to the buildings and in the campus park next to the pedestrian walkway.

ADVANTAGES:
- Location next to buildings enables integration with buildings and better accessibility to APGM service.
- Location in park causes no visual obstacles or aesthetic disturbance.
- In both locations APGM be a positive image factor for the area.

DISADVANTAGES:
- Location next to buildings causes visual obstacles.
- Location next to buildings causes aesthetic disturbance in places where are accentuated entrances or other 2-floors high building parts.
- Travelway in the park is more difficult to integrate with buildings.
 LOCATION:
• In the park, usually on public property.
• In the example the travelway is following pedestrian walkway among the forest-like park.

 ADVANTAGES:
• Location can be chosen freely from the viewpoint of limitations that are related to buildings.
• APGM trips can be very enjoyable experiences when adding travelway sequences that go through park areas.

 NOTABLE:
• Travelway can cause aesthetic disturbance and visual obstacles also in park. Travelway structures should not be placed to cover important landscape elements (water, views, planting groups, art elements, etc.).
• Parks have different styles as well as different historical and cultural values. Placing travelways in parks needs also careful aesthetic and spatial analyses of individual cases.
CONCLUSIONS

In most of the contemporary streetscapes in the case study areas there is plenty of room for a new transportation infrastructure – both in the traffic areas as well as in private estates. Also, APGM system can be regarded as a positive image factor in many environments.

There are two major rules that need to be taken into account when designing the network and placing it in the streetscape. They are representing two viewpoints to the system: from outside the system and from inside of the system as a customer. If observed from outside the system, it is recommendable that APGM travelways are placed on publicly owned transportation areas or plots in order to minimize the possible functional, visual or aesthetic obstacles that travelways are causing. From the operational and customer point of view, it is recommendable to place APGM travelways as close as possible to the buildings or areas where potential customers are in order to provide the best possible accessibility.

APGM AND LAND USE PLANNING

As APGM is a new transportation infrastructure, there exists no procedure, which would self-evidently define how to prepare the documents and plans needed in implementing the APGM system. APGM system consists both of travelways and station buildings. They both need to be defined in detailed land-use plans as well as they need building and implementation permissions. Details of these documents will be defined in the first pilot project of APGM. In tailoring the permission procedures, documents and processes, the municipality that will give the permissions, will have a central role. However, concerning the standardisation of a new mode of transportation, these questions will be treated also on national and European Union level.

Following list gathers some notes and recommendations concerning the detailed land-use planning:

• In detailed land-use plans APGM travelway routes will be marked with similar symbols as other infrastructural lines and areas reserved for them. See example.
• These markings are to be made both in transport areas and in other land-use areas such as private and public estates of residence, industry, merchandise, etc.
• When crossing private estates, APGM equals to other easements such as bicycle routes.
• It is recommendable to place APGM in transportation areas. When placed on private estates, there will most likely be several different land-owners in row of adjacent plots. If placed on private properties, the starting point is that all land-owners are dedicated to the project.
• If other routes are not possible without excessive disadvantage and other private properties need to be crossed, then caused disadvantage is aimed to be compensated by redemption and contract procedures.
• Implementation of APGM systems will most likely require Environmental Impact Assessment (EIA) procedure. A comprehensive
participatory process, as well as assessment process, is recommendable - and most likely obligatory as well.

- Necessary permissions for travelways will be defined during the first pilot. Stations and depot areas will require building permissions.

(Notes and recommendations are drawn on the basis of the case study and commented by senior inspector Anne Jarva, Ministry of Environment in interview in May 2005.)

**APGM STATIONS IN URBAN CONTEXT**

The metaphor used for describing the APGM system is horizontal elevator. This metaphor is most descriptive when used to explain especially the operation of stations. The access to vehicles should be made as easy as ordering an elevator in a lounge and stepping into it to be transported to the chosen destination. Especially, if integrated into buildings, the comparison of APGM to horizontal elevator has a lot of correspondence. On the other hand, in separately placed stations there are issues that make the APGM operation more complicated than just stepping into an elevator. The station itself is a closed building which can not be entered without choosing the trip destination and paying the fare in the station - either by automate or by mobile phone.

In addition to the vehicle itself, the stations are an important interface to the whole system. First impressions of APGM services are formed infrom the beginning of the travel experience. Thus high quality of design and implementation is required from functional and aesthetic points of view. This concerns both the architecture of the station building exterior and interior - and whole user interface consisting of fare collection system,
information system, signboards and route maps.

From the viewpoint of vehicle operation, it is important to estimate the passenger demand for vehicles in order to define the size of the station. Stations can be roughly divided into three categories on the basis of their operation. First, one of the stations should operate also as a depot area used for storing and maintenance of vehicles. Depot area can be also a separate depot, but most practically it is located as a main terminal of APGM system. Main terminal is located in the most densely operated point in the network, providing multiple entrances in order to supply as many vehicles as possible during the peak hours. Second and third categories are regular stations and smaller stops. Regular stations include 1-2 entrance doors to vehicles and a small depot for 1-5 vehicles. Smaller stops include one entrance door providing room for one waiting vehicle at the entrance. Stations that are integrated into buildings can also belong to these three categories. All stations are closed spaces, equipped with stairs, safety doors and elevators, if placed in 3-5 meters above ground level.

Stations are large constructions in streetscape, for example if compared to bus stops. Adjusting them into existing environment follows the same logic as designing any other building. The design is related to the context. Different context prefers different solutions. However, it is recommendable that the stations have good quality of architecture as new-comers in the streetscape - raising the quality either by standing out as special architectural items themselves or adapting to the qualities of the environment.

The floor areas vary from 10 square metres of non-elevated small stops to over 100 square meters multi-entrance stations. By alteration of placing stairs and elevators different architectural variations in station architecture can be accomplished.
APGM stations

stairs, ascent=5000mm + Door + additional doors + elevator
APGM SYSTEM INTEGRATED WITH BUILDINGS AND OTHER INFRASTRUCTURE

APGM system has one special feature that does not occur with many other public transportation systems. It can be integrated with buildings. Passengers can have straight access to vehicles within the building by integrating APGM station inside. Here the metaphor of horizontal elevator describes also well the operation principle of APGM. When integrated to buildings, stations remind ever more the elevator lobby by their functions and appearance.

Integrating with buildings is not an easy task – at least if it is carried out in existing buildings. In the buildings that will be designed according to the knowledge of planned or existing APGM, most of the pitfalls can be avoided already in the early planning phases, beginning from the land-use planning. Within the range of this study, there are three main issues that are related to the question of integration with existing buildings. They are functional, visual and aesthetic issues. From the functional point of view, a new spatial organisation will be required within the building in order to provide new station lobby for APGM. In most of the cases this will be in the second floor of the building where there usually is not any lobby space to connect to. Running the travelway itself through the building is far more complicated task, because it disconnects internal pedestrian routes within the building. These kinds of crossings require electric doors or other arrangements in order to provide safety crossings. In general, these situations are recommendable to be avoided.

Integrated stations include also that the travelway is placed right next to the building. This causes visual problems by blocking the views from the windows at the same height level. Even though the travelways are built as transparent as possible – and watching the passing travellers can be enjoyable – the travelway is still a visual obstacle that should be placed further from the windows. If looked at from the opposite direction, the aesthetic issue of integrating APGM in buildings is also related to the proximity of travelway structures next to buildings. There are architecturally recognised buildings and parts of the buildings – like two floors high and accentuated entrances – that must not be concealed behind travelway structures.

APGM can also be integrated to other built structures than merely buildings. Urban environments can benefit from the new infrastructure also by other means than just as transport vehicle. For example, travelways can be designed to cover pedestrian walkways from rain by integrating roof like structures to the travelways or by designing the travelway itself in the shape that can give protection over the pedestrian areas. Another example is from different kind of environment: travelway tubes can be placed next to traffic areas on ground level and used as a noise barrier. This is possible in the non-pedestrian environments, where ground-level placement creates no physical obstacle for pedestrians or other traffic.
As a conclusion, integration with buildings is very recommendable in general. It improves the user convenience and accessibility to the APGM system. In the implementation, above-mentioned functional, visual and aesthetic viewpoints need to be taken into account. In the planning phase of the building projects near the area where APGM system is under consideration, it is recommendable to take integration into account in planning and design projects already in advance. Integration issues are also a possible playground for the future innovations and visions.

**Integrating with buildings**

**APGM travelway can be designed to cover pedestrian walkways**

**travelway tubes can be placed next to traffic areas on ground level and used as a noise barrier.**
2.2 CONNECTIONS TO THE TRANSPORT SYSTEM

PUBLIC TRANSPORT SYSTEM

APGM is often part of a longer trip chain and provides feeder services for other public transport modes, car and sometimes also walking or bicycle. Especially in the public transport connections the transfers from one public transport mode to another should be as fluent as possible, because the transfer is generally perceived as the most undesirable part of the public transport trip. On the other hand an efficient PRT system can shorten the walk time to the bus stop or train station and therefore reduce the generalised costs of the trip.

In the Hervanta case study area the APGM network has been planned both to improve the level of service of the internal public transport system of Hervanta and to improve the overall accessibility of the existing public transport system. Thus the network has a role of a feeder network and a role of an independent internal network of Hervanta. In the APGM public transport alternative some of the bus lines have been altered to have their terminal in the local centre of Hervanta instead of continuing to the suburban areas. Figure 2.1 presents the bus line network of Hervanta in the basic forecast and in the APGM alternative. Three of the bus routes serving southern and eastern parts of Hervanta in the basic forecast have in the APGM alternative been altered to have their terminal station in the local centre of Hervanta. The local centre has in the APGM alternative been developed into an important public transport terminal offering a high service level headway to city centre by bus.

Figure 2.1 Bus line network in 2020 in the basic forecast and in the APGM alternative. In the basic forecast bus lines 23, 30a, 30b, 31, 32, 13, 20 and 6 are serving the Hervanta area. In the APGM alternative lines 13, 31 and 32 have their terminal in the local centre of Hervanta and line 30a has been removed from the network. Line 20 has been moved to another route inside Hervanta.
In most of studies concerning the public transport travel time weights the transfer has been found to be the most inconvenient part of the trip. If the transfer is well organized, it is not considered as inconvenient as an unorganized transfer. In Finland the relative weight of a transfer has been found to be 2.0 - 3.5 times greater than the ride time (Karasmaa 2000). In Norway the relative weight of transfer time was found to be 2.9 times greater than the ride time (Kjoerstad and Renolen 1996).

Although the transfer itself has been assessed to increase the inconvenience of the public transport trip, the APGM system presents a more user friendly feeder service due to the short wait time and individual character of the feeder service. In the most important transfer stops the APGM system can offer large station areas, where vehicles can be stored and directed to the station in advance according to the previously gathered information concerning the passenger demand. Intelligent and learning guidance system can reduce the waiting time significantly. Waiting time is usually considered more inconvenient than the ride time or walk time to the stop. The relative inconvenience of the waiting time can be reduced by effective real time information about the waiting time - the uncertainty concerning the remaining waiting time and the unreliability of the time tables tend to increase the experienced wait time.

The relative weight of the wait time has in Finland in the metropolitan
area been found to be 1.1 - 3.7 times greater than the ride time (Karhunen 1993, Karasmaa 2000). In Norway the relative weight of the wait time was found to be 1.5 - 3.1 depending on the size of the urban area (Kjoerstad and Renolen 1996). Generally the wait time is considered more inconvenient in the large urban areas where passengers are used to short headways and reliable time tables.

The relative importance and experienced inconvenience of the wait time can in the APGM system be reduced by real time information system. In a feeder use the passenger can in the APGM vehicle receive information about the bus line connections at the destination station through a display terminal monitor. In an APGM station the information system can provide real time information concerning the remaining wait time. Real time information system is especially important in the APGM network where the destination is often fairly close to the origin. Thus the passenger has to have enough information about the wait time to be able to make the decision whether to travel by APGM or walk to the destination. In the planning of the PRT system the design goal is, that the passenger does not have to wait the vehicle - instead the vehicle waits for the passenger. (Tegnér 1999)

The most important transfer stations in the case study area of Hervanta are the local centre of Hervanta and Hermia station. The transfers between the APGM system and bus lines have been assumed to be well organised allowing passengers to change mode in the local centre of Hervanta at the same level. The guidance system of APGM has been assumed to be intelligent and thus be able to reserve vehicles to the stations where there is expected demand in order to minimize the wait time. Vehicle can also be reserved in advance with mobile phone services to reduce the wait time and unreliability of the total travel time.

Walk distance to the station can in the APGM system be one of the most important service level factors. As the PRT system has been developed primarily to compete with the private car use, the walk distances to the stations should be relatively short. According to the public transport travel time surveys walk time is considered significantly less annoying than transfer time or wait time. In Finland the relative weight of walk time to the bus stop has been estimated to be 1.1 - 1.5 times higher than the ride time (Karhunen 1993, Kurri and Pursula 1994). In Sweden the walk time weight has been assessed to be 1.4 - 2.9 times greater than the ride time weight (Widlert and Algers 1992).

Walk distance to the station is eminently important for the passenger groups of disabled persons or elderly people having difficulties to walk long distances. Also passengers travelling with heavy luggage, baby carriage, or for example heavy groceries usually prefer short walk distance in the both ends of the trip. Personal access is an important design goal for the APGM system in order to provide a transport service suitable for all passenger groups. APGM system can partly replace or complement the service bus lines providing door to door services for disabled and elderly people.

PEDESTRIAN AND BICYCLE FACILITIES

In many of the planned PRT networks the distances between the stations are relatively long due to the land use and urban environment of the
In both case study areas of this feasibility study the station spacing is comparatively short. In the case study area of Hervanta the average walk distance to an APGM station is approximately 100 metres and in the University Hospital area approximately 80 metres. In the APGM network the station spacing does not affect the station to station journey speed and therefore the system serves passengers efficiently with relatively short spacing. On the other hand, the stations are comparatively expensive to build and maintain, favouring longer spacing between stations. In the case study area of Hervanta the distances between stations is 70 - 500 metres and in the University Hospital area 90 - 400 m.

Stations are connected to major pedestrian and bicycle paths and all grade-separated stations have an elevator or escalator connection to ground level in order to provide access to all passenger groups. Station furniture include parking facilities for bicycles, because bicycle can sometimes be an attractive feeder mode although the distances to the stations are relatively short and the main mode to arrive the station is by walk.

**CAR PARKING**

APGM system can be utilised in solving the parking facility problems by locating the parking facilities further off the central areas and providing an efficient APGM connection from the parking facility to the central area. The automated transport system offers many possibilities for locating the parking facilities, because it can transport the passenger to the destination without requiring the passenger to know precisely where the final destination is. Therefore automated system is particularly suitable for congested areas lacking parking space where the passengers visit on an occasional basis.

In many of the planned airport applications of PRT systems the parking facilities have been located further away from the airport and the transports between the parking facility and the airport are organized by PRT (Andréasson 2001). For example in the Vantaa Aviapolis feasibility study of the APGM application in the Helsinki-Vantaa airport area the amount of passengers between the remote parking facilities and airport has assessed to be 2 300 trips per day in the year 2025 (Teknillinen korkeakoulu 2005).

In the case area of the Tampere University hospital area the parking facilities are the most important stations of the whole area. The daily number of patents and their escorts and visitors is in the Tampere University hospital about 2 200 persons (Säily 2004). Totally 70 % of the patents and other visitors arrive to the hospital area by car. Most of the visitors or patents visit the Hospital area less than once a year and almost 40 % of the visitors have difficulties to find their destination inside the Hospital area. The parking areas are at the moment distributed into several locations and there is not a large parking facility in the area. In the planned APGM network the parking facilities are located along Vieritie and Biokatu offering possibilities to arrive to the area through other routes than the congested Kuntokatu. APGM enables to locate the parking facilities even further off the hospital area and improve their integrated use by Finn-Medi Technology Centre, university units and Polytechnics in the area.
The location of parking facilities and the instructions to utilise APGM services could be included in the general patent instructions and in the driving instructions of the hospital and the Technology Centre.

In the case study area of Hervanta the large parking facilities in the 2020 network are located in the Technology Centre Hermia and in the Tampere University of Technology. Also in the campus area of Hervanta the APGM system would enable common parking facilities serving the whole campus area and thus decreasing the costs for several smaller parking facilities. Both facilities have APGM station integrated in the parking facility in the planned APGM network.

### 2.3 USER PREFERENCES FOR APGM SYSTEM

User preferences for public transport trips vary according to the purpose of the trip (Wardman 2004, Widlert and Algers 1992). In commuting trips and leisure trips the relative weight of walk time has been found to be greater than on other trip groups (Widlert and Algers 1992). Thus passengers are generally less willing to walk long distances to station on their commuting or leisure trips. In general, the leisure trips are considered to be more pleasant than shopping trips or commuting trips.

APGM can be estimated to attract passengers especially from the public transport users and to some extent also walking and bicycling passenger. In the feeder transport role APGM is likely to be used more often than other available modes (e.g. taxi). Many passenger groups - especially passengers travelling with small children, elderly passengers and disabled passengers - value highly the walk time to the stop (Krygsman et al. 2004). Therefore the passenger preferences indicate that the stations should be close to the origins and destinations. In the residential area and in the densely built office and shopping centre areas the spacing of the stations should therefore be adequate considering the walk distances.

People having a car available are in general more critical to public transport travel time than other passengers. APGM is providing a new mode containing qualities from both private and public modes. It resembles public modes in having a predetermined starting point and destination but unlike in public transport the vehicle is reserved for one user or one group of passengers. Also the wait time is expected to be significantly shorter than in normal public transport when the system is demand responsive.

In a passenger response study made in Cardiff the passengers were well disposed to the elevated track of the PRT. In Cardiff there is a test track for ULTrA vehicle, which is one of the latest PRT systems in pilot phase. The visual appearance of the vehicle and infrastructure was assessed to be good. According to the passenger interviews the PRT would attract also car users and other passenger who are not using frequently public transport. (Cook et al. 2004, EDICT 2002)
FOCUS GROUP INTERVIEWS IN THE CASE STUDY AREA OF HERVANTA

The objective of the focus group interviews was to study the user needs and preferences for the APGM system and services. The user needs are essentially important to take into account in the design, planning and implementation of the system. The user needs and preferences were studied with focus group interviews of the potential passenger groups of the APGM system in Hervanta. The focus groups were:

- research group consisting of personnel of the institutions of Urban Planning and Design and Transportation Engineering (expert panel / test panel)
- students of the Tampere University of Technology
- representatives of the residents’ association of Hervanta region and other local civic organisations
- employees of the Technology Centre Hermia or Tampere University of Technology
- representatives of the local shopkeepers and business life

In each focus group there were 5 - 8 participants. The APGM system and the planned network and services in Hervanta were demonstrated by animations and illustrations in the focus group interviews. The use of APGM system was presented through example trips demonstrating how the APGM operates in the passenger viewpoint. The discussion themes in the focus groups were issues concerning safety and security, travelling comfort, usability, attractiveness and image impacts, vehicle design, station and infrastructure development, willingness to pay for the services, preferences for information and ticketing services, and preferences for the service concepts.

ATTRACTIVENESS AND LEVEL OF SERVICE

Most of the focus group participants found the APGM system as an enticing alternative to travel internally in the Hervanta area. Many respondents assessed that the APGM would mostly attract trips that would be otherwise made by walk or by bicycle. Several respondents suggested that they would prefer walking if the trip was shorter than 2 kilometres. However, on a foul weather most of the users would generally choose APGM over walking. Majority of the focus group participants would use APGM at least occasionally. Many participants assessed that the network should be extended to the new Vuores residential area in the east or to the hypermarket area Turtola in the north in order to gather more passengers.

Most of the respondents assessed that the APGM system would increase the public transport level of service as an effective feeder mode. However, the connections from local centre of Hervanta to the city centre would in this case have to be extremely frequent and the APGM system would have to function without long waiting times. In general a wait time of 2 minutes was accepted by the respondents, but if the wait time would increase, passengers would choose another mode.

The travel speed of 40 km/h was considered relatively high and some of the participants suggested that a lower speed could increase the travelling comfort. According to the focus groups the vehicle should be spacious
enough to transport luggage, baby carriage or wheel chair without problems. All the seats should preferably face the travel direction in order to be able increase the travel comfort.

The participants of focus groups were not unanimous in their opinions concerning the impacts of the APGM network on the townscape. Most of the respondents assessed that the APGM system can be successfully adapted in the area of Technology Centre, University campus and in the University Hospital area, if the infrastructure and vehicle design is thoroughly contemplated and adjusted to the environment. However, the residential area was considered as a problematic area in viewpoint of townscape and attractiveness of the living environment. Some of the respondents would welcome the system to the densely populated residential areas, but on the other hand many participants thought that the infrastructure design needs substantial development in order to be able to improve the townscape in the residential areas.

The travelway should be light-structured in order to avoid a monolithic overview. The cover material should be transparent in order to increase the travel comfort and to improve the visual appearance of the system. The vehicle and the tube should be well air-conditioned to ensure the transparency in all weather conditions. In the focus groups participants suspected, that in wintertime when it is raining wet snow, the tube is difficult to keep clear.

Participants also suggested that local elements of townscape could be reflected in the travelway design. The travelway could also be hidden into the landscape with plantings. It was also suggested, that solar panels producing electricity for the APGM system could be installed on the roof of the travelway. The travelway was additionally envisaged as a pleasant roof for pedestrian and bicycle paths providing comfortable environment for walk during a rainy or hot weather.

Generally the station areas were considered to be most demanding elements in adjusting the system to the townscape. Focus group participants preferred the stations that were integrated in the buildings and considered elevated stations demanding for both aesthetic design and protection for vandalism. Elevated stations requiring elevators or escalators were also not considered as inviting as the stations on the ground level or integrated to buildings. The stations were desired to be light-structured, luminous and open places.

The APGM system was in the focus group interviews assessed to be useful in deliveries inside the Hervanta area. Companies could send small deliveries to each other instead of having to drive to the destination by car or van. Functioning as a delivery system would demand from APGM system rather sophisticated booking system and personal receiving of the delivery based on mobile solutions. Also home deliveries of grocery shopping were suggested to be transported by APGM so that the customer would collect the groceries from the station.

APGM was assessed to improve the competitiveness of the local centre of Hervanta. The attractiveness would be improved if the supply of commercial activities would increase and become more diverse. APGM would attract people to visit the local centre instead of choosing other shop location outside Hervanta. Also the public transport terminal activities
could improve the competitiveness of the local shops in the centre. Participants suggested that local shopkeepers could advertise in the vehicles with outdoor advertisements and inside the vehicle through a monitor. When the walk distance to the indoor station in the local centre of Hervanta is short, the APGM would induce passengers to shop in the centre especially during the transfer from buses to APGM.

SAFETY AND SECURITY

APGM system was in the focus groups considered safe and reliable based on the animations presented in the focus groups. The safety risks revealed in the focus group discussions were primarily related to social security - not to the technical reliability or traffic safety.

Most severe risk brought out in the focus groups was the threat for vandalism in the station areas and in the vehicles. Many participants suggested that vandalism would decrease the attractiveness and sense of security notably. In order to keep the stations safe for vandalism, especially in the residential areas where the passenger demand is smaller, the system would require substantial amount of electronic surveillance and guarding.

Participants presented also their anxiety about passengers who would spend their leisure time in the vehicles by travelling from one place to another. Especially teenagers and children were expected to travel around for fun and occupy a vehicle for one hour, if there is a normal right to transfers included in the APGM fare. This phenomenon was suggested to be prevented with surveillance and guarding.

In failure situations participants expected to receive real-time information concerning the delay and necessary safety actions. Most of the participants requested an online help desk, which could be contacted by a phone installed in the vehicle as in many elevators. Possibility to a personal contact was considered important in extraordinary situations. Online information about the failure could also be received through a display monitor inside the vehicle.

WILLINGNESS TO PAY FOR THE TRAVELLING

In general, the participants were prepared to pay for the APGM services the same fare as in the public transport system at the present. The system should include free transfers to buses on the same ticket during one hour, as in the present public transport system. Most of the participants suggested that the single fare of 2 euros would be too high fare for an internal trip in Hervanta. Therefore participants suggested that the single fare would be for internal trips 1 euro and for other trips 2 euros. The latter fare would include a right to transfer to bus free of charge within one hour. The passengers travelling with season ticket or stored value ticket would primarily be willing to pay the same fare as for the bus trip inside Tampere (1,05 - 1,40 euros per trip).

Participants agreed that the trip could be paid by public transport smart card (Tampere Travel Card) or by mobile phone. Mobile phone can only be used for paying single fares. Most of the participants did not regard the cash payment opportunity important - instead many respondents considered that the cash payments with ticket machines might be problematic and cause insecurity in the stations.
Inside the campus area and Technology Centre area the APGM system was envisaged as horizontal elevator system. The employees of the University should inside the campus area be allowed to use the APGM free of charge, as well as the employees of the Technology Centre Hermia inside the Hermia area. In this case the employer could reclaim the employees' internal trips from the operator and thus take part in the operation costs.

Also the local shopkeepers were assessed to be interested to share the ticket costs by offering customer free fares to APGM for example for a shopping over a certain amount of money. Free tickets were suggested to encourage customers to visit the local centre more often instead of choosing another shopping location.

**INFORMATION SYSTEM**

Participants requested for real-time information concerning the wait time at the stations, if the vehicle was not directly available at the station. The wait time could be displayed to passenger before the trip has to be paid, so that the passenger could walk to the destination instead of waiting, if the wait time becomes longer than the passenger expected. The vehicle should be able to be reserved in advance by a mobile phone.

The focus panel participants required that the vehicle should be easy to use for all passenger groups. The destination could be chosen from a touch screen or a simple display. The user interface could also be partly speech guided. Elderly people could receive smart cards carrying information concerning the destination, for example local grocery shop, doctors’ appointment or home station. In this case passenger would take the card along and the system would read the destination from the card. It should also be possible to change the destination and thus recode the destination during the trip.

Participants considered possibilities to customized services as a very positive feature of APGM, although customisation would require user identification. APGM system could identify the user on the basis of the smart card or mobile phone. Most of the participants were well disposed to the user identification possibilities of the APGM system. Usually passengers make routine trips and the same origins and destinations are repeated. System could gather information concerning the previous trips the passenger has made and during the next boarding the system would offer the previous destination. The user identification would facilitate the destination choice and the passenger would on a routine trip only to have to choose whether the destination is the same as usually or not. Passenger could also identify herself a profile, in which she could for example ask for daily news on the display monitor or define favourite music or the radio channel she wants to listen to during the trip.
### STRENGTHS
- Provides a fast and convenient mode for short trips inside the area
- Improves connections to local centre
- Improves significantly travelling inside the campus and Technology Centre
- Improves the door to door service possibilities of the public transport
- Idea of private - public mode attracts passengers

### WEAKNESSES
- Attracts trips that would otherwise be made by walk or bicycle
- Demands extensive electronic surveillance and guarding due to the threat of vandalism
- Expensive alternative to walking and bicycling
- Does not completely replace the need for service buses for elderly and disabled passengers

### OPPORTUNITIES
- APGM can improve the image of the area as a technological forerunner
- Can improve the public transport level of service by providing an efficient feeder connections
- Infrastructure and design can improve townscape if the aesthetic planning is successful and takes into account the local circumstances
- The attractiveness and competitiveness of the local centre can improve due to the APGM network
- Elevated travelway can be utilised as roofed pedestrian and bicycle way
- Can improve mobility of elderly and disabled passengers in the residential area
- Possibilities for service customisation

### THREATS
- Vulnerability for vandalism
- Automatic operation eliminates the need for personnel, which can in the malfunction situations cause problems
- Unsuccessful pilot would fall the area into disrepute
- Prospective accidents and breakdowns would decrease the passenger demand permanently - the system would have to be completely reliable already in the pilot phase
- User interface becomes too complicated and difficult to use
- Expensive tickets can cut down passenger demand
2.4 FORECAST OF PASSENGER DEMAND

FORECAST METHOD

The passenger demand forecast for the case study area of Hervanta has been conducted with the Tampere regional traffic model (TALLI 2000) developed in the Tampere University of Technology. The traffic model consists of a four-step model for internal passenger traffic, a car ownership model, a gravity model for external passenger traffic, and a gravity model for freight traffic. Figure 2.4.1 presents the structure of the traffic model. The model is based on travel behaviour data collected with travel surveys during 1996 - 1998. Tampere regional traffic model is a zone based model, where the region is divided into 336 zones. The forecast year of the model is 2020. The model includes the trips of the population over 14 years of age. (Kalenoja et al. 2002)

In the traffic model the internal trips on the region are divided into home-based trips and non-home-based trips. The home-based group is divided into commuting trips, school trips, shopping trips and leisure trips. The trip generation, destination choice and mode choice are modelled separately for each trip group. Network assignment procedure is conducted for the passenger cars, vans and lorries and public transport. The traffic model includes applications for impact assessment in the form of emission calculation and estimation of vehicle costs for passenger cars. (Kalenoja et al. 2002)

Zoning has in the case study area been transformed denser than it is in the traffic model in general. In Hervanta there is in the basic fore-
cast altogether 15 zones. In the APGM assessment the number of zones in Hervanta has been increased to approximately 60 zones in order to describe the land use, network and access to APGM stations in more detail.

In the traffic model the most important mode and destination choice variable of the public transport is weighted travel time, which consists of following components: walk time to and from public transport stop, wait time, ride time and transfer time. Each travel time component has a weight describing the relative inconvenience of the component compared to the public transport ride time. In the traffic model the weight for walk time is 1.5, for wait time 2.3 and for transfer time 5.2. (Kalenoja et al. 2002)

APGM has in the forecasts been described in the public transport supply as a separate public transport mode. The public transport demand has been assigned on the network in the VIPS/3 programme. The relative weights of the public transport travel time components have been assumed to be the same as in the public transport system in general. However, the wait times and walk times have in the APGM supply been assumed to be significantly shorter than in the bus or train supply.

In several studies the PRT systems have been assessed to appear to passengers as more attractive modes than other public transport modes due to the greater speed and avoidance of stopping at intermediate stations or bus stops. The station to station journey speed of the PRT systems has in general estimated to be twice as fast as the speed of a ordinary bus journey (Buchanan 2004). Also the travelling comfort has in the user studies found to be greater than in the other public transport modes (Tegnér et al., Andrésson 2001). Thus the ride time weight has in the APGM system been assumed to be 20 % lower than in other public transport modes due to the individual and more private character of the APGM.

The APGM network has in the assignment programme been described as lines that are operated on 2 minutes headway, because the applied public transport assignment system does not distinguish demand responsive public transport supply. As the number of lines has to be limited, some of the connections in the APGM network are technically described with transfers, but in these occasions the transfers have been defined as matched transfers. However, the transfer time weight is valid in the whole network and in all public transport modes. Therefore certain APGM connections are described as less attractive as they would in reality appear. Thus the forecast represents relatively moderate demand estimation.

The network has been adjusted in the analysis of the passenger demand in order to adapt the transport supply to the demand. The number of stations has been reduced according to the preliminary passenger forecasts and some of the lines have been transformed from one-way travelways to two-way travelways. However, the studied network has not been optimised according to the passenger demand.

The APGM fare has in the forecasts been assumed to be the same as in the bus system in Tampere and include free transfer to other public transport lines within one hour.
In the case study area of Hervanta the studied APGM network would increase the public transport level of service significantly. The number of public transport trips originating in Hervanta increases by 11% due to the APGM services. Table 2.4.1 presents the modal split of the trips originating in the case study area of Hervanta. The number of public transport trips originating in or destined for Hervanta is in the APGM network almost 18 000 trips per day, as the travel patterns are in general symmetric.

Table 2.4.1 Number of daily trips originating in the case study area of Hervanta in 2020 (trips/day).

<table>
<thead>
<tr>
<th></th>
<th>walk trips</th>
<th>bicycle trips</th>
<th>car trips</th>
<th>public transport trips</th>
<th>altogether</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic network</td>
<td>13 280</td>
<td>2 990</td>
<td>38 640</td>
<td>8 010</td>
<td>62 900</td>
</tr>
<tr>
<td>APGM network</td>
<td>13 000</td>
<td>2 930</td>
<td>38 300</td>
<td>8 910</td>
<td>63 100</td>
</tr>
</tbody>
</table>

DIFFERENCE COMPARED TO BASIC SCENARIO

<table>
<thead>
<tr>
<th></th>
<th>number of trips</th>
<th>%</th>
<th>number of trips</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-280</td>
<td>-2.1 %</td>
<td>-60</td>
<td>-2.0 %</td>
</tr>
<tr>
<td></td>
<td>-340</td>
<td>-0.9 %</td>
<td>900</td>
<td>11.2 %</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.3 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to the model results the APGM system attracts passengers from all modes and increases the level of service and thus attracts more trips to the area than in the basic scenario. Most of the new public transport trips (Figure 2.4.2) in Hervanta are from private car or walking. Altogether 200 new trips are destined for the case study area. These trips are in the basic forecast destined for other areas than Hervanta.

Figure 2.4.2 Changes from other modes of the new public transport trips in the case study area of Hervanta.

The total number of passengers in the studied APGM network is 14 500 per weekday. Most of the APGM passengers are transferring from APGM to bus or from bus to APGM system. The number of internal APGM trips inside Hervanta is 940 trips per day, of which 28% are made during the afternoon peak hours (between 15:00 and 18:00). The daily amount of transfer trips to or from buses is 13 500. Most of the passengers in the APGM system are travelling between the Technology Centre Hermia, University and the local centre of Hervanta. Figure 2.4.2 presents the number of passengers in the APGM system during the afternoon peak hours in the case study area in 2020. The most congested part of the
network is the line in the local centre of Hervanta having over 2,600 passengers travelling towards Hervanta centre between 15:00 and 18:00. The maximum demand is approximately 14 passengers per minute during the peak hours. In this part of the network the lines from University area and residential areas are connected. From the area of Technology Centre Hermia there is approximately 1,200 passengers travelling towards local centre during the afternoon peak hours, on the average 7 passengers per minute. The demand in the residential area network is to some extent smaller. In the assessment of the passenger demand it should be noticed that the presented figures do not include the trips made by children (under 15 years of age). It is likely that the system would be frequently used by children in the residential areas especially on school trips and leisure trips.

Figure 2.4.2 Number of passengers on APGM network and bus network during a weekday afternoon peak hours (15:00 - 18:00) in 2020.

The most frequent users of the APGM services measured in trips per person are the employees of the Technology Centre and the University, and the inhabitants of the southern residential areas. Figure 2.4.3 presents the daily number of APGM trips per work place or per inhabitant in the case study area. On the average inhabitants of the densely built apartment house areas make 0.53 APGM trips per weekday. In the areas of detached or semidetached housing the daily number of APGM trips is 0.45 trips per day. There is, however, significant variations in the daily number of trips due to the different land use types and availability of local services and work places. In the south-westerly areas the daily number of trips is relatively high due to the high level of services and small number of inhabitants.
Most of the transfers to and from bus system are made in the local centre of Hervanta. There is also some transfers in the Hermiankatu area and in the Arkkitehdinkatu area especially from the bus lines from Vuores and Annala. Figure 2.4.4 presents the transfer points in the APGM network. Transfer points and stations are the most important parts of the network, because most of the passengers are transferring from APGM to bus or from bus to APGM.
An average APGM trip is 1,2 km long and the daily APGM passenger mileage is in the Hervanta network 19 900 passenger km per weekday.

The busiest stations are the transfer stations presented in Figure 2.4.4. In the Local Centre of Hervanta there is over 12 000 boardings and alightings per day. In the Hermia main building area (Hermia 1) the number of daily passengers is over 2 500 passengers. Figure 2.4.5 presents the number of boarding and alighting passengers per weekday in the other stations than the Local Centre of Hervanta. In the University area the number of passengers per station is 300 - 600 passengers and in the Hermia area 40 - 450 passengers per station. In the residential areas the number of passengers varies between 40 and 600.

**Figure 2.4.5** Number of boarding and alighting passengers in the APGM stations per weekday in 2020. The Local Centre of Hervanta is not included in the figure.
CAPACITY UTILISATION AND VEHICLE DEMAND

According to the passenger demand the number of vehicles needed during the peak hours is 70 - 100. The vehicle demand is much smaller during the off peak hours. As there are altogether 47 stations, there is on the average 1 - 2 vehicle per station and the main stations (Figure 2.4.6) can store 5 - 15 vehicles.

The busiest stations are in the system functioning as depots thus offering shortest possible waiting time of the vehicles during the peak hours. Figure 2.4.6 presents the proposed stations including a small depot area for the unused vehicles.

Figure 2.4.6 Proposed location of the stations functioning also as vehicle depots.
The impacts of the APGM system have in this case study been assessed according to the framework presented in the national transport policy of Finland. The target areas of the transport policy are the service level and costs of the transport system, health and safety, social sustainability, regional and urban development, and negative impacts on the natural environment (Ministry of Transport and Communications 2001). The assessment of the impacts is based on the results from the case study areas.

As the studied network has not been optimised in relation to the passenger demand, the economical assessment presented in this chapter is suggestive in its nature. The assessment aims to portray different types of appraisable impacts and their scale in the studied network, rather than present the exact values of the impacts of an optimised network.

**PUBLIC TRANSPORT LEVEL OF SERVICE**

According to the passenger demand model the planned APGM network increases the public transport level of service in the case study area of Hervanta notably. APGM provides fast feeder connections to the local centre offering frequent bus headway to and from city centre. Travel times from Hervanta subareas to the local centre of Hervanta and to city
centre by public transport are much shorter than in the basic network. Figure 2.5.2 presents the public transport travel time from the subareas of Hervanta to city centre in the APGM network compared to the basic network.

Figure 2.5.2 Public transport travel time from the subareas of Hervanta to city centre compared to the basic network. Travel time includes walking time, waiting time, ride time and transfer time.

On the average the public transport travel time from Hervanta to city centre is 8.5 minutes shorter than in the basic network (Table 2.5.1). Especially the waiting time, walking time and total transfer time are shorter than in the basic network.

Table 2.5.1 Average public transport travel time from Hervanta to city centre in basic network and in APGM network.

<table>
<thead>
<tr>
<th></th>
<th>Basic Network</th>
<th>APGM Network</th>
<th>Difference Compared to Basic Network</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td>ride time</td>
<td>27.0</td>
<td>23.3</td>
<td>-3.7</td>
</tr>
<tr>
<td>wait time</td>
<td>4.0</td>
<td>0.7</td>
<td>-3.3</td>
</tr>
<tr>
<td>walk time</td>
<td>3.0</td>
<td>1.6</td>
<td>-1.3</td>
</tr>
<tr>
<td>transfer time</td>
<td>0.3</td>
<td>0.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>total time</td>
<td>34.3</td>
<td>25.8</td>
<td>-8.5</td>
</tr>
</tbody>
</table>
In the whole region the studied APGM network of Hervanta decreases the average public transport travel time by 1.8%. Thus the annual time saving compared to the basic network is approximately 331 000 hours per year. The value of the public transport travel time saving has been assessed to be 1.8 million €/year, when the passenger time value is 5.5 € per hour (Tiehallinto 2001). The value of travel time savings has been calculated by comparing the total travel time in the APGM network to the total travel time in the basic network with the same passenger demand as in the APGM network.

**TRAVEL BEHAVIOUR IN THE REGION**

According to the regional traffic model the APGM network increases the daily amount of public transport trips in the Tampere region by 1 350 trips (by 1.1%). Table 2.5.2 presents the effects of the APGM network on the travel behaviour in the whole region. APGM services decrease slightly the amount of car trips, bicycle trips and walk trips in the region. In Hervanta the effects of the modal split are greater as presented in chapter 2.4, as most of the changes in the travel pattern are focused on the Hervanta area.

Table 2.5.2 Number of daily trips by each mode in the region in 2020.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Basic Network</th>
<th>APGM Network</th>
<th>Difference Compared to Basic Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk trips (num trips)</td>
<td>181 320</td>
<td>180 930</td>
<td>-390</td>
</tr>
<tr>
<td>Bicycle trips (num trips)</td>
<td>39 740</td>
<td>39 640</td>
<td>-100</td>
</tr>
<tr>
<td>Car trips (num trips)</td>
<td>692 000</td>
<td>691 140</td>
<td>-860</td>
</tr>
<tr>
<td>Public transport trips</td>
<td>125 200</td>
<td>126 550</td>
<td>1 350</td>
</tr>
<tr>
<td>Altogether</td>
<td>1 043 900</td>
<td>1 043 900</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>%</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk trips</td>
<td>-0.2%</td>
<td>-0.3%</td>
<td></td>
</tr>
<tr>
<td>Bicycle trips</td>
<td>-0.3%</td>
<td>-0.1%</td>
<td></td>
</tr>
<tr>
<td>Car trips</td>
<td>-0.1%</td>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td>Public transport trips</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td>0.0%</td>
</tr>
</tbody>
</table>

**ECONOMICAL ANALYSIS**

**INVESTMENT COSTS**

The studied APGM network in the case study area includes 16 km travelway, of which 7.4 km is 1-way line. There are altogether 47 stations in the planned network. The investment costs are based on the APGM Aviapolis study, where following investment costs were defined (WSP 2005):

- APGM travelway 2 100 000 €/km
- APGM station 120 000 €/station
- APGM vehicles 30 000 €/vehicle
- Vehicle depot 2 100 000 €/depot
- Electrical system 6 000 000 €
Most of the costs follow from the travelway including the support pillars. The second largest cost items are the stations including elevator systems and safety doors. Also the electrical system including the IT system, ticketing system and passenger information system has been estimated to be a relatively large cost item. IT system includes also surveillance equipment. (Ritola et al. 2005)

In Sweden the travelway for SkyCab system has been estimated to cost 2,3 million €/km (Tegnér et al. 1999). The SkyCab travelway has to some extent heavier construction than the planned APGM system due to the larger vehicle size, but on the other hand the SkyCab travelway does not have a covering transparent tube. The assessed investment costs assessed in the APGM feasibility study of Aviapolis are hence in line with the Swedish cost assessment.

The estimated investment costs of the studied APGM system in Hervanta consist of following items:

<table>
<thead>
<tr>
<th>number of units</th>
<th>total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>APGM travelway 16,0 km</td>
<td>33 600 000 €</td>
</tr>
<tr>
<td>APGM station 47 stations</td>
<td>5 640 000 €</td>
</tr>
<tr>
<td>APGM vehicles 70 vehicles</td>
<td>2 100 000 €</td>
</tr>
<tr>
<td>vehicle depot 1 depot</td>
<td>2 100 000 €</td>
</tr>
<tr>
<td>electrical system</td>
<td>8 000 000 €</td>
</tr>
<tr>
<td>total costs</td>
<td>51 440 000 €</td>
</tr>
</tbody>
</table>

The overhead costs have in the APGM Aviapolis feasibility study been assessed to be 20 % of the construction costs (WSP 2005, Ritola et al. 2005). In this study the overhead costs have been assessed to be 8 million €. The total infrastructure costs including the overhead costs are thus 59,4 million € leading to system costs of 3,7 million €/km.

As the costs of the infrastructure can be in the public transport investments divided for 30 years and the residual value can be assumed to be 25 %, the annual investment costs are 3,7 million € with 5 % annual interest calculated with annuity method. (Ministry of Transport and Communications 2003)

If the network was implemented in a smaller extent, the investment costs would be significantly lower. The total investment costs would decrease to 28,1 million €, if the network was implemented between the local centre of Hervanta, technology Centre Hermia and the University campus, consisting of 1,7 km two-way travelway and 2,7 km one-way travelway and 25 stations. In the limited network the annual investment costs would be 1,7 million €/year with 5 % annual interest and 30 years investment time calculated with annuity method.

**INCOME**

The annual amount of passengers in the APGM system is according to the demand forecast in 2020 approximately 3,8 million passengers. As the APGM has been assessed to be implemented as part of the regional public transport system, the fare has been assumed to be harmonised with the fares in the public transport system. Thus the fare has been assumed
to be the same as in the internal public transport in Tampere including free transfers to other public transport modes within one hour. As many of the APGM trips include transfers to or from buses, the revenues are divided between different operators. The revenues have been calculated and allocated to public transport modes in the public transport assignment programme VIPS/3 with these assumptions.

Table 2.5.3 presents the assessed annual passenger revenues in both bus system and APGM system. The total public transport revenues increase by 2 %. The annual revenues of the APGM system have been assessed to be 2,0 million €. However, the implementation of APGM network decreases the bus revenues by 12 %.

Table 2.5.3  Annual passenger revenues (million euros / year) in the internal public transport of Tampere in the basic network and in APGM network in 2020. (Including vat)

<table>
<thead>
<tr>
<th></th>
<th>BUS *)</th>
<th>APGM</th>
<th>ALTOGETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic network</td>
<td>14,6</td>
<td>0,0</td>
<td>14,6</td>
</tr>
<tr>
<td>APGM network</td>
<td>12,9</td>
<td>2,0</td>
<td>14,9</td>
</tr>
</tbody>
</table>

DIFFERENCE COMPARED TO THE BASIC NETWORK

| Million €/year | -1,7 | 2,0 | 0,3 |
| %              | -12 % | - | 2 % |

*) in the Tampere city area

OPERATING COSTS

The operating costs of the APGM have in the APGM feasibility study in Aviapolis area estimated to be 0,11 €/vehicle km, when the annual mileage is approximately 2 million vehicle km (WSP 2005, Ritola et al. 2005). Operating costs of PRT systems have in the in USA been assessed to be somewhat higher - generally 0,2 - 0,3 €/km, when the annual number of passengerkm is between 5 and 10 million km (Tegnér et al. 1999). However, APGM vehicles are smaller and more energy-efficient than the vehicles in the rail-borne PRT systems. Thus the operating costs can be assessed to be lower than in the existing PRT systems. Operating costs have in this assessment been estimated to be 0,11 €/vehicle km in accordance with the Aviapolis study. Costs include energy consumption, maintenance and insurances.

The bus vehicle mileage is in the APGM network 1,8 % smaller than in the basic network due to the altered bus lines in the Hervanta area. Several lines has in the APGM network guided to the local centre of Hervanta, from where there is a APGM connection to the southern residential areas and University area and Technology Centre. Table 2.5.4 presents the differences in the daily vehicle mileage in the basic network and the APGM network.

<table>
<thead>
<tr>
<th>vehicle mileage (km/day)</th>
<th>BUS</th>
<th>APGM</th>
<th>PASSENGER CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic network</td>
<td>101 500</td>
<td>-</td>
<td>5 258 500</td>
</tr>
<tr>
<td>APGM network</td>
<td>99 700</td>
<td>19 900</td>
<td>5 251 000</td>
</tr>
</tbody>
</table>

DIFFERENCE COMPARED TO THE BASIC NETWORK

| vehicle km per day | -1 800 | 19 900 | 7 500 |
| %                  | -1,8 % | -      | -0,1 % |
The operating costs of the internal bus network of city of Tampere has been estimated to decrease by 4.0% compared to the basic network due to the decreased mileage. The operating costs of the bus lines are based on the cost model including driver costs, vehicle costs and other crew costs. Cost values are different for each bus type.

The annual operating costs of the public transport have in the APGM network been assessed to be 0.5 million € less than in the basic network (Table 2.5.5). The cost savings are due to the decreased operating costs of the bus network and relatively low operating costs of the APGM system.

Table 2.5.5 Annual public transport operating costs (million €) in the city of Tampere in the basic network and in the APGM network in 2020.

<table>
<thead>
<tr>
<th>operating costs</th>
<th>BUS *)</th>
<th>APGM</th>
<th>altogether</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic network</td>
<td>26.26</td>
<td>0.00</td>
<td>26.26</td>
</tr>
<tr>
<td>APGM network</td>
<td>25.21</td>
<td>0.57</td>
<td>25.79</td>
</tr>
</tbody>
</table>

**DIFFERENCE COMPARED TO THE BASIC NETWORK**

<table>
<thead>
<tr>
<th>Million €/year</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.05</td>
<td>-4.0%</td>
</tr>
<tr>
<td>0.57</td>
<td>-1.8%</td>
</tr>
</tbody>
</table>

*) in the Tampere city area

**SAVINGS IN PASSENGER CAR ACCIDENT COSTS, ENVIRONMENTAL COSTS AND VEHICLE COSTS**

As the APGM network decreases the passenger car mileage by 0.1% in the whole region, also the traffic accident costs, environmental costs and vehicle costs of passenger cars can be assumed to decrease. The daily passenger car mileage has been assessed to decrease by 7,500 km/day (Table 2.5.4) which annually leads to 2.2 million km smaller passenger car mileage than in the basic network.

Table 2.5.6 presents the annual changes in the passenger car accident costs, exhaust gas emission costs and vehicle costs compared to the basic network. The amount of passenger car emissions and vehicle costs has been calculated with the Tampere regional traffic model (TALLI 2000). Accident costs have been assessed on the grounds of the reduction of the passenger car mileage *. Emission cost, accident cost and vehicle cost values have been defined in the national assessment guidelines (Ministry of Transport and Communications 2003). The studied APGM network in Hervanta would reduce passenger car accident costs, emission costs and vehicle costs by 0.53 million € per year in 2020 compared to the basic network.

Table 2.5.6 Change in the passenger car accident costs, emission costs and vehicle costs compared to the basic network in 2020.

<table>
<thead>
<tr>
<th>change compared to basic network</th>
</tr>
</thead>
<tbody>
<tr>
<td>annual mileage</td>
</tr>
<tr>
<td>accident costs</td>
</tr>
<tr>
<td>emission costs</td>
</tr>
<tr>
<td>vehicle costs</td>
</tr>
</tbody>
</table>

*) The accident costs of the APGM system have not been assessed in this study.
Socio-economical costs include all the cost factors containing commercial costs to operator, consumer welfare and social costs. The studied APGM network is socio-economically slightly unprofitable due to the relatively large time savings of the public transport passengers.

<table>
<thead>
<tr>
<th>socio-economical cost assessment (excl. taxes)</th>
<th>M€/v</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>costs</strong></td>
<td></td>
</tr>
<tr>
<td>investment costs</td>
<td>3,7</td>
</tr>
<tr>
<td>APGM ticket costs to passengers</td>
<td>1,8</td>
</tr>
<tr>
<td>bus ticket cost savings to passengers</td>
<td>-1,6</td>
</tr>
<tr>
<td>APGM operating costs</td>
<td>0,6</td>
</tr>
<tr>
<td>savings in bus operating costs</td>
<td>-1,0</td>
</tr>
<tr>
<td>passenger car accident cost savings</td>
<td>-0,21</td>
</tr>
<tr>
<td>passenger car emission cost savings</td>
<td>-0,03</td>
</tr>
<tr>
<td>passenger car vehicle cost savings</td>
<td>-0,29</td>
</tr>
<tr>
<td>total costs</td>
<td>3,0</td>
</tr>
<tr>
<td><strong>income</strong></td>
<td></td>
</tr>
<tr>
<td>APGM passenger income</td>
<td>1,8</td>
</tr>
<tr>
<td>decreased passenger income in bus traffic</td>
<td>-1,6</td>
</tr>
<tr>
<td>travel time savings of public transport passengers</td>
<td>1,8</td>
</tr>
<tr>
<td>total income</td>
<td>2,1</td>
</tr>
<tr>
<td><strong>altogether</strong></td>
<td>-0,9</td>
</tr>
</tbody>
</table>
CONCLUSIONS
APGM system provides an attractive mode combining qualities from both private motorised and public transport modes. Short ride time due to origin destination service, on-demand services and privacy during the ride resemble private modes. On the other hand the public operability of the services and the walk time needed to access stations in both ends of the trip resemble traditional public transport services.
3. Conclusions

NEW TRANSPORT MODE IN-BETWEEN TRADITIONAL PUBLIC AND PRIVATE MODES

APGM system provides an attractive mode combining qualities from both private motorised and public transport modes. Short ride time due to origin destination service, on-demand services and privacy during the ride resemble private modes. On the other hand the public operability of the services and the walk time needed to access stations in both ends of the trip resemble traditional public transport services.

In a polycentric network city APGM is well suited for the nodes of the network having large transport demand. Such nodes can be for example public transport stations, extensive work place areas, campus areas, shopping centres or science parks. These nodes are in general recently built large scale areas requiring considerable area of land use. In these environments the APGM system is generally relatively uncomplicated to locate in aesthetic and functional viewpoint. APGM system can also be assessed to have potential to provide transport connections between the nodes and in the neighbouring area of the nodes. In addition, APGM can offer possibilities for efficient transverse connections between the nodes.

Although APGM system has many common features with traditional public transport modes, it contains less unpleasant qualities than the conventional public transport modes. On-demand services offer short wait times and relieve passenger from planning the starting time of the trip in detail in advance. Ride time is short because the vehicle travels automatically to the destination without stopping at the intermediate stations. APGM stations are mainly located on short intervals providing short walk time to the station, and in public properties direct access to the interior space. Advanced information systems can provide real-time information of the wait and ride time and decrease the uncertainty concerning the total travel time. Thus APGM improves significantly the level of service of the public transport system. APGM has also been assessed to improve the image and quality factors of public transport as a modern and high quality transport mode. In this point of view the APGM system supplements the accessibility by providing easier door to door connections by public transport.
In the built environment APGM is a new arrival in the urban morphology with already established transport system. In the new construction areas completely new urban typologies can be developed including integrated APGM system. APGM is relatively uncomplicated to integrate to new constructions, but in the existing built environment the integration demands thorough planning, because locating the infrastructure is not unambiguous. The scale of urban environment, cultural values and values of urban landscape are not unanimous. Thus it is not possible to predefine the environments where APGM can be applied, as the feasibility depends on the local context. However, it is possible to specify various principles of locating the system in different urban environments as presented in chapter 2.

In locating the infrastructure regarding the existing building stock the goals are to some extent paradoxical. Considering the maximal usability and accessibility of the stations, the travelways and stations should be located as close to the buildings as possible. However, in the viewpoint of the residents and employees the travelways and stations cause visual and aesthetic disadvantages in the immediate surroundings of the building. In the new construction areas the problems can be avoided in the planning of the building unit and in the planning of the connections between the building units. In addition, the requirements concerning travelway geometry limit the planning of the APGM infrastructure. Large gradients should be avoided in order to be able to reduce the barrier effect and improve the aesthetic qualities of the infrastructure, as well as to increase the travelling comfort. APGM travelways can form large intersection areas which are aesthetically challenging elements in the urban environment.
The station areas of the APGM system have in this study been mini-
mised in order to ease the planning of the station locations in the built
environment. Nevertheless, the stations are relatively large constructions
requiring thorough planning in small scale urban environment. The ar-
chitectonic solutions and user interfaces essentially need to be of high
quality. Architectonic solutions and integration to buildings enable also
altogether new innovations that can enrich the urban environment.

One of the most important specified planning tasks are the details in the
integration of the travelway and the stations to the buildings. A number
of principal solutions are presented in this study. However, the need for
development of more detailed guidelines for land reservations in the land
use planning is evident.

The APGM system has been estimated to accompany relatively large infra-
structure investment costs. One of the important development chal-

lenges is to attain cost-effective infrastructure solutions without reducing
the aesthetic quality of the travelways and stations. A high-quality end
product in the shape of vehicles, travelways, stations and user interface is
an essential goal defining the image value of the system.

**APGM ATTRACTS PASSENGERS FROM ALL MODES**

According to the traffic forecast the APGM system induces passengers
from all other modes, especially from private car. In this viewpoint APGM
can strengthen the existing public transport system by attracting new
passengers to public transport. The system attracts also passengers who
would otherwise walk or use bicycle, which can have negative impacts on
public health.

Car users can due to the APGM system have better access to their des-
tination than in the present transport system, where walking distances
from parking place can be relatively long especially in extensive work
place or shopping areas. In these areas the APGM system can provide a
feeder service from parking facility to the destination and thus increase
possibilities to locate the parking facilities further away from activities
and increase possibilities to utilize the near-by area to the main activi-
ties. In the viewpoint of land use planning and location of activities the
APGM system increases the adaptability of land use, when the location
of activities is less dependent on minimising the walking distances.

APGM can in general be assessed to improve the image and attractiveness
of its area of operation. Basically it can in the built environment be in-
terpreted to resemble elevator offering better accessibility in the internal
travel and transport needs, and to resemble private car in offering better
accessibility in the external travel and transport needs. Thus it can be
foreseen to improve the level of service of the properties and increase the
property value.

**APGM SYSTEM SUPPORTS MANY OF THE TARGETS OF
THE TRANSPORT POLICY**

According the impact assessment the APGM system would have several
kinds of positive socio-economical effects on the transport system. The
system would increase traffic safety and reduce the negative environmen-
tal effects of transport by reducing private car mileage. The APGM system would accompany substantial time cost savings for public transport passengers.

The system has also been assessed to increase the social equality and sustainability of the transport system by providing increased door to door accessibility to all passenger groups. However, the user interface of the system should be thoroughly planned in order to be able to ensure that the system is usable for all passenger groups. A sophisticated user interface including advanced and intelligent information system would in general improve the service level of the system and thus attract passengers from other modes and destinations.

DEMAND FOR INNOVATIVE FINANCING, OPERATION AND MAINTENANCE ORGANISATION

As the APGM system contains features from both elevator system and public transport system, it requires new and innovative operation organisation. APGM can in the shopping centre areas, work place areas, science parks and e.g. hospital areas be seen as part of the facility services providing internal travel connections like an elevator system. In this point of view passengers could utilise the system free of user charge, or the system could be used with smart cards. In this type of utilisation the system would mainly benefit one facility owner or a group of owners.

On the other hand the APGM can be seen as a feeder mode to public transport providing fast and convenient connection from and to the public transport station. Thus it has an important role in improving the public transport level of service and accessibility. APGM can also form an internal public transport network as in the studied case area of Hervanta. In these applications the APGM passengers would pay for the use of the system in a similar way as in public transport in general. In such applications the APGM system would be seen as part of conventional public transport system collecting user charges as in the public transport in general. In this point of view the system should be connected to the existing public transport system and APGM system should utilise similar kind of ticketing and information systems as the public transport system in general.

Since the APGM system would in most of the application areas have both internal passengers travelling inside the facility complex and public transport passengers travelling longer and external trips, the APGM operation should be organised in a new form of co-operation between public administration, private facility owners, facility users and public transport operators. Thus the relatively large infrastructure investments costs should be allocated to all stakeholders gaining from the system. In this type of financing structure the investment costs could be covered partly by ticket income, other user charges, property rents, increased land use flexibility, and partly as a transport investment. Financing structure and operation organisation should in each application be tailored by the local interest groups according to prevailing circumstances.


